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Reading assistance

0 (https://intercom.help/kognity)

B3.1 Teacher view

Gas exchange

B3. Form and function: Organisms / B3.1 Gas exchange

The big picture

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43534/print/) Assign

? Guiding question(s)

- How are multicellular organisms adapted to carry out gas exchange?
- What are the similarities and differences in gas exchange between a flowering plant and a mammal?

Keep the guiding questions in mind as you learn the science in this subtopic. You will be ready to answer them at the end of this subtopic. The guiding questions require you to pull together your knowledge and skills from different sections, to see the bigger picture and to build your conceptual understanding.

Like many other amphibians, salamanders (**Figure 1**) have an unusual method of obtaining and excreting gases. They can ‘breathe’ through a process called cutaneous gas exchange. This involves exchanging oxygen and carbon dioxide across their skin, rather than relying solely on lungs or gills, the primary organs of gas exchange in mammals and fish respectively.

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Figure 1. The Japanese giant salamander (*Andrias japonicus*), which can reach up to 1.5 m in length, exchanges gases through its skin in the process of cutaneous gas exchange.

Credit: Martin Voeller, Getty Images

Salamander skin is richly supplied with blood vessels and is thin and permeable to gases, allowing for efficient gas exchange. Many salamanders have wrinkled skin, increasing the surface area across which gases can be exchanged (see subtopic B2.1 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43205/) for more information about surface area). These adaptations allow salamanders to inhabit environments with low oxygen levels, such as swamps or ponds, where other animals would struggle to survive.

However, this reliance on cutaneous gas exchange requires the salamander to ensure that its skin is kept moist at all times, which can limit the organism to certain habitats (see subtopic B4.1 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43536/) for more information about adaptations to ecological niches). It also makes the salamander vulnerable to absorbing any toxins in its environment through its skin, including pollutants and pesticides.

But how are the lungs of mammals, the gills of fish, and the leaves of plants adapted to absorb the gases required for respiration, and how do they remove the waste gases they produce?

Creativity, activity, service

Strand: Activity
Learning outcome: Demonstrate engagement with issues of global significance

When people swim in lakes or other bodies of water wearing sunscreen, the chemicals in the sunscreen can accumulate in the water.

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Some sunscreens contain chemicals such as oxybenzone and octinoxate that can have a variety of negative effects on aquatic animals, including developmental disorders and hormonal abnormalities.

For animals that carry out cutaneous gas exchange, this can be particularly harmful, as the chemicals can be absorbed through the highly permeable skin, interfering with gas exchange, along with a variety of other negative side effects.

To minimise the effect of sunscreen on organisms that carry out cutaneous gas exchange, it is recommended to use sunscreens that are classified as 'reef safe' or 'ocean safe'. These typically contain mineral sunscreens such as zinc oxide and titanium dioxide rather than the harmful chemicals found in other sunscreens.

It is also recommended that people should limit the use of sunscreen when swimming in natural bodies of water and avoid the use of sunscreens in areas with vulnerable populations of aquatic organisms.

Design a leaflet or short video to explain to your school community:

- the importance of wearing sunscreen
- the importance of protecting aquatic organisms against the harmful chemicals found in some sunscreens
- alternative ways to protect your skin.

Prior learning

Before you study this subtopic make sure that you understand the following:

- How molecules pass across biological membranes (see subtopic B2.1 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43205/)).
- Cell specialisation, including surface area-to-volume ratio (see subtopic B2.3 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43533/)).

Practical skills

Once you have completed this subtopic, you can gain application of skills for determining stomatal density by going to Practical 1: Using microscopes and calculating magnification (/study/app/bio/sid-422-cid-755105/book/using-microscopes-and-calculating-magnification-id-46529/).

B3. Form and function: Organisms / B3.1 Gas exchange

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Gas exchange as a vital function

Learning outcomes

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

- Outline the need for gas exchange in living organisms.
- Describe properties of gas-exchange surfaces.
- Explain how concentration gradients are maintained at exchange surfaces in animals.
- Describe the adaptations of mammalian lungs for gas exchange.

The need for gas exchange

All organisms carry out gas exchange, a vital function that is essential for life. Gas exchange allows organisms to obtain the gases required for cellular processes such as aerobic respiration and photosynthesis, and remove waste gases produced in metabolic reactions. How are organisms, from the tiniest amoeba to a flowering plant to an elephant, adapted to allow efficient gas exchange?

Gas exchange occurs via a process called diffusion. Diffusion is the random net movement of particles from an area of higher concentration to an area of lower concentration, leading to equilibrium – an equal distribution of particles.

Figure 1 illustrates the effect of size on the surface area-to-volume ratio in different organisms, which are represented as cubes. As the size of the cube (organism) increases, the surface area-to-volume ratio decreases and the distance between the surface of the organism and the cells in the interior of the organism increases (see section B2.3.5–6 (/study/app/bio/sid-422-cid-755105/book/cell-adaptations-hl-id-44445/)).

Video 1 gives a detailed explanation of this relationship.

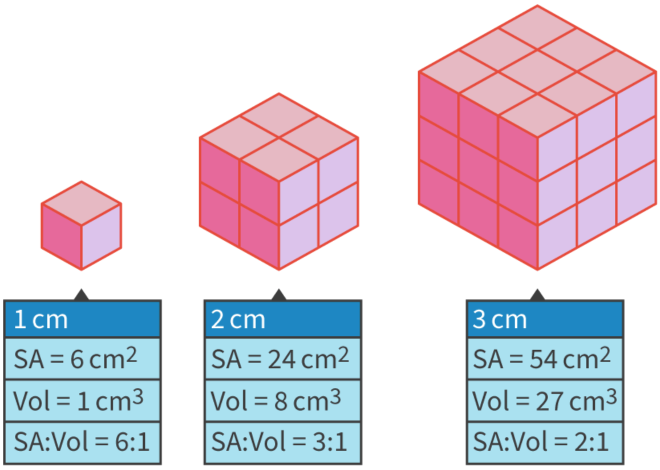

Figure 1. As the size of the organism increases, the surface area-to-volume ratio decreases.

More information for figure 1

The image shows three cubes of increasing size. Each cube's side length, surface area (SA), volume (Vol), and surface area-to-volume ratio (SA:Vol) are provided.

1. First Cube:
2. Side Length: 1 cm
3. Surface Area: 6 cm²
4. Volume: 1 cm³
5. Surface Area-to-Volume Ratio: 6:1

6. Second Cube:

7. Side Length: 2 cm
8. Surface Area: 24 cm²
9. Volume: 8 cm³
10. Surface Area-to-Volume Ratio: 3:1

11. Third Cube:

12. Side Length: 3 cm
13. Surface Area: 54 cm²
14. Volume: 27 cm³
15. Surface Area-to-Volume Ratio: 2:1

The image illustrates how as the cube size increases, the surface area-to-volume ratio decreases.

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Video 1. This video explains the relationship between organism size and surface area-to-volume ratio.

Organisms with a very high surface area-to-volume ratio can rely on diffusion across their body surface to obtain and release gases, including single-celled organisms such as bacteria and yeast. As organisms increase in size, surface area-to-volume ratio decreases and there is a greater need for specialised structures to facilitate efficient gas exchange. In such larger organisms, exchange across the body surface alone would not supply or remove gases efficiently. These specialised structures have evolved certain properties, such as being highly folded or branched in structure, increasing the surface area available across which gases can be exchanged.

Properties of gas-exchange surfaces

Examples of specialised exchange surfaces include the alveoli in the lungs of mammals, birds and reptiles, the gills in fish and the tracheal system in insects (**Interactive 1**).

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Interactive 1. Mammalian lungs, fish gills and tracheal systems in insects are all types of gas-exchange surfaces.

More information for interactive 1

An interactive slideshow with three slides demonstrates different respiratory systems in three organisms: humans, fish, and insects. Users can explore the key structures involved in gas exchange across various species. The interactive highlights the alveoli in human lungs, the gills in fish, and the tracheal system in insects, allowing users to compare their mechanisms of oxygen and carbon dioxide exchange.

Slide 1: Human Respiration: Focuses on alveoli, capillaries, red blood cells, and gas exchange through the alveolar walls. Oxygen enters the alveoli and diffuses into the blood, and carbon dioxide diffuses out.

Slide 2: Fish Respiration: Highlights gill filaments, blood vessels, lamellae, and countercurrent gas exchange with water flow. Oxygen-rich water flows over the gills and diffuses into the blood, and carbon dioxide moves into the water.

Slide 3: Insect Respiration: Demonstrates spiracles, tracheoles, tracheae, and air sacs as part of a direct gas exchange system. Air enters the spiracles and moves through the tracheae, and gases are exchanged directly with tissues.

The details are provided in the table below:

Organism	Oxygen Intake Structure	Carbon Dioxide Removal Structure	Mechanism
Human	Alveoli (lungs)	Alveolar walls & capillaries	Diffusion into blood

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Fish	Gill filaments & lamellae	Blood vessels in gills	Countercurrent exchange with water
Insect	Spiracles & tracheae	Tracheal system	Direct diffusion through the body

This interactivity helps users understand the differences in respiratory adaptations among terrestrial and aquatic organisms, learn how gas exchange occurs in mammals, fish, and insects, and compare the efficiency of different respiratory systems in terms of oxygen uptake and carbon dioxide removal.

Effective gas-exchange surfaces share some properties that make them efficient at exchanging gases such as oxygen or carbon dioxide. These properties include:

- **large surface area** – there is more membrane surface available for gases to diffuse across (find out more about adaptations to increase surface area-to-volume ratios of cells in section B2.3.7 (/study/app/bio/sid-422-cid-755105/book/quaternary-structure-of-proteins-and-form-id-44446/))
- **permeability** – the exchange surface must have pores or openings that allow gases to be exchanged across its surface; for example, plants have stomata – small pores located mostly on the underside of the leaf through which gases can move into and out of the leaf
- **composed of a thin tissue layer** – so that there is a short distance across which gases need to move
- **having a moist surface** – this helps to dissolve gases before they diffuse across the exchange surface; for example, alveolar fluid in the alveoli
- **concentration gradient** – for diffusion to occur there has to be a difference in concentration of the gas between two areas. The gas will move from an area of higher concentration to an area of lower concentration.

Maintenance of concentration gradients

Concentration gradient refers to the difference in concentration of a substance between two areas. The bigger the difference in concentration, the steeper the concentration gradient, and the faster the rate of diffusion (**Figure 2**).

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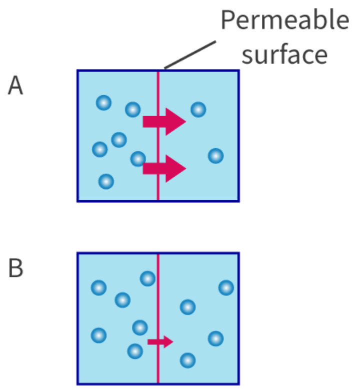

Figure 2. Diffusion occurs faster in A as there is a steeper concentration gradient.

More information for figure 2

The image is a diagram comparing diffusion across a permeable surface, labeled as A and B. In section A, there are two compartments separated by a permeable surface, with a higher concentration of particles on the left side than on the right. Arrows indicate the direction of diffusion from left to right, showing a steeper concentration gradient and faster diffusion. In section B, a similar setup is present, but the concentration of particles is more evenly distributed, leading to a less steep gradient and slower diffusion, as indicated by a single arrow. The diagram visually explains how the difference in concentration affects the rate of diffusion across a permeable surface.

[Generated by AI]

Adaptations in the exchange surfaces of animals to maintain steep concentration gradients include:

- a **dense network of blood vessels**, which means that there is much opportunity for substances to be exchanged between the surface and the blood
- **continuous blood flow**, which ensures that, as soon as substances move into the blood, they are transported away by the continuous blood flow, ensuring a low concentration of that substance in the blood supply adjacent to the exchange surface
- **ventilation**, which ensures the air or water rich in the desired gas is moved across the exchange surface. Mammals inhale air into the lungs, and exhale to remove air from the lungs. As shown in **Video 2**, fish have various mechanisms to ventilate the gills, including pumping water over the gills through the mouth.

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Video 2. Ventilation in fish.

International Mindedness

The term 'respiration' can refer to both the process of ventilation and the chemical reactions that occur in cells to produce ATP.

To distinguish between these meanings, scientists use the term 'cellular respiration' when identifying the latter. Without this, it could be unclear which meaning is being referred to, which could result in misinterpretation and confusion. This is especially important in international contexts which may involve communication between scientists from diverse cultural and linguistic backgrounds.

Mammals are also able to maintain steep concentration gradients by separating oxygenated and deoxygenated blood. This is possible because of a double circulatory system which helps to ensure that blood transported to respiring cells is highly oxygenated. Differences between the single circulation of bony fish and the double circulation of mammals are covered in detail in section B3.2.14–16 (/study/app/bio/sid-422-cid-755105/book/adaptations-of-the-heart-hl-id-44448/).

Adaptations of the mammalian lungs for gas exchange

In mammals, the lungs are the organs responsible for the exchange of gases between the air and the bloodstream.

The structure of the lungs

Click on each structure of the lungs in **Interactive 2** to learn about its function.

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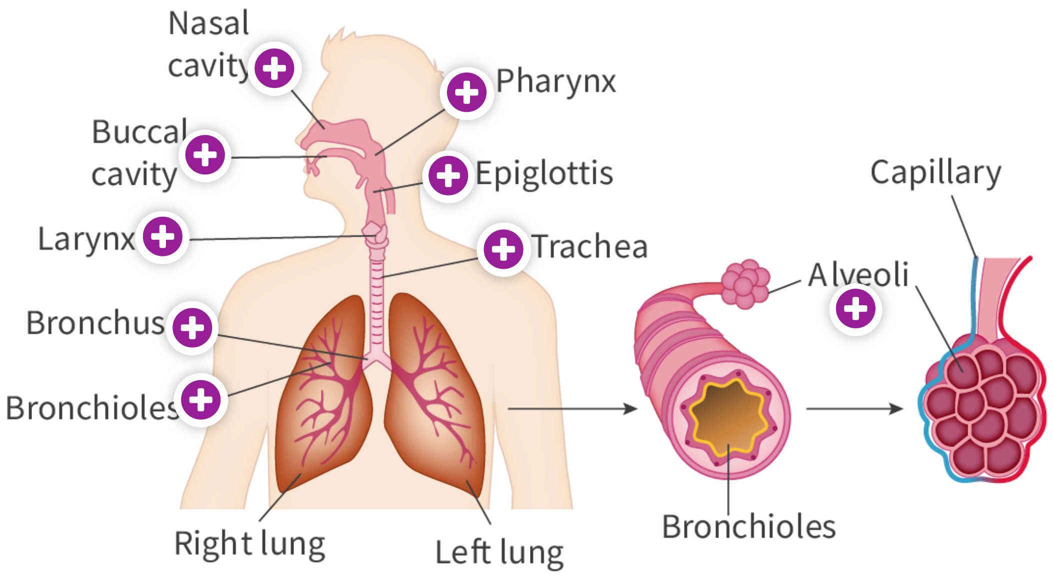

Interactive 2. The Human Lungs and Associated Organs.

More information for interactive 2

This interactive diagram provides a detailed overview of the human respiratory system, highlighting key structures involved in the process of breathing. The interactive explains that each part of the system plays a crucial role in ensuring the efficient exchange of oxygen and carbon dioxide, essential for sustaining life.

In the diagram, the human respiratory system is illustrated with labeled parts including the nasal cavity, buccal cavity, pharynx, epiglottis, larynx, trachea, bronchus, bronchioles, right lung, and left lung. A magnified view of the bronchioles leads to another magnified view of alveoli surrounded by capillaries, illustrating the gas exchange process in the lungs. Each main structure is marked with a plus sign representing a hotspot indicating additional interactive information. Read below for the information.

Nasal cavity: allows air to enter the respiratory system through the nose, filters the air for pathogens and allergens and warms the air. Most of the time, normal breathing takes place through the nasal cavity, but during exercise and other periods of increased oxygen requirement, breathing also takes place through the buccal cavity.

Buccal cavity: the mouth, works with the nasal cavity to allow the passage of air into the trachea.

Larynx: a hollow tube that lets air pass from the pharynx (throat) through to the trachea. Also contains the vocal cords.

Bronchi: airways that lead from the trachea into the bronchioles.

Bronchioles: branches of the bronchi that lead into the alveoli.

Pharynx: commonly called the throat, is the passage through which air travels from the mouth and nose into the trachea. Also part of the digestive system, where it carries food and water into the oesophagus.

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Epiglottis: a flap of cartilage that covers the trachea when you swallow so food doesn't go down the trachea.

Trachea: also known as the windpipe. The trachea is an airway that carries air into the lungs from the nasal and buccal cavities. The trachea contains C-shaped cartilaginous rings which provide structure to the trachea, keeping it from collapsing during breathing. The smooth muscle helps regulate airflow, while the mucous membrane lining produces mucus to trap dust, debris, and bacteria before they reach the lungs.

Alveoli: tiny sacs with a large surface area across which oxygen and carbon dioxide are exchanged between the air and the blood.

Alveolar fluid/surfactant

Type II pneumocytes secrete alveolar fluid which moistens the surface of the alveoli, allowing gases to dissolve into the surfactant before diffusing across the wall of the alveoli and capillary into the blood. Alveolar fluid contains surfactant, a mixture of lipids and proteins (**Figure 3**). Surfactant has a key role in reducing the surface tension of the alveoli and this helps to prevent alveolar collapse during exhalation. Adaptations of type I and type II pneumocytes in alveoli are covered in more detail in section B2.3.8 (/study/app/bio/sid-422-cid-755105/book/summary-and-key-terms-id-44449/).

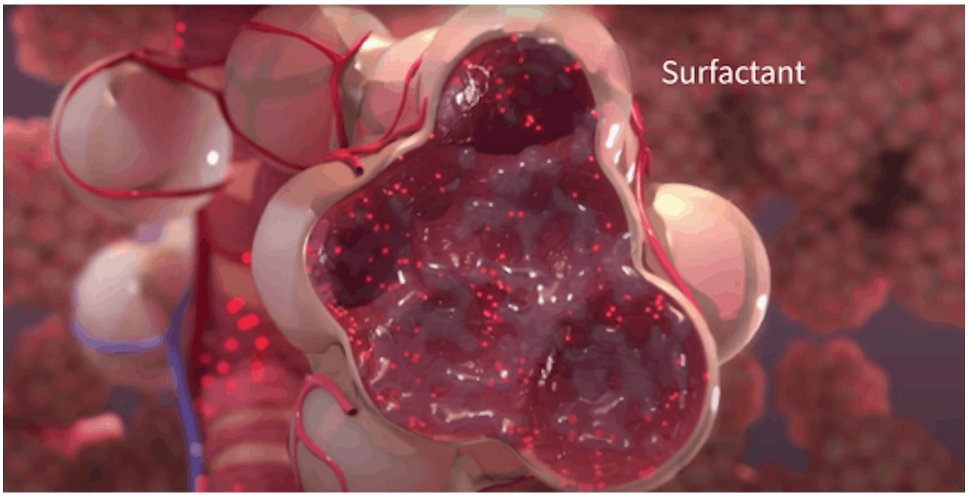

Figure 3. Alveoli and alveolar fluid containing surfactant.

More information for figure 3

The image is a detailed diagram showing the alveoli in the lungs. The rounded, sac-like structures represent the alveoli, with a detailed cross-section to see the interior. Inside the alveoli, a fluid containing surfactant is shown, depicted as a substance that reduces surface tension. The text "Surfactant" labels the fluid, emphasizing its presence. The surrounding area is filled with tiny blood vessels, illustrating the close proximity necessary for gas exchange between the alveoli and blood. This diagram highlights the important role of surfactant in respiratory physiology by preventing alveolar collapse during the breathing cycle.

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A highly branched network of bronchioles

Each bronchiole branches into many alveoli, the exchange surface of the lungs (**Figure 4**). This increases the surface area available for gas exchange, thus increasing the rate of gas exchange. The high degree of branching also ensures that air is distributed throughout the lungs. The small diameter of the bronchioles compared with the bronchi and trachea also helps to slow down rate of the airflow, increasing the efficiency of gas exchange.

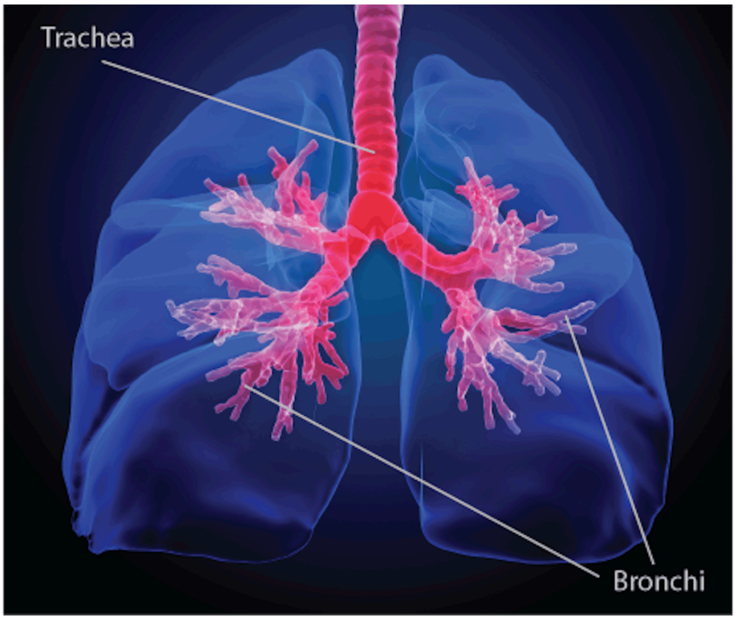

Figure 4. An illustration showing the air passages in a lung.
Credit: ANDRZEJ WOJCICKI / SCIENCE PHOTO LIBRARY, Getty Images (https://www.gettyimages.co.uk/detail/illustration/human-lungs-illustration-royalty-free-illustration/545863899)

More information for figure 4

Extensive capillary beds surrounding the alveoli

Around the alveoli are many capillaries (**Figure 6**). This means that there is a very short distance for oxygen to diffuse from the air in the alveoli into the blood and for carbon dioxide to diffuse from the blood into the alveoli. The structure and adaptations of capillaries is covered in section B3.2.1–6 (/study/app/bio/sid-422-cid-755105/book/blood-vessels-id-44450/).

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Many alveoli

Many alveoli create a larger surface area, totalling roughly the same area as a tennis court for the average adult. This means that there is lots of area across which carbon dioxide and oxygen can be exchanged. Surface area is covered in more detail in section B2.3.6 (/study/app/bio/sid-422-cid-755105/book/cell-adaptations-hl-id-44445/).

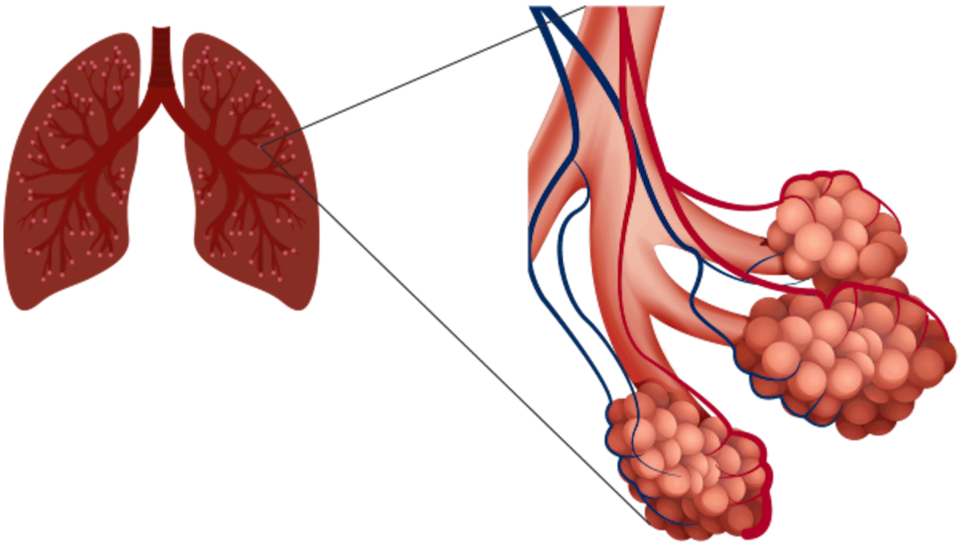

Figure 5. Alveoli create a large surface area and are surrounded by extensive capillary beds.

More information for figure 5

The image is a detailed diagram showing the structure of alveoli within the lungs. On the left, there is a simplified depiction of the lungs, illustrating the branching bronchial tree. Towards the right, the diagram zooms into the structure of the alveoli, displaying a cluster of small sac-like structures. These alveoli are surrounded by a network of capillaries, represented by blue and red lines, indicating the flow of deoxygenated and oxygenated blood, respectively. The diagram highlights the large surface area created by the alveoli, facilitating efficient gas exchange between carbon dioxide and oxygen in the lungs. The image visually emphasizes the relationship between the alveoli and the capillary networks.

[Generated by AI]

Watch **Video 3** for a brief summary of how the alveoli are adapted for efficient gas exchange.

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Video 3. Adaptations of the alveoli for efficient gas exchange.

Try this drawing activity to check your understanding of adaptations of alveoli for gas exchange.

Activity

- **IB learner profile attribute:** Thinker
- **Approaches to learning:** Thinkers — Reflecting at all stages of the assessment and learning cycle
- **Time required to complete activity:** 20 minutes
- **Activity type:** Individual activity

Draw and label a diagram of the alveoli and surrounding blood vessels. Ensure that your diagram shows:

- the direction of diffusion of oxygen
- the direction of diffusion of carbon dioxide
- concentration gradients of these two gases between the alveoli and blood
- permeability of the exchange surfaces (refer to section B3.2.1—6 (/study/app/bio/sid-422-cid-755105/book/blood-vessels-id-44450/) to review the adaptations of capillaries for the exchange of materials)
- short diffusion distance
- large surface area of the exchange surface
- the moist surface of the exchange surface.

Higher level (HL)

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HL students should refer to section B2.3.8 (/study/app/bio/sid-422-cid-755105/book/summary-and-key-terms-id-44449/) and include details of type I and type II pneumocytes.

5 section questions

B3. Form and function: Organisms / B3.1 Gas exchange

Ventilation in the lungs

B3.1.5: Ventilation of the lungs B3.1.6: Measurement of lung volumes

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Learning outcomes

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

- Explain the process of ventilation.
- Determine measurements of lung volumes.

Ventilation of the lungs

For gas exchange to occur in the alveoli, we need to get air into and out of the lungs. How does this process of ventilation occur?

The following muscles are involved in ventilation (**Figure 1**):

- The diaphragm, a sheet of muscle found below the ribs.
- The intercostal muscles, a group of muscles found between and anchored to the ribs. There are two types of intercostal muscles, the internal and external intercostal muscles, which are antagonistic due to their opposing actions on the ribs during breathing.
- The abdominal muscles.

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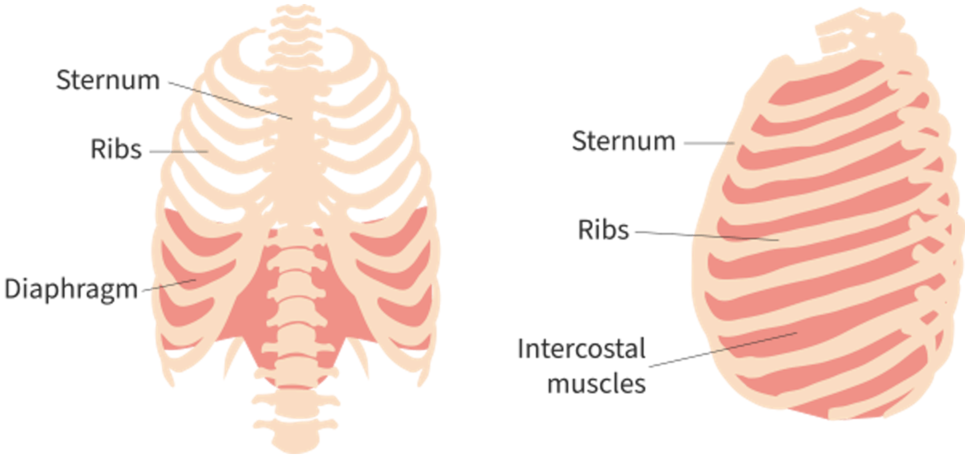

Figure 1. The thoracic cavity. Notice the location of the diaphragm below the ribs and the intercostal muscles between the ribs.

More information for figure 1

The image shows two simplified illustrations of the human thoracic cavity. The illustration on the left depicts a front view of the ribs, showing the sternum in the center and the diaphragm below the ribs. Each rib arches around from the sternum. The diaphragm is labeled beneath the ribcage, highlighting its position. The image on the right presents a side view, adding labels for the intercostal muscles, which are positioned between the rib bones. This view gives a sense of the layering and positioning of these muscles in relation to the bones. Both views clearly label the major components: the ribs, the sternum, the diaphragm, and the intercostal muscles, demonstrating how these features fit together forming the thoracic cavity.

[Generated by AI]

The relationship between volume and pressure

When you inhale, the volume of your thoracic cavity **increases**. This means that particles have more space to move, and so collide less frequently with each other and the walls of the lungs. As a result, pressure in the lungs **decreases**, allowing air from outside the body to rush into the lungs. When you exhale, the converse is true; the volume of your thoracic cavity decreases, so particles have less space to move and collide with each other and the walls of the lungs more frequently. This results in an increased pressure in the lungs, forcing air out of the body.

Interactive 1 is an animation that shows the relationship between volume and pressure.

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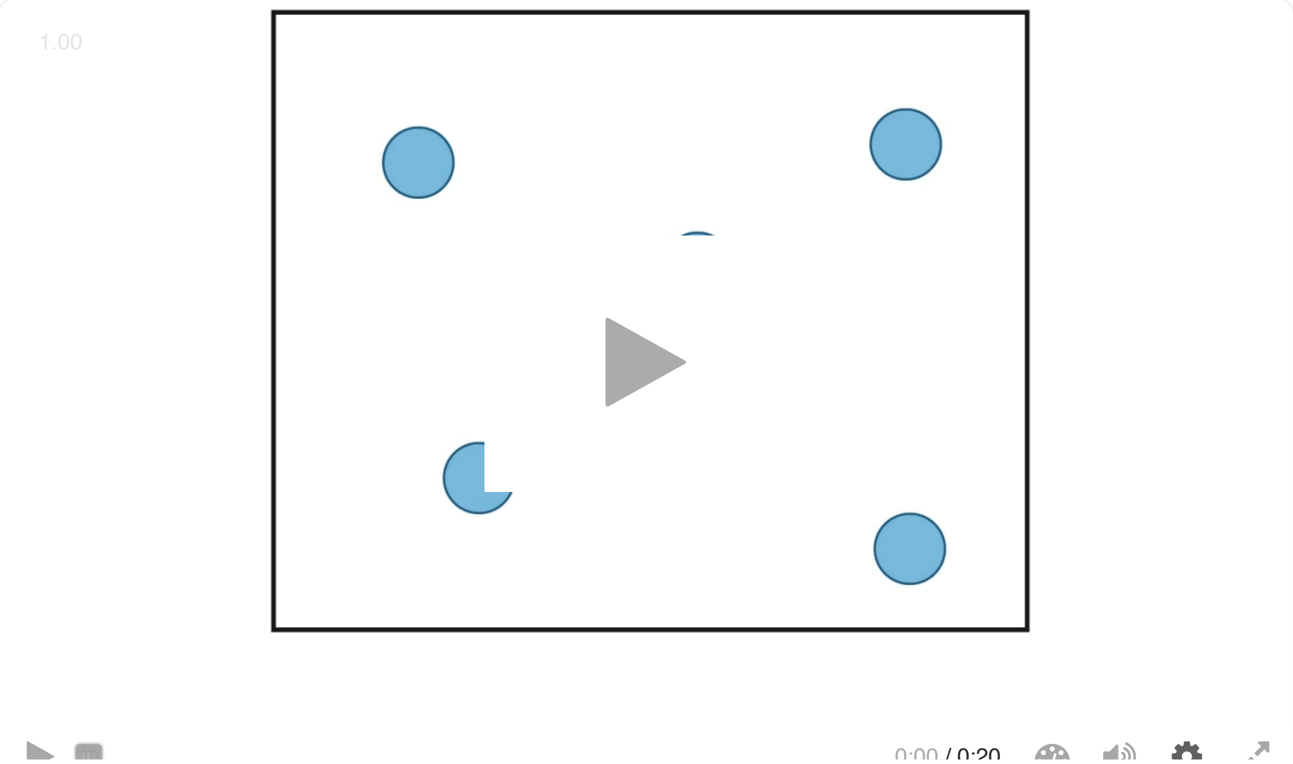

Interactive 1. Inverse Relationship Between Pressure and Volume.

More information for interactive 1

An interactive video demonstrates the relationship between pressure and volume. In the video, a container holds five particles that move randomly inside. As the video progresses, the volume of the container decreases, making the container look smaller. As a result, the pressure inside the container increases, and the particles collide more frequently due to the reduced space.

As the video continues, the volume of the container increases, making the container look larger. Consequently, the pressure decreases, and the particles collide less frequently due to more space.

This video depicts how pressure, volume, and collisions of the particles are related to each other. It shows that pressure is inversely proportional to volume.

Inspiration

During inspiration:

- The diaphragm contracts and moves downward.
- The external intercostal muscles contract, and the internal intercostal muscles relax, causing the rib cage to move up and out.
- This increases the volume of the thoracic cavity, and so decreases the pressure in the lungs.
- As a result, air moves down its pressure gradient **into** the lungs.

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Expiration

During quiet breathing expiration:

- The diaphragm relaxes, moving upwards and inwards.
- The external intercostal muscles relax, and the internal intercostal muscles also relax, causing the rib cage to move down and in.
- This results in a decreased volume of the thoracic cavity, and so increases the pressure in the lungs.
- As a result, air moves down its pressure gradient **out** of the lungs.

During forced breathing expiration:

- The diaphragm relaxes, moving upwards and inwards.
- The external intercostal muscles relax, and the internal intercostal muscles contract, causing the rib cage to move down and in forcefully.
- This results in a decreased volume of the thoracic cavity, and so increases the pressure in the lungs.
- As a result, air moves quickly down its pressure gradient and forcefully **out** of the lungs.

Figure 2 gives a summary of ventilation.

The abdominal muscles also play a role in forced expiration, contracting and pushing up, decreasing the volume of the thoracic cavity and pushing a greater volume of air out of the lungs.

HL students will find out more about the role of the muscles and muscle contraction in subtopic B3.3 (/study/app/bio/sid-422-cid-755105/book/big-picture-hl-id-43535/).

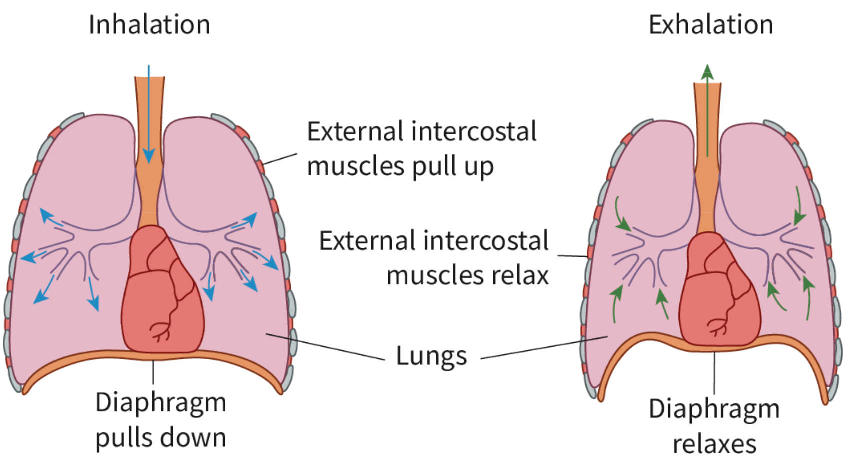

Figure 2. The role of the diaphragm and external intercostal muscles in ventilation.

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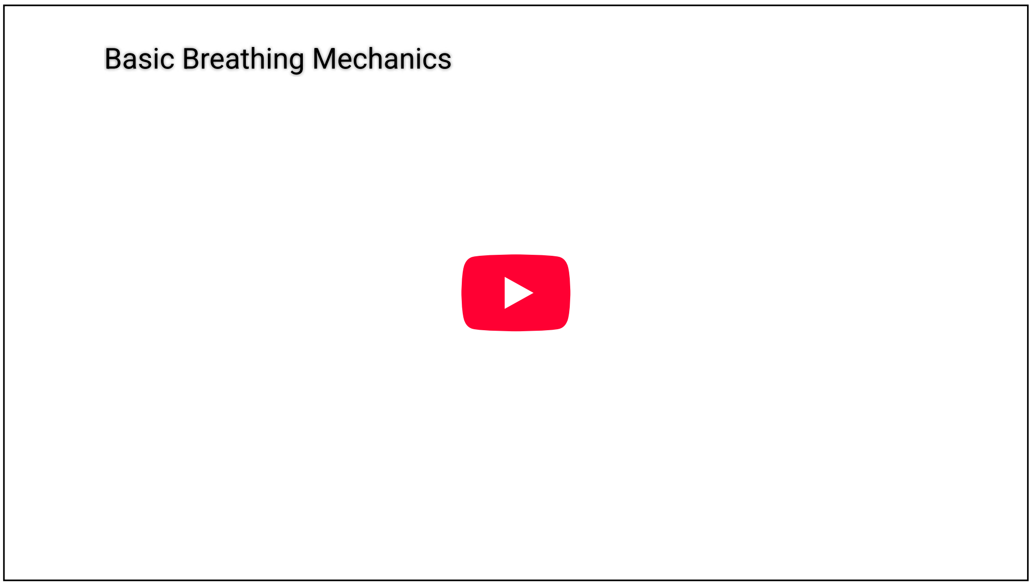
More information for figure 2

The diagram illustrates two stages of breathing: inhalation and exhalation. On the left, inhalation is depicted with arrows indicating air entering the lungs as the diaphragm pulls down and the external intercostal muscles pull up, expanding the chest cavity. During exhalation on the right, the diaphragm relaxes and moves up, while the external intercostal muscles relax, reducing the chest cavity's volume as air exits the lungs. Labels identify the lungs, diaphragm, and muscles involved in breathing, providing a visual explanation of the ventilation process.

[Generated by AI]

Video 1 summarises the mechanics of inspiration and expiration, identifying the roles of the diaphragm, intercostal muscles, abdominal muscles and ribs.



Video 1. Mechanics of ventilation.

Use **Interactive 2** to drag and drop the steps of inhalation into the correct sequence.

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1. The diaphragm contracts and moves downwards.
2.
3.
4.
5.
6.

Air moves down its pressure gradient into the lungs.

The volume of the thoracic cavity increases.

This causes the ribcage to move up and out.

The external intercostals muscles contract.

The pressure in the thoracic cavity decreases.

Check

Interactive 2. Order the Steps to Show the Process of Inhalation.

Measurements of lung volumes

Take a big breath, trying to inhale as much air as possible. The total volume of air in your lungs is your total lung capacity. The average total lung capacity of a human is 6 litres.

Now exhale as much air as possible. The volume of air that you can forcibly exhale is your forced vital capacity. The volume of air remaining in your lungs that cannot be exhaled is the residual volume. Without the residual volume your lungs would collapse.

The volume of air that moves into and out of your lungs with each normal breath is your tidal volume. After taking a normal breath, the additional volume of air that you can inhale is the inspiratory reserve. After a normal exhale, the additional volume of air that you can exhale is the expiratory reserve (**Figure 3**)

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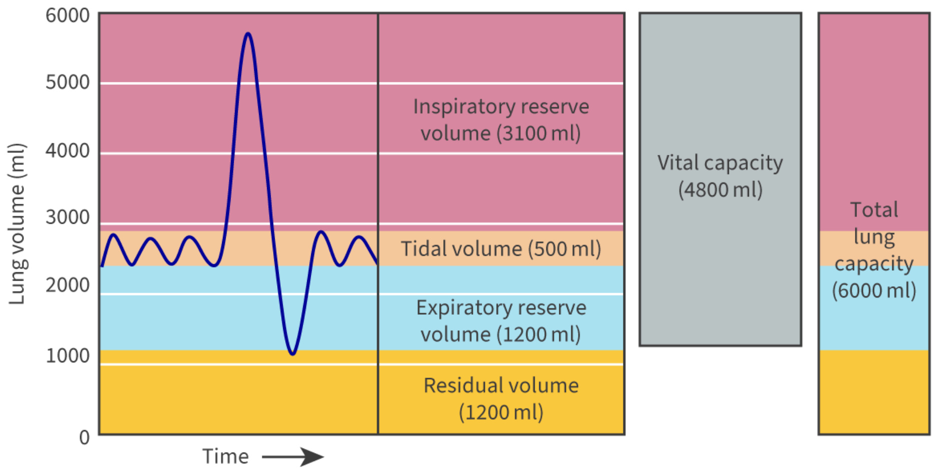

Figure 3. Lung volumes.

More information for figure 3

The image is a diagram illustrating lung volumes over time. The Y-axis represents lung volume in milliliters (ml), ranging from 0 to 6000 ml. The X-axis represents time. The graph shows a wavy blue line depicting the changes in lung volume during breathing. The tidal volume is marked at 500 ml, representing the volume of air moved in and out of the lungs with each breath. Above the tidal volume is the inspiratory reserve volume, marked at 3100 ml, indicating the additional volume that can be inhaled after a normal inhalation. Below the tidal volume is the expiratory reserve volume, marked at 1200 ml, indicating the additional volume that can be exhaled after a normal exhalation. Residual volume is also depicted at 1200 ml, representing the air left in the lungs after a forceful exhalation. Two vertical bars on the right illustrate vital capacity (4800 ml) and total lung capacity (6000 ml).

[Generated by AI]

There are several factors that can affect human lung capacities, including:

- age – lung capacities tend to increase with age up to about 25 years of age
- body size – larger people tend to have larger lungs and so have larger lung capacities
- biological sex – in general, males tend to have larger lung capacities than females, although it is important to note that there are more differences within each sex than there are between the means of the two sexes
- respiratory disease – diseases such as chronic obstructive pulmonary disease (COPD) and asthma can reduce lung capacities
- levels of physical activity – regular exercise can increase lung capacities.

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Lung volume can be measured using a pulmonary function test called spirometry, a technique that involves a person breathing into a machine called a spirometer (**Figure 4**). The volume and speed of exhaled air is measured and used to evaluate lung function and diagnose respiratory conditions such as asthma and COPD.

Figure 4. A spirometer is a device used to measure lung function. There are many different types of spirometers. This one belongs to a large group of handheld spirometers.

Credit: Svitlana Hulko, Getty Images (https://www.gettyimages.com/detail/photo/patient-checking-his-lung-function-with-spirometer-royalty-free-image/1397422850)

If you have spirometers in your school, you may use them to make measurements of lung volumes, including tidal volume and forced vital capacity.

Theory of Knowledge

In the following activity you will create a model to aid understanding of the mechanics of breathing. While creating your model, think about the extent to which your model is useful, as well as the limitations that should be considered when analysing and interpreting your model.

Activity

- **IB learner profile attribute:** Thinker
- **Approaches to learning:** Thinking skills — Designing procedures and models
- **Time required to complete activity:** 20 minutes

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- **Activity type:** Individual activity

In this activity you will make a model of the lungs and then evaluate your model.

Equipment:

- scissors
- 2 balloons
- straw
- elastic band
- ball of modelling clay, approximately 2 cm in diameter
- pencil
- plastic bottle, approximately 600 cm^3
- ruler.

Follow the instructions in this video (https://www.youtube.com/watch?v=CBv2BqqAydE&ab_channel=Questacon) to make a model of the lungs.

Caution: Be careful how you hold the modelling clay. **Do not** push the pencil towards your hand.

As you breathe into the straw, you should see the model lungs expand.

Exhale into the straw at rest without actively blowing and measure the diameter of the balloon using a ruler. Then carry out some exercise, such as walking up a set of stairs, or doing jumping jacks for one minute. Exhale into the straw (again, without actively blowing), and measure the diameter of the balloon.

Then evaluate your model using the following questions:

1. What do the different structures in your model represent?
2. How does your model lung show the process of ventilation?
3. Are there any key parts of the lungs and associated structures involved in breathing that are not represented by your model?
4. How does your model help you to visualise changes in the volume of air exhaled following exercise?
5. How could your model lung be improved or modified to address its limitations?

5 section questions

B3. Form and function: Organisms / B3.1 Gas exchange

Gas exchange in leaves

Student
view

Learning outcomes

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

- Outline the adaptations of leaves for gas exchange.
- Draw and label a plan diagram to show the distribution of tissues in a transverse section of a dicotyledonous leaf.
- Outline the process of transpiration and the factors that affect the rate of transpiration.
- Determine stomatal density.

Adaptations of the leaves for gas exchange

The leaves are the main organs of gas exchange in a plant. How are they adapted for this function? And what effect does the loss of water vapour into the air have on the water in the xylem?

During times when the rate of photosynthesis is higher than the rate of respiration, carbon dioxide will diffuse into the leaf, and excess oxygen will diffuse out. The converse is true during times when the rate of respiration is higher than the rate of photosynthesis. Water vapour is transported from the roots to the leaves in the xylem (see section B3.2.7–10 (/study/app/bio/sid-422-cid-755105/book/transport-in-plants-id-44452/)). Most of the water absorbed by the plant will be released in the process of transpiration, the diffusion of water vapour out through the stomata.

Dicotyledonous leaves are adapted for the exchange of oxygen, water vapour and carbon dioxide in the following ways:

- Leaves are thin and flat, meaning they have a large surface area across which gases can diffuse into and out of the leaf. It also means they have a large surface area to absorb sunlight.
- A waxy cuticle covers the cells of the upper epidermis. The waxy cuticle is hydrophobic, so it is resistant to water and does not allow water to penetrate easily, providing a waterproof barrier that prevents water loss and dehydration. See section B1.1.8–11 (/study/app/bio/sid-422-cid-755105/book/properties-and-functions-of-lipids-id-44588/) for more information on the hydrophobic properties of lipids.
- Below the waxy cuticle and on the underside of the leaf is the epidermis. The epidermis regulates the exchange of gases between the leaf and the external air through small pores called stomata (**Figure 1**). Some stomata may also be found on the upper side of the leaf and

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on the stem, but most are found on the underside of the leaf to prevent excess water loss. The stomata are also more protected against physical factors such as rain and physical contact on the underside of the leaf. The opening and closing of stomata is regulated by the shape of guard cells. When the stomata are open the rate of gas exchange increases, and when they are closed the rate of gas exchange decreases.

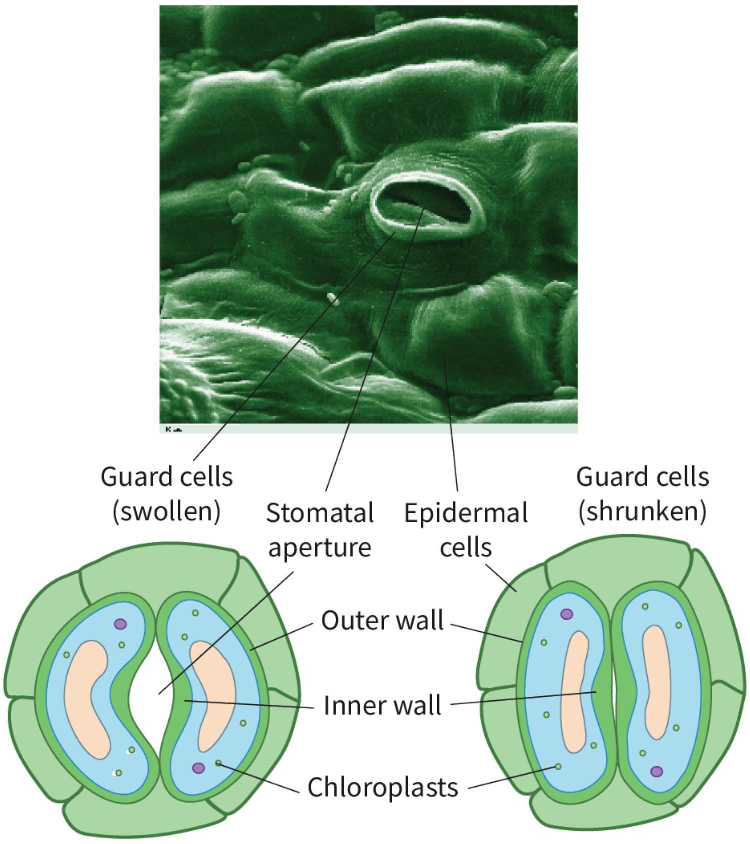

Figure 1. Photomicrograph of a leaf surface viewed using ×400 magnification.

More information for figure 1

The image consists of a photomicrograph and a diagram. The top part shows a photomicrograph of a leaf surface under high magnification. It highlights the details of a stomatal aperture, surrounding epidermal cells, and guard cells. The bottom part is a detailed, simplified diagram illustrating two scenarios of guard cells: swollen and shrunken. The diagram labels parts like the chloroplasts, inner wall, and outer wall within the guard cells. Arrows connect each labeled part in the diagram to the corresponding feature in the photomicrograph for clearer understanding.

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- The spongy mesophyll layer provides many air spaces to allow gases to diffuse from one part of the leaf to another.

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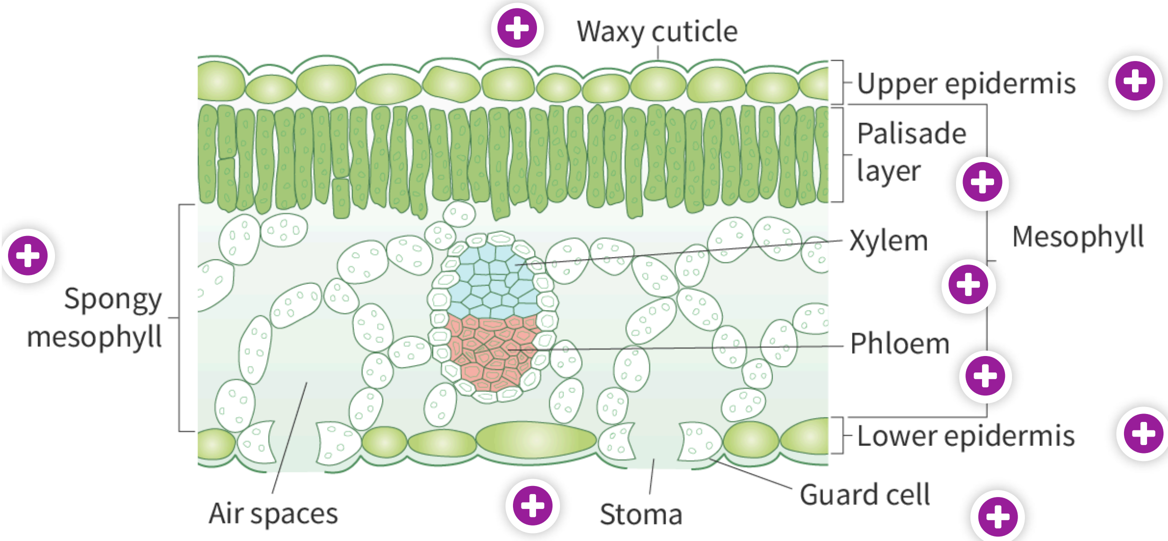
- Veins transport water from the roots to the leaves. Veins, called vascular bundles, are made of xylem and phloem tissue. Xylem tissue transports water and dissolved minerals, and phloem tissue transports sugars and amino acids (see sections B3.2.7–10 (/study/app/bio/sid-422-cid-755105/book/transport-in-plants-id-44452/) and B3.2.17–18 (/study/app/bio/sid-422-cid-755105/book/phloem-and-xylem-hl-id-44454/)). This water will diffuse out of the leaf in the process of transpiration.

Use **Interactive 1** to review the functions of each part of the leaf tissue.



Interactive 1. Distribution of Tissues in a Dicotyledonous Leaf.

More information for interactive 1

The interactive image provides a detailed cross-sectional view of a dicotyledonous leaf, highlighting its internal structure and the distribution of various tissues involved in photosynthesis, gas exchange, and transport.

The interactive consists of 9 clickable hotspots, each represented by a plus sign. Clicking on the hotspot reveals information about the specific part of the leaf. The hotspots are named hotspot 1, hotspot 2, hotspot 3, hotspot 4, hotspot 5, hotspot 6, hotspot 7, hotspot 8, and hotspot 9.

At the very top, the waxy cuticle is shown as a protective, waterproof layer that helps prevent water loss from the surface of the leaf. Hotspot 1 is located near the waxy cuticle and the text on hotspot 1 states “Waxy cuticle: provides a waterproof barrier that prevents water loss from the upper side of the leaf.”

Just beneath the waxy cuticle is the upper epidermis, a single layer of cells that provides protection and allows light to pass through to the photosynthetic tissues below. Hotspot 2 is located near the upper epidermis and clicking on it reveals the text “Upper epidermis: protective layer.”

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Beneath the upper epidermis lies the mesophyll layer. The mesophyll region includes both the palisade layer and the spongy mesophyll. Right below the upper epidermis lies the palisade layer, where tightly packed, elongated cells rich in chloroplasts are arranged vertically to maximize light absorption. This is where most of the photosynthesis takes place. Hotspot 3 is located near the palisade layer and clicking on it reveals the text “Palisade layer: contains many palisade cells which are packed full of chloroplasts, the organelles that carry out photosynthesis.”

The spongy mesophyll is shown below the palisade layer and consists of loosely arranged cells with many air spaces between them. These spaces are labelled air spaces in the diagram and allow for efficient gas exchange (oxygen, carbon dioxide, and water vapour) within the leaf. Hotspot 4 is located near the spongy mesophyll label and clicking on it reveals the text “Spongy mesophyll: contains many air spaces to allow gases to diffuse from one part of the leaf to another.”

In the center of the leaf section, vascular bundles are visible and are made up of xylem and phloem tissues. A bundle sheath made of parenchyma cells surrounds the vascular bundle. The xylem, shown in blue, transports water and minerals from the roots to the leaves and fills the upper half of the vascular bundle. Hotspot 5 is located near the label “Xylem” and clicking on it reveals the text “Xylem: transports water and dissolved minerals.”

The phloem, shown in red, carries the sugars produced during photosynthesis to other parts of the plant and fills the lower half of the vascular bundle. Hotspot 6 is located near the label “phloem” and clicking on it reveals the text “Phloem: transports sugar and amino acids.”

These vascular tissues are vital for maintaining the flow of nutrients and water throughout the plant.

The lower epidermis forms the bottom layer of the leaf and, like the upper epidermis, serves as a protective covering. Hotspot 7 is located near the lower epidermis and clicking on it reveals the text “Lower epidermis: functions as a protective layer and also helps to regulate gas exchange.”

Embedded within the lower epidermis are structures labeled stoma (plural: stomata), which are tiny openings that regulate gas exchange and water loss. Hotspot 8 is located near the stoma and clicking on it reveals the text “Stoma: small pore that allows the exchange of gases between the leaf and the air outside.”

Flanking each stoma are guard cells, which control the opening and closing of the stomatal pore based on environmental conditions. Hotspot 9 is located near the label “guard cells” and clicking on it reveals the text “Guard cell: controls the opening and closing of the stoma.”

This diagram effectively illustrates how each structure within a leaf is specialised to perform its role efficiently. From light absorption and photosynthesis to the movement of gases and nutrients, all the components work together to support the plant's growth and survival. The labelled hotspots provide a quick and focused understanding of each part seen directly in the image, making it a useful visual tool for learning about leaf anatomy.

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Figure 2 shows a plan diagram of a section through a leaf.

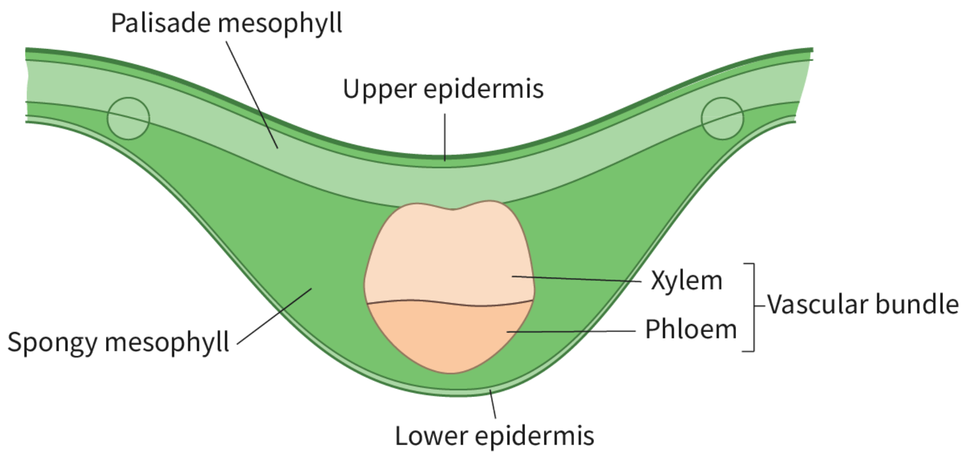

Figure 2. Plan diagram to show distribution of tissues in a transverse section of a dicotyledonous leaf.

More information for figure 2

The diagram illustrates a transverse section of a dicotyledonous leaf. It shows multiple layers and tissues labeled for clarity. Starting from the top, the 'Upper epidermis' is visible, followed by a dense layer labeled 'Palisade mesophyll.' Below this is the 'Spongy mesophyll,' which appears less dense. The 'Lower epidermis' forms the bottom layer of the leaf section.

Towards the center of the leaf, the 'Vascular bundle' is highlighted. Within the vascular bundle, two key components are labeled: 'Xylem' and 'Phloem.' The xylem is typically responsible for water transport, while the phloem distributes nutrients.

Each section is marked with labels to denote its position in the leaf, indicating the organization and distribution of tissues within the leaf's structure.

[Generated by AI]

Try this activity to check your understanding of the distribution of tissues in a leaf and to practise how to draw them in transverse section.

Activity

- **IB learner profile attribute:** Thinker
- **Approaches to learning:** Thinking skills — Reflecting at all stages of the assessment and learning cycle
- **Time required to complete activity:** 20 minutes
- **Activity type:** Individual activity

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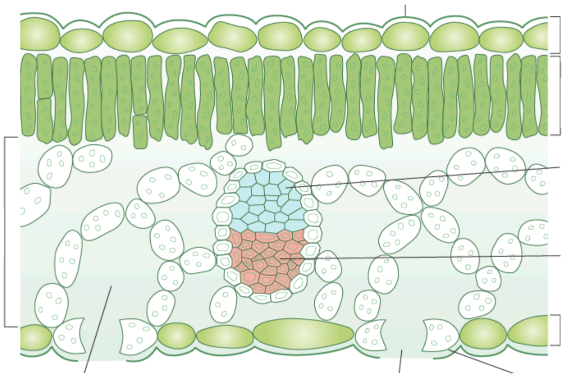
You need to be able to draw and label a plan diagram to show the distribution of tissues in a transverse section of a dicotyledonous leaf.

First test your understanding of the locations of the tissues in a dicotyledonous leaf using the activity below.



Upper epidermis
Lower epidermis
Phloem
Guard cell
Spongy mesophyll
Waxy cuticle
Air space
Xylem
Palisade layer
Stoma

Check

Interactive 2. Understanding of the Locations of the Tissues in a Dicotyledonous Leaf.

More information for interactive 2

The drag and drop interactive shows a **plan diagram of the transverse section (T.S.) of a dicot leaf** showing the distribution of tissues.

The leaf exhibits a bifacial arrangement, meaning the upper and lower surfaces have distinct anatomical features. At the top of the image is a waxy cuticle, represented by a thin green curved line. Below the waxy cuticle, there is a row of small spherical light green structures, representing the upper epidermis.

Below this upper epidermis, the mesophyll or middle tissue layer is located. This mesophyll consists of a layer of tightly packed elongated cells called the palisade layer. This palisade layer is located just beneath the upper epidermis and it consists of several chloroplasts, making it the primary site for photosynthesis. Just below the palisade layer is the spongy parenchyma. Spongy parenchyma consists of loosely arranged, irregularly shaped cells with ample intercellular spaces to facilitate gas exchange. The empty spaces between the spongy mesophyll cells that facilitate the movement of gases during photosynthesis and respiration are called air spaces.

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Embedded within the mesophyll, is a vascular bundle, often centrally located. It is encased by a bundle sheath made of parenchymatous cells. Inside the vascular bundle are the xylem and phloem. Xylem transports water and minerals from roots to leaves; positioned towards the upper side. Phloem transports the food prepared in the leaf during photosynthesis to other parts of the plant; located towards the lower side.

Below the mesophyll layers is the lower epidermis. It consists of a single layer of cells similar to the upper epidermis but with a thinner cuticle. Stoma are present, each flanked by two guard cells containing chloroplasts, regulating gas exchange and transpiration. A stoma is a small pore found in the lower epidermis. The stoma allows gases to enter and exit the leaf and plays a key role in transpiration and photosynthesis. The guard cells are the two bean-shaped cells that surround each stoma. They regulate the opening and closing of the stoma based on the plant's needs and environmental conditions.

The image consists of several drop boxes at different parts of the image where the labelled parts need to be dragged and dropped. Different labelled parts of the diagram are given at the bottom as options. These options include: Upper epidermis, Lower epidermis, Phloem, Guard cell, Spongy mesophyll, Waxy cuticle, Air space, Xylem, Palisade layer, and Stoma. The user needs to drag and drop the labelled parts into their correct places in the diagram.

After dragging and dropping the labelled parts of the leaf into their respective dropboxes, users can check their results using the “Check” option located at the bottom left corner of the interactive.

Read below for a solution:

The drop box at the top should be “Waxy cuticle”.

From top to bottom on the right side:

The first drop box on the right should be “Upper epidermis”.

The second drop box on the right should be “Palisade layer”.

The third drop box on the right should be “Xylem”.

The fourth drop box on the right should be “Phloem”.

The fifth drop box on the right should be “Lower epidermis”.

The drop box on the left should be “Spongy mesophyll”.

The drop box on the bottom left should be “Air space”.

The drop box on the mid bottom should be “Stoma”.

The drop box on the bottom right should be “Guard cell”.

The drag-and-drop interactive tests the user's understanding of the location of tissues in a dicotyledonous leaf. The interactive helps users draw and label the parts of a transverse section of a dicotyledonous leaf. This drag and drop interactive helps users understand the internal organization of a leaf and how different tissues are arranged to perform vital functions like photosynthesis, gas exchange, and transportation of water and food.

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Once you are confident that you know how to label the structures, on a blank piece of paper, draw and label a transverse section of a leaf without looking at any diagrams. Review and refine your diagram until you can confidently complete the diagram from memory.

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Transpiration as a consequence of gas exchange in the leaves

Transpiration is the loss of water vapour through the leaves, stems, and other above-ground parts of the plant.

Because there is a greater concentration of water vapour in the leaf than the surrounding air, water vapour diffuses out from the leaf, through the stomata.

The diffusion of water out into the atmosphere through the stomata results in a negative pressure, which pulls on water molecules in the xylem in a process called capillary action, which is covered in more detail in section B3.2.7–10 (/study/app/bio/sid-422-cid-755105/book/transport-in-plants-id-44452/). Capillary action occurs due to the cohesive and adhesive properties of water (see sections A1.1.1–3 (/study/app/bio/sid-422-cid-755105/book/structure-of-water-id-43194/) and A1.1.4–5 (/study/app/bio/sid-422-cid-755105/book/interactions-with-water-id-43195/)).

As well as allowing a plant to absorb water and nutrients from the soil, and transport these throughout the plant, transpiration plays a role in regulating the temperature of the plant. Water that is transpired can carry away excess heat, helping to keep the plant cool. On a larger scale, the water that is transpired from many plants, such as the Amazon rainforest, generates atmospheric water vapour which leads to cooling, airflow and rainfall (see section D4.2.3 (/study/app/bio/sid-422-cid-755105/book/stability-of-ecosystems-id-44455/)).

Measuring the rate of transpiration

The rate of transpiration can be estimated using a potometer (**Figure 3**). A potometer measures the volume of water taken up by a plant, which will be approximately equal to the volume of water lost from the plant in the process of transpiration during that time.

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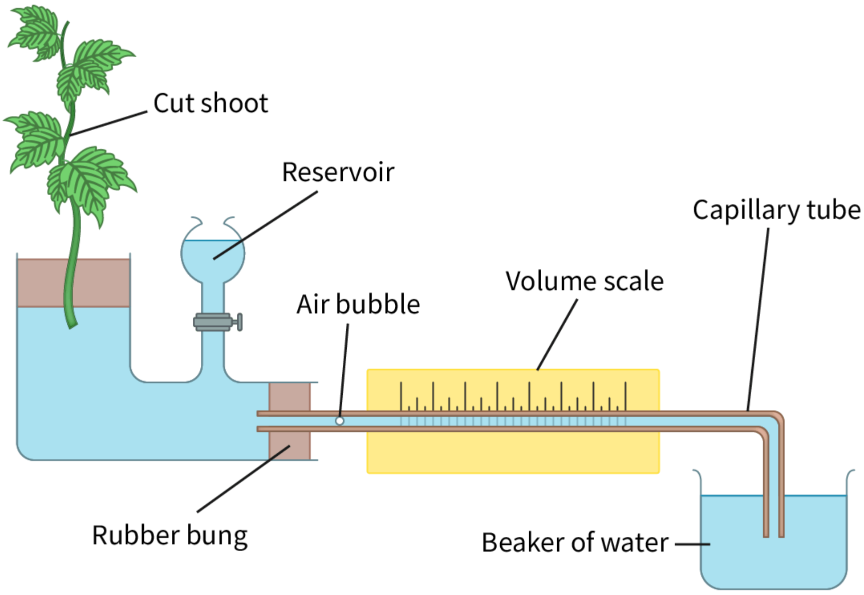

Figure 3. The rate of transpiration can be estimated using a potometer.

More information for figure 3

The diagram illustrates a potometer setup used to measure the rate of transpiration in plants by estimating the volume of water uptake. It consists of several parts:

1. **Cut Shoot**: A portion of a plant inserted into the apparatus to take up water.
2. **Reservoir**: Contains water and provides a steady supply to the cut shoot.
3. **Air Bubble**: Used as an indicator to measure water uptake within the capillary tube.
4. **Rubber Bung**: Seals the setup to prevent air leakage.
5. **Capillary Tube**: A long, narrow tube where the air bubble moves, allowing measurement of water uptake.
6. **Volume Scale**: Calibrated scale attached to the capillary tube for measuring the volume of water displaced.
7. **Beaker of Water**: Connected to the capillary tube, ensuring continuous water supply to the plant.

The movement of the air bubble along the volume scale indicates the rate of water uptake by the plant, which correlates with the rate of transpiration.

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Factors affecting the rate of transpiration

The rate of transpiration can be affected by temperature, humidity, wind speed and light intensity.

Temperature – The higher the temperature, the more kinetic energy water molecules have, and so the faster they evaporate and diffuse out of the stomata. High temperatures also increase the saturation point of the air outside the leaf, meaning the air is able to hold more water vapour molecules.

Humidity – Humidity refers to the amount of moisture in the air. The higher the humidity of the surrounding air, the more water vapour molecules in the air outside the leaf. As a result, there is a lower concentration gradient between the leaf and the surrounding air, slowing the rate of diffusion of water vapour.

Wind intensity – The higher the wind speed, the faster water molecules are moved away from the leaf once transpiration has occurred. This results in an increased concentration gradient between the stomata and the air outside the leaf, increasing the rate of diffusion of water molecules.

Light intensity – When light intensity is higher, guard cells cause the stomata to open wider to allow more carbon dioxide to diffuse into the leaf for photosynthesis. This means that more water evaporates from the plant.

Try this simulation activity to check your understanding of the factors that affect the rate of transpiration.

Activity

- **IB learner profile attribute:** Thinker
- **Approaches to learning:** Thinking skills — Experimenting with new strategies for learning
- **Time required to complete activity:** 20 minutes
- **Activity type:** Individual activity

You can use this simulation (https://iwant2study.org/lookangejss/biology/ejss_model_transpiration/transpiration_Simulation. to investigate the effect of heat, wind speed and light intensity on the rate of transpiration. Read the 'instructions' and 'experiment info' before using the simulation. Then, once you have used the simulation, consider the questions in the 'practice questions' tab.

Student view

Stomatal density

Stomatal density is the number of stomata in a particular unit of area of a leaf or other plant organ.

Knowing the stomatal density is useful for a number of reasons, including:

- Plants with more stomata tend to have a higher rate of transpiration, and therefore the stomatal density can indicate how efficiently a plant uses water.
- Changes in stomatal density in different environments can help us to understand the effect of climates and climate change on plant physiology.
- Similarities and differences in stomatal density can indicate phylogenetic relationships between plants.
- Stomatal density of plant fossils can be used as an indicator of past environmental conditions.

Determining stomatal density

To determine stomatal density, you need to know:

- The area of your field of view. You can use a stage micrometre and graticule to determine the measurements of your field of view. See section A2.2.1–2 (/study/app/bio/sid-422-cid-755105/book/using-microscopes-id-43573/) for a reminder on using stage micrometres and graticules. Once you have measured these values you can calculate the area of your field of view using the equation area = πr^2.
- If you are using a square field of view, the formula for finding the area of a square is area = a x a (where a = one side of the square). The results are given as a^2.
- The number of stomata in the field of view.

Worked example 1

A student is observing stomata under the microscope. The student takes the following five photomicrographs (**Figure 4**).

Calculate the mean stomatal density, giving your answer to the nearest whole number.

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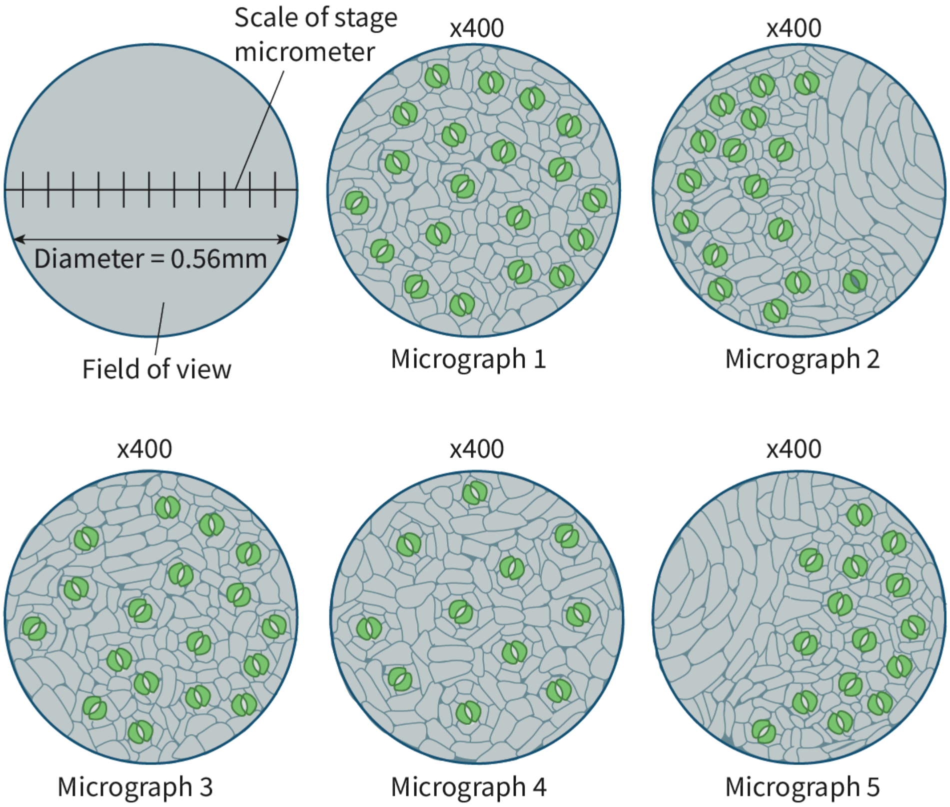

Figure 4. Five photomicrographs of leaves.

More information for figure 4

The image shows five circular photomicrographs labeled Micrograph 1 to Micrograph 5, each at 400x magnification. These circles represent leaf surfaces with multiple green stomata visible. The first circle also shows a scale with a label 'Scale of stage micrometer,' indicating a field of view diameter of 0.56 mm. Each micrograph displays different distributions of green stomata, which are the pores on the leaf surface, essential for calculating the mean stomatal density. The cells surrounding the stomata are illustrated with a darker outline, emphasizing each stomatal structure.

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1. First calculate the radius of the field of view by dividing the diameter by two.
   As the diameter of the field of view is 0.56 mm, the radius is 0.28 mm
2. Now find the area of the field of view, using the equation πr^2.
   $\pi \times 0.28 \times 0.28 = 0.25$ mm^2 *(to two decimal places)*
3. Then calculate the number of stomata in each field of view.

Micrograph	Number of stomata
1	20

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Micrograph	Number of stomata
2	16
3	18
4	11
5	15

1. Calculate the mean number of stomata in the field of view:

$$\frac{20+16+18+11+15}{5}=16$$

2. Divide the mean number of stomata by the area:

$$\frac{16}{0.25}=64.00 \text{ stomata per mm}^2$$

3. Give your answer to the number of decimal places specified.
In this case we have been asked to give our answer to the nearest whole number = 64 stomata per mm^2

Performing and observing a leaf cast

As well as using pre-prepared slides or observing micrographs, you can perform a leaf cast to observe stomata and calculate stomatal density (**Figure 5**).

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Interactive 3. Taking a Leaf Cast to Observe Stomatal Density.

More information for interactive 3

The interactive slideshow guides you through the process of creating and analyzing a **leaf cast** to observe **stomata** under a microscope. You will select a suitable leaf, apply nail varnish to create an impression and examine the cast using different magnifications.

The interactive consists of 6 slides. Each slide has an image on the right with a text on the left that guides you through the process of creating a leaf cast and observing stomata under a microscope.

Read below to learn about each slide in detail:

Slide 1

The image shows the first step in a leaf experiment, where a person uses scissors to cut a leaf from a plant.

The text on the left is as follows: 1. Select and cut off a leaf from a plant. Be aware that not all leaves will have stomata that will create a clear impression. Flat leaves with a smooth surface tend to give the clearest impressions. Leaves that are too thin or fragile may tear during the casting process and are therefore unsuitable. You might choose one of the following plants: *Tradescantia virginiana* (Spiderwort); *Vicia faba* (Broad bean), or *Chlorophytum comosum* (Spider plant).

Slide 2

The image illustrates the second step of a scientific procedure involving a leaf. The image depicts a leaf placed on a dark flat surface with nail varnish applied to the underside of the leaf. There is a bottle to the right side of the leaf, likely indicating a nail varnish bottle.

The text on the left is as follows: 2. Place the leaf on a flat surface and coat the underside of the leaf in clear nail varnish. Solvent-based nail varnishes are often used because they dry faster than water-based nail varnishes, but they are also more likely to damage the plant structures.

Slide 3

The image in slide 3 represents the third step of a plant-related experiment. The illustration features a green leaf placed flat on a dark surface with nail varnish applied to its underside. The leaf is accompanied by a clock symbol at the top with arrows indicating the passage of time, visually reinforcing the idea of waiting for the varnish to dry before proceeding.

The text on the left of this slide is as follows: 3. Allow the nail varnish to dry.

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It instructs the user to allow the clear nail varnish, previously applied to the underside of the leaf, to dry completely. This step is crucial to ensure that a solid, peelable layer forms, capturing the fine surface details of the leaf.

Slide 4

The image illustrates the fourth step of a leaf impression experiment. In the illustration, the tape is shown being applied to the leaf, with a separate image of a tape on top, visually demonstrating how the tape is applied to the leaf.

The text on the left is as follows: 4. Place a strip of clear tape over the nail varnish, press it down and then peel it off. This should remove the nail varnish leaf cast.

This action lifts the thin layer of dried nail varnish, which carries an impression of the leaf's surface structures—effectively creating a cast of the leaf.

Slide 5:

The image on right shows the leaf impression—now attached to the piece of clear tape—is placed onto a microscope slide for observation.

The text on the left is as follows: 5. Place the leaf with the tape on a microscope slide. You do not need to use a cover slide as this is not a biological specimen, only an impression of one.

Slide 6

The image shows a microscope with a prepared slide placed on the stage. On the slide is a small green leaf impression, created earlier using nail varnish and tape. The microscope is oriented for observation, with the eyepiece at the top and objective lenses pointed at the slide. The setup illustrates the process of examining the leaf cast under magnification.

The text on the left of this slide is as follows: 6. View the leaf cast under the microscope, using a magnification of $\times 100$ or $\times 400$. Adjust the focus so that you can clearly see and count the stomata. Adjust the field of view to another area of the leaf cast and count the number of stomata in that area. Take repeat measurements to obtain five measurements and then follow the instructions detailed previously to calculate the mean stomatal density.

The interactive slideshow provides step-by-step instructions to learners on how to create a leaf cast using nail varnish and tape and how to view it under a microscope. The interactive also provides instructions to learners on how to view stomata under the microscope and calculate stomatal density. This exercise helps learners to develop skills in microscopy, data collection, and stomatal density calculation.

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Aspect: Measurements

Reliability of quantitative data is increased by repeating measurements. In this case, repeated counts of the number of stomata visible in the field of view at high power illustrate the variability of biological material and the need for replicate trials (see section 1.5.4 (/study/app/bio/sid-422-cid-755105/book/data-analysis-id-46700/) for data processing).

Creativity, activity, service

Strand: Service
Learning outcome: Demonstrate engagement with issues of global significance

Growing your own food can be a more sustainable and environmentally friendly way to feed yourself and your community. Consider setting up a greenhouse or vegetable patch in your school grounds. Think about the best place to situate this in terms of what the plants need to thrive, and consider what you will need to set up and maintain your greenhouse or patch.

Try this activity to test your understanding of calculating stomatal density.

Activity

- **IB learner profile attribute:** Inquirer
- **Approaches to learning:**
  - Thinking skills — Applying key ideas and facts in new contexts
  - Research skills — Comparing, contrasting and validating information
- **Time required to complete activity:** 20 minutes
- **Activity type:** Individual activity

In this activity you will calculate stomatal density. You can choose one of the following activities:

1. Perform leaf casts on different leaves and use this to calculate the stomatal density.
2. Use the provided micrographs (A to F) in **Figure 5** to calculate the mean stomatal density.

Student
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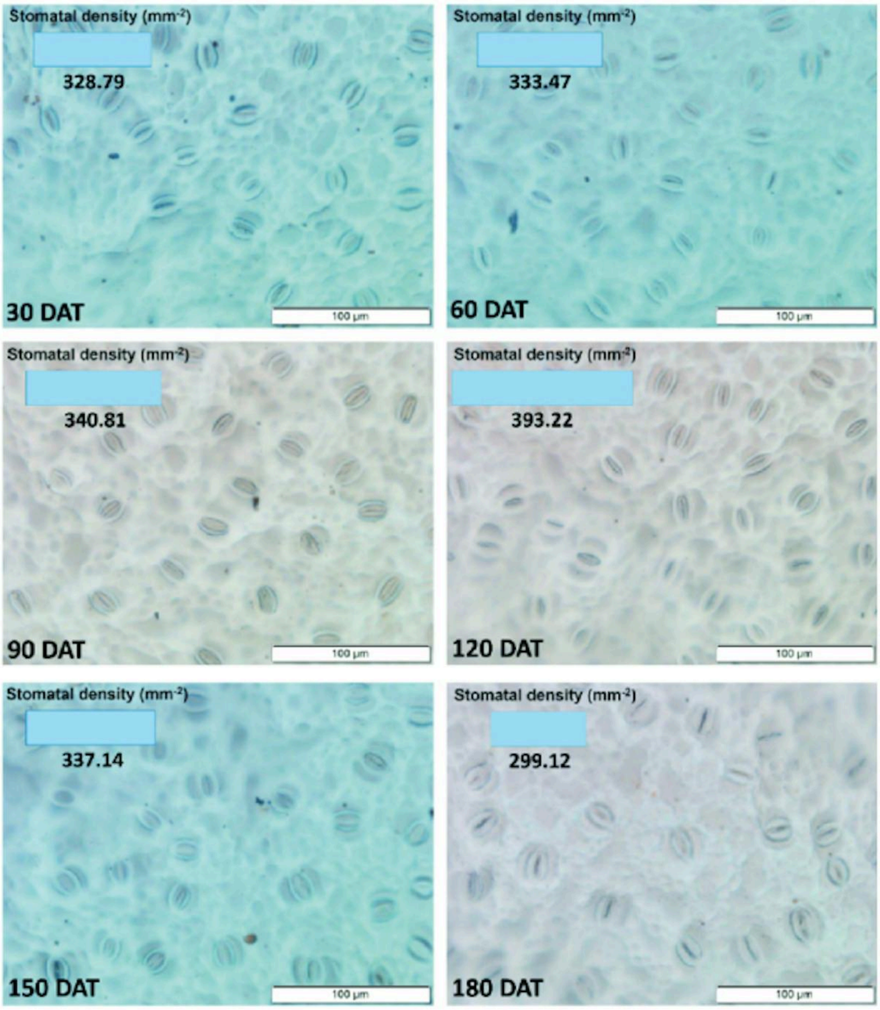

Figure 5. Micrographs for calculating mean stomatal density.

Source: "Density of stomata in the axial epidermis of the leaves of the seedlings of *Hymenaea courbaril L.* (https://www.researchgate.net/figure/Density-of-stomata-in-the-axial-epidermis-of-the-leaves-of-the-seedlings-of-Hymenaea_fig1_342041714)" by Daniele de Cássia Vieira de Sousa, Layara Alexandre Bessa, Fabiano Guimarães Silva and Márcio Rosa is licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/)

More information for figure 5

The image displays a series of six micrographs labeled with different stomatal densities, measured in square millimeters, at different days after treatment (DAT): 30, 60, 90, 120, 150, and 180 days. Each micrograph shows epidermal tissue with stomata visible as small openings. The stomatal density values are as follows: 328.79 at 30 DAT, 333.47 at 60 DAT, 340.81 at 90 DAT, 393.22 at 120 DAT, 337.14 at 150 DAT, and 299.12 at 180 DAT. Each micrograph provides a scale bar indicating a length of 100 micrometers.

[Generated by AI]

Follow the guidelines specified in **Interactive 3** (taking a leaf cast) and Worked example 1 (calculating stomatal density).

Student view

Transport of oxygen (HL)

Higher level (HL)

Learning outcomes

By the end of this section you should be able to:

- Outline the adaptations of foetal and adult haemoglobin for the transport of oxygen.
- Explain the Bohr shift and the benefits for respiring tissues.
- Analyse and explain oxygen dissociation curves.

Vertebrates tend to have a high metabolic rate. Because of this they require a high rate of oxygen delivery to, and carbon dioxide removal from, cells. How are these gases transported around the body?

Adaptations of foetal and adult haemoglobin

Haemoglobin is a protein that is found in the red blood cells of vertebrates. Haemoglobin is responsible for:

- transporting oxygen from the lungs to respiring tissues
- transporting carbon dioxide from respiring tissues back to the lungs where it can be exhaled.

When haemoglobin is bound to oxygen, the molecule is called an oxyhaemoglobin complex. Haemoglobin that is not bound to oxygen is called deoxyhaemoglobin.

Foetal haemoglobin

Foetal haemoglobin (HbF) is a type of haemoglobin produced by the developing foetus during pregnancy. It is the dominant form of haemoglobin during foetal development and will remain in the infant until 6 months old, being gradually replaced by adult haemoglobin.

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HbF has a quaternary structure, being composed of two alpha and two gamma polypeptide chains, each of which contains a haem group that can bind reversibly to oxygen (**Figure 1**).

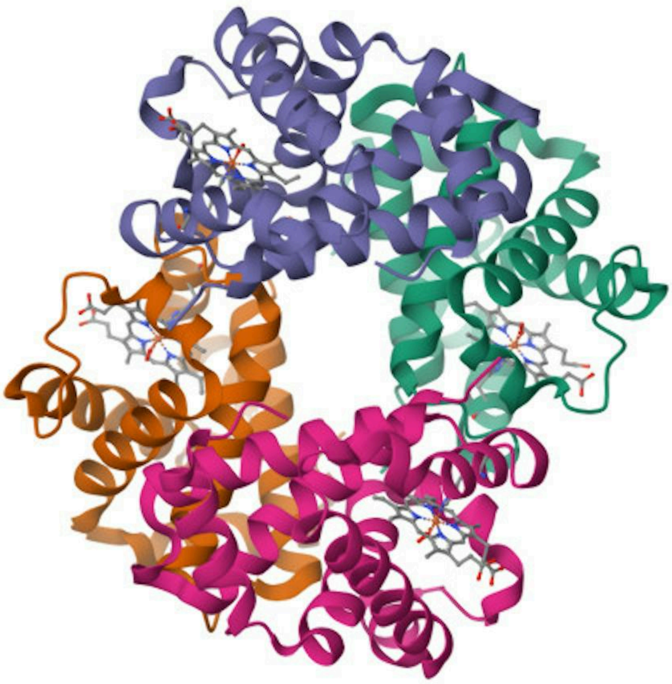

Figure 1. The structure of foetal haemoglobin. The two alpha polypeptide chains are shown in green and blue, and the two gamma polypeptide chains are shown in orange and pink. Each polypeptide chain has a haem group, which contains an iron atom to which oxygen binds reversibly.

More information for figure 1

The image is a diagram representing the 3D structure of fetal hemoglobin (HbF). It features four polypeptide chains: two alpha chains depicted in green and blue, and two gamma chains shown in orange and pink. Each polypeptide chain contains a haem group, visualized as a central component with an iron atom to which oxygen can bind reversibly. These chains are intertwined, creating a complex quaternary structure that allows for the transport of oxygen in fetal circulation. The color coding of the chains helps distinguish between the alpha and gamma polypeptides, highlighting their distinct roles in the hemoglobin molecule. This structure emphasizes the unique properties of HbF, particularly its higher affinity for oxygen compared to adult hemoglobin, due to the presence of gamma polypeptides instead of beta ones.

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Student view

Due to the presence of the gamma polypeptides, HbF has a higher affinity for oxygen than does adult haemoglobin, which contains beta polypeptides instead.

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This increases the efficiency with which the foetus obtains oxygen from the mother's blood across the placenta. You can find out more about the placenta in section D3.1.18 (/study/app/bio/sid-422-cid-755105/book/placenta-and-hormonal-control-of-pregnancy-hrt-hl-id-44456/). The high affinity of HbF to oxygen is important for foetal development and survival as the oxygen concentration in foetal blood circulation is much lower than the oxygen concentration in the mother's circulation.

Adult haemoglobin

Like HbF, adult haemoglobin (HbA) has a quaternary structure, being composed of four subunits – two alpha and two beta polypeptide chains (**Figure 2**). Each polypeptide chain contains a prosthetic group called haem group, which contains an iron atom that can bind reversibly to a molecule of oxygen. The structure of proteins is covered in subtopic B1.2 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43531/).

HbA has a lower affinity for oxygen than foetal haemoglobin. This is because it has a higher affinity for a molecule called 2,3-bisphosphoglyceric acid (2,3 BPG). An organic phosphate found in red blood cells. 2,3 BPG normally competes with oxygen for the binding to haemoglobin.

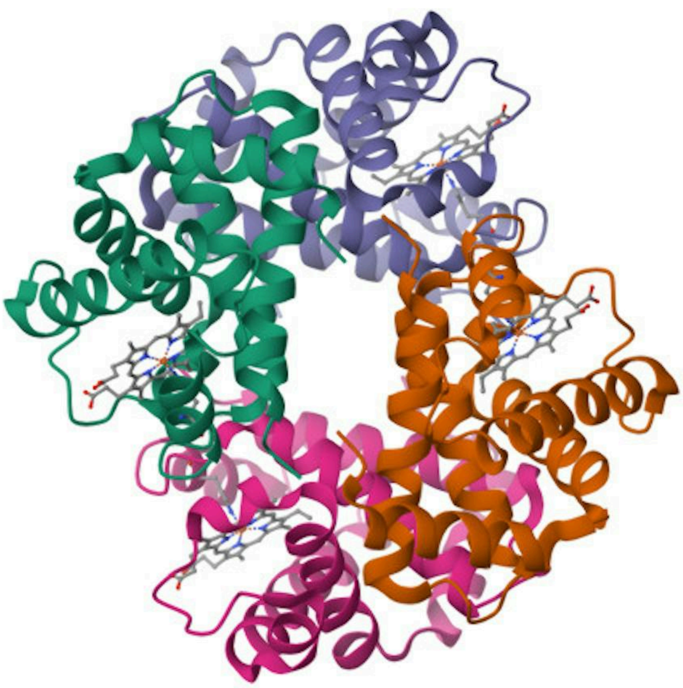

Figure 2. The structure of adult haemoglobin. The two alpha polypeptide chains are shown in green and blue, and the two beta polypeptide chains are shown in orange and pink. Each polypeptide chain has a haem group, which contains an iron atom to which oxygen binds reversibly.

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More information for figure 2

This image is a 3D model of the structure of adult hemoglobin, showing its composition of four polypeptide chains. The model distinguishes these chains using different colors: two alpha polypeptide chains in green and blue, and two beta polypeptide chains in orange and pink. Each polypeptide chain is attached to a haem group, represented as small molecular structures within the chains, which include iron atoms responsible for binding oxygen.

[Generated by AI]

You can find out more about HbF and HbA here:

Foetal haemoglobin: https://pdb101.rcsb.org/motm/257 (https://pdb101.rcsb.org/motm/257)

Adult haemoglobin: https://pdb101.rcsb.org/motm/41 (https://pdb101.rcsb.org/motm/41)

You may also come across a third type of haemoglobin in your reading, myoglobin, the transport molecule found in muscle tissue. Myoglobin consists of only one polypeptide chain and has a much higher affinity for oxygen than either HbF or HbA.

Cooperative binding of oxygen to haem groups

When one oxygen binds to one haemoglobin subunit, this changes the conformation of the molecule, increasing the affinity of haemoglobin to oxygen and therefore making it easier for other oxygen molecules to bind to the remaining haem groups. This process is called cooperative binding (**Figure 3**).

Conversely, when an oxygen molecule is released from a haem group, the conformation of the haemoglobin changes, reducing the affinity of haemoglobin to oxygen.

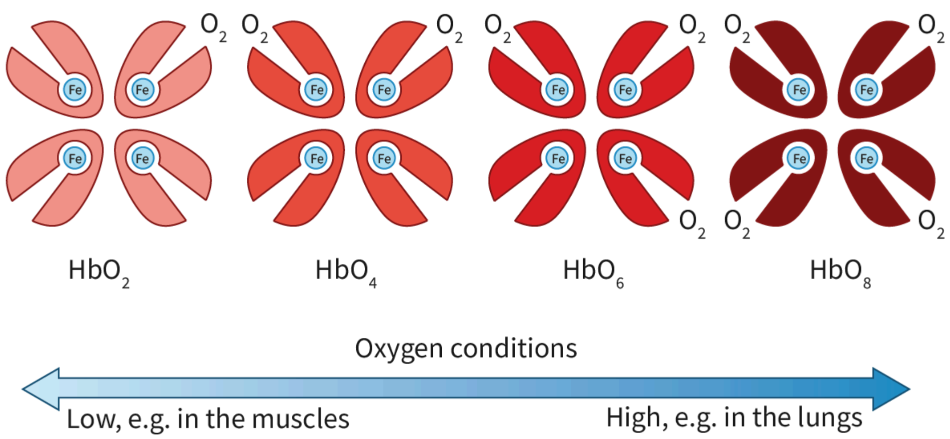

Figure 3. Cooperative binding of oxygen to haemoglobin.

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More information for figure 3

The diagram illustrates the cooperative binding of oxygen (O2) to haemoglobin (Hb) through four stages. At the far left, haemoglobin (HbO2) is shown with a single pair of oxygen molecules attached to flattened, pink-red petals. As you move rightward, each subsequent pair of oxygen molecules binds to the haem groups, changing their color to a progressively darker shade of red, illustrating increased oxygen saturation: HbO4, HbO6, and finally HbO8. Each haem group contains an iron (Fe) ion at its center, illustrated as a small circle. At the top, individual oxygen molecules are shown detaching and attaching to the haem groups. Below the series of haemoglobin states is a blue gradient arrow indicating oxygen conditions, ranging from 'Low, e.g. in the muscles' on the left to 'High, e.g. in the lungs' on the right.

[Generated by AI]

The oxygen dissociation curve plots the partial pressure (concentration) of oxygen on the *x*-axis, and the percentage saturation of haemoglobin with oxygen on the *y*-axis (**Figure 4**). Cooperative binding of haemoglobin to oxygen results in a sigmoidal (S-shaped) oxygen dissociation curve. The rate of oxygen uptake by haemoglobin increases rapidly as the partial pressure of oxygen increases. But it eventually levels off as the haemoglobin becomes fully saturated with oxygen in areas of higher partial pressures of oxygen, such as in the lungs.

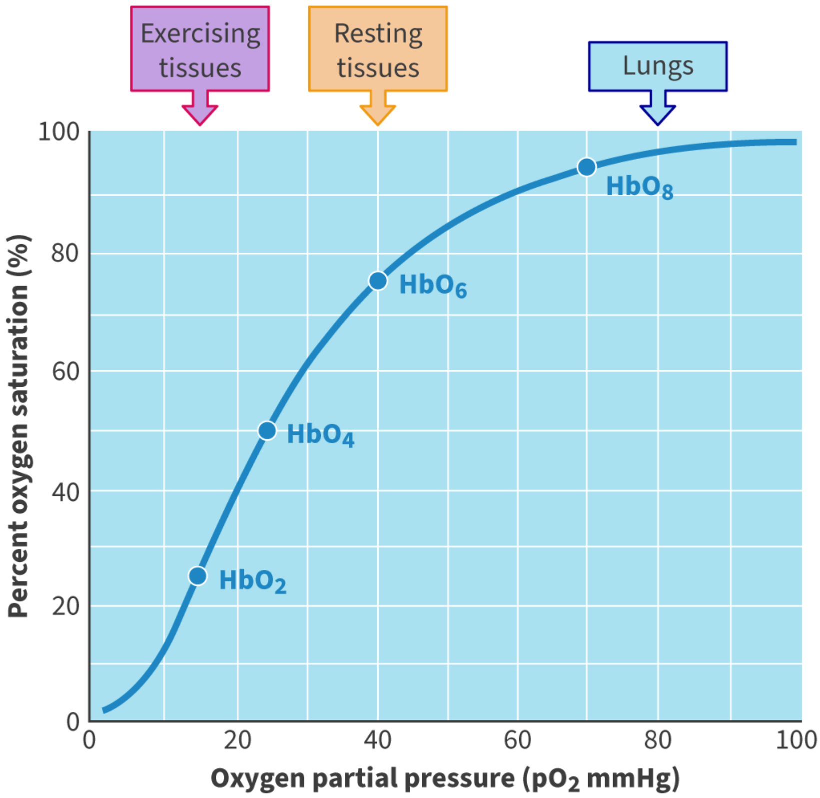

Figure 4. Cooperative binding of oxygen to haemoglobin results in a sigmoidal oxygen dissociation curve.

More information for figure 4

Student view

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The image is a graph depicting the oxygen dissociation curve. The x-axis represents the oxygen partial pressure (pO2) in mmHg, ranging from 0 to 100 mmHg, while the y-axis shows the percent oxygen saturation of haemoglobin (%), from 0 to 100%. The curve is sigmoidal, demonstrating cooperative binding of oxygen to haemoglobin.

Key points are labeled along the curve: - At approximately 20 mmHg, the curve shows increasing steepness, representing HbO2. - Around 40 mmHg, an inflection point is marked as HbO4. - Near 60 mmHg, the curve starts to level off, marked as HbO6. - At 100 mmHg, the curve saturates, labeled as HbO8.

Annotations indicate physiological contexts with arrows: - Exercising tissues around 20 mmHg. - Resting tissues near 40 mmHg. - Lungs at 80 mmHg and above, where oxygen saturation nears completion, around HbO8.

[Generated by AI]

Allosteric binding of carbon dioxide

As well as transporting oxygen, haemoglobin can transport a small amount of carbon dioxide. Unlike oxygen, carbon dioxide binds to an allosteric region of haemoglobin, rather than the haem group. This is known as allosteric binding and causes haemoglobin to form carbaminohaemoglobin, undergoing a conformational change which results in a decreased affinity for oxygen. This is important for ensuring that haemoglobin unloads oxygen in areas of low partial pressure of oxygen, such as respiring tissues.

The Bohr shift

Cooperative binding of oxygen and the allosteric binding of carbon dioxide result in the sigmoidal or 'S'-shaped oxygen dissociation curve.

The oxygen dissociation curve can be shifted to the right with higher partial pressures of carbon dioxide in the blood in a process called the Bohr shift.

Although some carbon dioxide will be transported while bound to haemoglobin, most will be dissolved in the plasma, where, in its dissolved form, it will react with water to form carbonic acid, lowering the pH of the blood. This, in turn, changes the tertiary structure of haemoglobin, decreasing its affinity for oxygen and shifting the oxygen dissociation curve to the right. The same effect can occur due to the presence of lactic acid in the blood and increased blood temperature.

As a result of the decreased affinity for oxygen, haemoglobin releases more oxygen into the tissues with higher partial pressures of carbon dioxide, such as those found in respiring muscles. Conversely, it loads up more oxygen in areas with higher partial pressures of oxygen, such as in the lungs. This shift to the right in the oxygen dissociation curve is called the Bohr shift (**Figure 5**).

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The Bohr shift occurs in both HbF and HbA, although to a lesser effect in HbF. It is believed to play a role in facilitating oxygen transfer from the mother to the foetus to help to ensure proper foetal development.

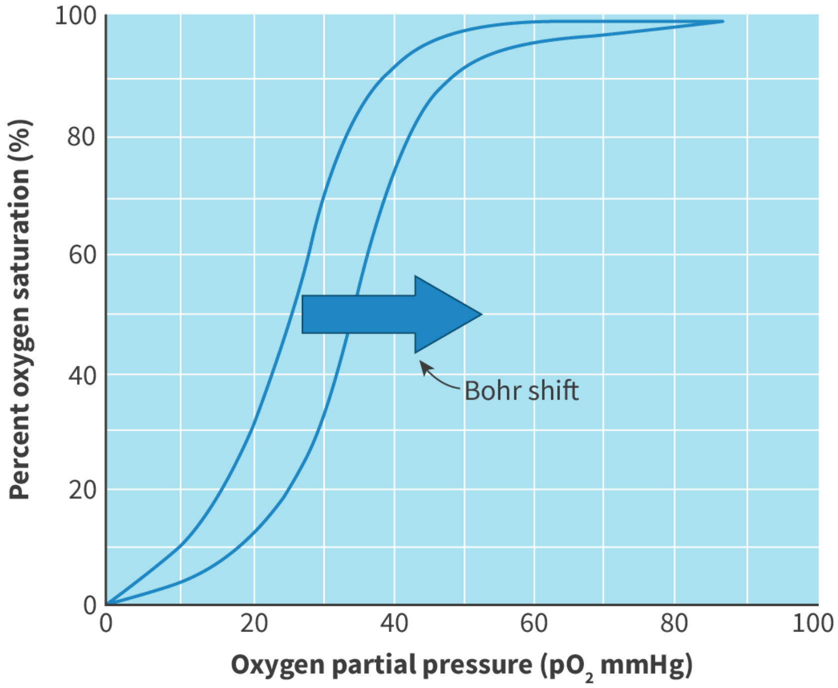

Figure 5. In areas of high partial pressures of oxygen the affinity of haemoglobin to oxygen increases, shifting the oxygen dissociation curve to the right.

More information for figure 5

The graph shows oxygen dissociation curves for haemoglobin, plotting percent oxygen saturation against oxygen partial pressure (pO2 in mmHg). The X-axis represents oxygen partial pressure (pO2), ranging from 0 to 100 mmHg. The Y-axis shows percent oxygen saturation, ranging from 0% to 100%. Two curves are depicted, with an arrow labeled 'Bohr shift' indicating a rightward shift in the curve at higher oxygen partial pressures. This demonstrates the effect of the Bohr shift on haemoglobin's affinity for oxygen, suggesting an increased affinity in areas of higher oxygen pressure.

[Generated by AI]

Try this activity to compare and contrast adult and foetal haemoglobin.

Activity

- **IB learner profile attribute:** Thinker
- **Approaches to learning:** Thinking skills — Reflecting at all stages of the assessment and learning cycle
- **Time required to complete activity:** 20 minutes

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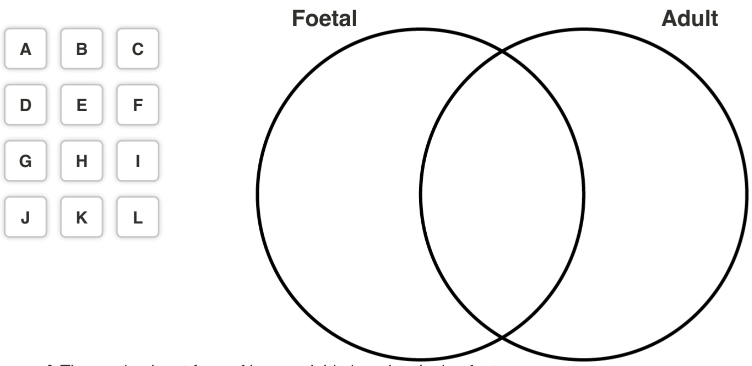
- **Activity type:** Individual activity

Organise the statements on the Venn diagram to compare and contrast between adult and foetal haemoglobin.



A The predominant form of haemoglobin in a developing foetus
B The predominant form of haemoglobin in an adult
C Found in Homo sapiens
D Higher affinity for oxygen
E Two alpha and two beta polypeptide chains
F Haem groups contain iron which binds to oxygen
G Two alpha and two gamma polypeptide chains
H Has a quaternary structure
I Can bind to up to four oxygen molecules
J Exhibits cooperative binding
K Can transport carbon dioxide as well as oxygen, but has a lower affinity for carbon dioxide
L Experiences the Bohr shift

Check

Interactive 1. Adult vs. Foetal Haemoglobin.

More information for interactive 1

This interactive illustrates a Venn diagram with two overlapping circles. The left circle is labeled "Foetal" at the top, and the right circle is labeled "Adult" at the top. It helps to compare and contrast between adult and foetal haemoglobin.The overlapping region represents characteristics shared by both foetal and adult stages.

On the left, there are 12 drag-and-drop buttons, A, B, C, D, E, F, G, H, I, J, K, and L

The options below the Venn diagram are:
A The predominant form of haemoglobin in a developing foetus
B The predominant form of haemoglobin in an adult
C Found in Homo sapiens
D Higher affinity for oxygen
E Two alpha and two beta polypeptide chains
F Haem groups contain iron which binds to oxygen
G Two alpha and two gamma polypeptide chains
H Has a quaternary structure
I Can bind to up to four oxygen molecules

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J Exhibits cooperative binding

K Can transport carbon dioxide as well as oxygen, but has a lower affinity for carbon dioxide

L Experiences the Bohr shift

Based on these suitable characteristics, the buttons should be dragged and placed in correct circles.

Read below for the solution:

Buttons A, D and G should be placed in the left circle.
Buttons B and E should be placed in the right circle.
Buttons L, I, K, H, C, J and F should be placed in the center- overlapping region of the two circles.

Once you have completed the Venn diagram, write a paragraph comparing and contrasting these two types of haemoglobin. Ensure that you are using comparative language in your answer and that you have included all of the points from the Venn diagram.

You may find these sentence starters useful:

> Both foetal and adult haemoglobin...
>
> However foetal haemoglobin...
>
> Whereas adult haemoglobin...

5 section questions

B3. Form and function: Organisms / B3.1 Gas exchange

Summary and key terms

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/summary-and-key-terms-id-44442/print/) Assign

- As organisms increase in size their surface area-to-volume ratio decreases. As such, diffusion of gases across the external surface alone will not allow sufficient gas exchange to meet the needs of the organism, and so gas-exchange surfaces such as lungs, gills and leaves are required.
- Properties of gas-exchange surfaces include a large surface area, permeability to gases, moist surface, a short diffusion distance and steep concentration gradients. Steep concentration gradients can be maintained in animals via a dense network of blood vessels close to the exchange surface, a continuous blood supply and ventilation.
- The lungs are the organs of gas exchange in mammals. Mammalian lungs contain adaptations for gas exchange, including tiny grape-like structures called alveoli, across which carbon

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dioxide and oxygen are exchanged.

- Ventilation moves air into and out of the lungs and involves the diaphragm and intercostal muscles. Forced expiration also involves the abdominal muscles.
- Lung volumes can be measured using a spirometer and can be used as an indication of lung function and overall health.
- The leaves are the organs of gas exchange in plants. Leaves contain adaptations for gas exchange, including tiny pores which are mostly located on the lower epithelium.
- Transpiration is the loss of water from the aerial parts of a plant. The rate of transpiration can be affected by temperature, wind speed, humidity and light intensity.
- Stomatal density is a measure of the number of stomata in a particular unit of area of a leaf. It can be calculated by dividing the number of stomata in a field of view by the area of the field of view.

Higher level (HL)

- Haemoglobin is a protein found in red blood cells that binds to and transports oxygen. There are two main forms: foetal and adult. Both consist of four polypeptide chains. Each polypeptide chain contains a haem group containing iron that can bind reversibly to one molecule of oxygen.
- Once the first polypeptide chain has bound to an oxygen molecule, the conformation of haemoglobin changes, increasing the affinity of the remaining polypeptide chains for oxygen. This is known as cooperative binding and results in a sigmoidal (S-shaped) oxygen dissociation curve. Carbon dioxide can bind to an allosteric site on the haemoglobin molecule, decreasing the affinity of haemoglobin for oxygen. Most of the carbon dioxide will be transported in the blood dissolved in the plasma. High levels of carbon dioxide in the blood decreases the affinity of haemoglobin to oxygen, resulting in the Bohr shift, shifting the oxygen dissociation curve to the right.

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Key terms

Review these key terms. Do you know them all? Fill in as many gaps as you can using the terms in this list.

1. Gas exchange is a . Gills, the lungs and leaves are all types of gas-exchange surfaces.
2. Gas-exchange surfaces need to be thin, , moist, have a large and there needs to be a steep gradient across the surface.
3. In mammalian lungs, gas exchange occurs across the wall of the . The high surface area of the alveoli, ventilation, surfactant and an extensive bed surrounding the alveoli help to ensure efficient gas exchange.
4. In the leaves of plants, gas exchange occurs through tiny pores called . The loss of water through the stomata is . The rate of transpiration can be affected by temperature, , wind speed and light intensity.
5. [HL] Red blood cells contain a protein called which has four haem groups containing iron which bind to and transport oxygen. Haemoglobin exhibits binding, whereby when one oxygen molecule binds, the conformation of haemoglobin changes, increasing its affinity for oxygen. Carbon dioxide can also bind to haemoglobin, although it binds away from the haem group. This is called binding. Increased concentrations of carbon dioxide in the blood result in the , decreasing the affinity of haemoglobin for oxygen.

permeable | vital function | stomata | Bohr shift | allosteric | transpiration | concentration | cooperative | humidity | surface area | capillary | haemoglobin | alveoli

Check

Interactive 1. Gas Exchange in Organisms.

Student view

B3. Form and function: Organisms / B3.1 Gas exchange

Checklist

What you should know

After studying this subtopic you should be able to:

- Outline the need for gas exchange in living organisms.
- Describe properties of gas-exchange surfaces.
- Explain how concentration gradients are maintained at exchange surfaces in animals.
- Describe the adaptations of mammalian lungs for gas exchange.
- Explain the process of ventilation.
- Determine measurements of lung volumes.
- Outline the adaptations of leaves for gas exchange.
- Draw and label a plan diagram to show the distribution of tissues in a transverse section of a dicotyledonous leaf.
- Outline the process of transpiration and the factors that affect the rate of transpiration.
- Determine stomatal density.

Higher level (HL)

- Outline the adaptations of foetal and adult haemoglobin for the transport of oxygen.
- Explain the Bohr shift and the benefits for respiring tissues.
- Analyse and explain oxygen dissociation curves.

Practical skills

Once you have completed this subtopic, go to Practical 1: Using microscopes and calculating magnification (/study/app/bio/sid-422-cid-755105/book/using-microscopes-and-calculating-magnification-id-46529/) in which you examine leaf stomata.

Investigation

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- **IB learner profile attribute:** Thinkers
- **Approaches to learning:** Thinking skills – Engaging with, and designing linking questions; Applying key ideas and facts in new contexts
- **Time required to complete activity:** 60 minutes
- **Activity type:** Individual activity

Your task

In this investigation you will choose to investigate the effect of one of the following variables on lung function:

- age
- biological sex
- height
- smoker or non-smoker.

1. Open the OpenScience Laboratory (https://learn5.open.ac.uk/mod/htmlactivity/view.php?id=1548) spirometry simulation. You may need to create an account.
2. Watch the introductory video.
3. Click on the 'Spirometer' tab and set your parameters.
4. Choose one independent variable to investigate.

Practical skills

Tool 1: Experimental techniques — Measuring variables

The **independent variable** is the thing that you manipulate in an investigation to determine its effect on the dependent variable. The **dependent variable** is the thing that you measure or observe. **Control variables** are the things you keep the same to ensure that the effect on the dependent variable is solely due to the independent variable.

1. Your dependent variable is the FEV_1/FVC (%).

   FVC is the forced vital capacity, the maximum volume of air that can be forcibly exhaled after taking a deep breath.

Student
view

FEV_1 is the volume of air that is forcibly exhaled in the first second of the FVC test.

FEV_1/FVC is a ratio that is commonly used to evaluate lung function. A normal FEV_1/FVC ratio is typically greater than or equal to 70%. Values below this can indicate respiratory conditions.

2. Ensure all other variables are kept constant.
3. Take at least five readings each time you change the independent variable.
4. Record your raw data in a suitable table. See the **Figure 1** below if you need guidance on how to structure your raw data table.

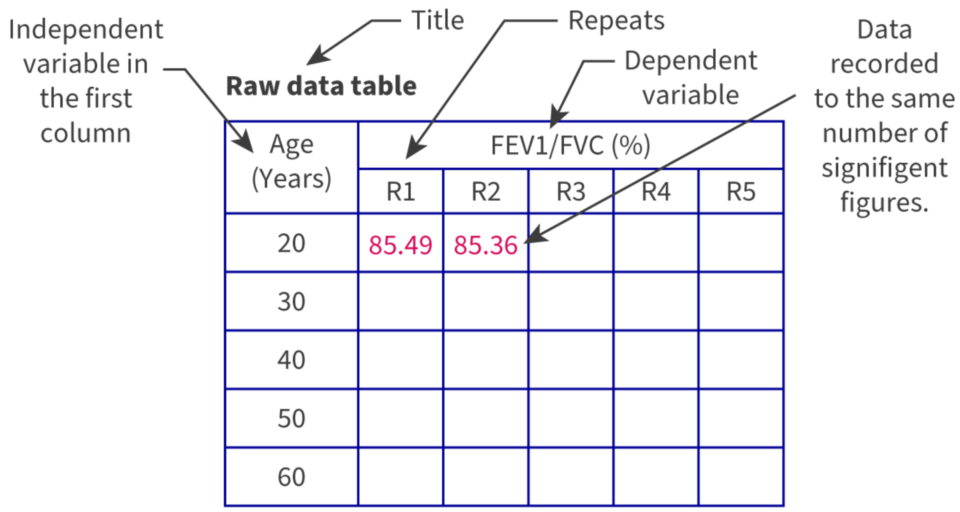

Figure 1. Example raw data table.

More information for figure 1

The image shows a raw data table with labeled columns and a sample entry. The first column is labeled 'Age (Years)' with entries from 20 to 60 in increments of 10. The next columns are labeled R1, R2, R3, R4, and R5 under the header 'FEV1/FVC (%)'. The table shows that age is the independent variable, while FEV1/FVC results are the dependent variable. The results for age 20 in R1 and R2 are 85.49 and 85.36, respectively, with the rest of the cells in the table being empty. There are annotations indicating the role of each variable and emphasizing that the data is recorded to a consistent number of significant figures.

[Generated by AI]

1. Construct a second data table, the processed data table where you will record the mean of each data set (see **Figure 2** for an example). Then calculate and record the standard deviation of your data sets. Anomalous data should be excluded from your calculations. **Video 1**

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explains the importance of standard deviation and how to calculate it (see section 1.5.4 (/study/app/bio/sid-422-cid-755105/book/data-analysis-id-46700/) for data processing).

Video 1. This video explains the importance of standard deviation and how to calculate it.

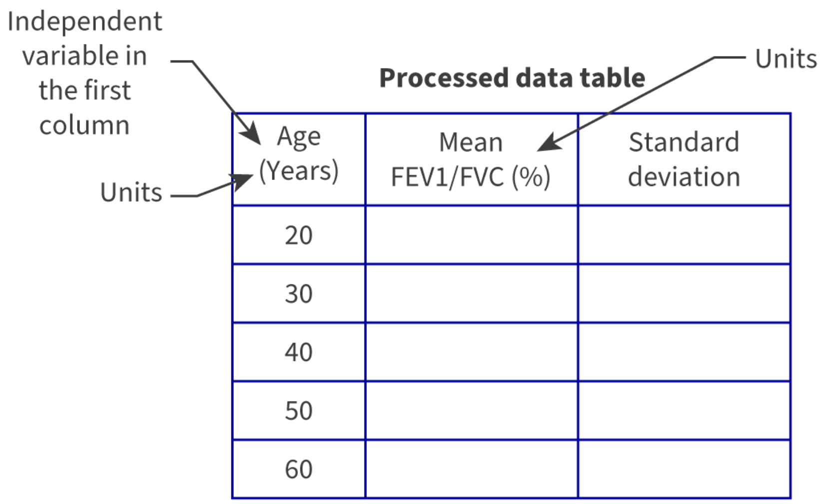

Figure 2. Example processed data table.

More information for figure 2

The image is a diagram showing a processed data table. It includes three columns with headings and annotations. The first column is labeled 'Age (Years)' with listed values: 20, 30, 40, 50, 60. The second column has the heading 'Mean FEV1/FVC (%)', and the third column is labeled 'Standard deviation'. Annotations point out that the independent variable is in the first column and units are specified. These annotations clarify the structure of the data table, highlighting the relationship between age and the measured statistics of FEV1/FVC mean and standard deviation.

[Generated by AI]

Student view

1. Optional step: carry out a t-test (or multiple t-tests (https://www.graphpad.com/guides/prism/latest/statistics/stat_how_to_multiple_t_tests.htm)) to determine the likelihood of differences between your data sets being statistically significant. **Video 2** explains the applications of the t-test and how to carry it out. You might also consider carrying out the one-way analysis of variance (https://www.graphpad.com/guides/the-ultimate-guide-to-anova) (ANOVA) test. The ANOVA test is used to determine if there are statistically significant differences between the means of three or more independent groups.

Video 2. Applications of the t-test, how to carry it out and how to interpret the results.

Plot your data on a graph. If the independent variable is continuous (measured on a continuous scale), such as age, a line graph is typically used. If your data is categorical (divided into discrete categories), use a bar graph. Plot the standard deviation as error bars.

Write a conclusion for your data. Refer to any trends shown in the data, standard deviation and any other statistical tests carried out.

B3. Form and function: Organisms / B3.1 Gas exchange

Reflection

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Teacher instructions

The goal of this section is to encourage students to reflect on their learning and conceptual understanding of the subject at the end of this subtopic. It asks them to go back to the guiding questions posed at the start of the subtopic and assess how confident they now are in answering them. What have they learned, and what outstanding questions do they have? Are they able to see the bigger picture and the connections between the different topics?

Students can submit their reflections to you by clicking on 'Submit'. You will then see their answers in the 'Insights' part of the Kognity platform.

Reflection

Now that you've completed this subtopic, let's come back to the guiding question introduced in The big picture (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43534/).

- How are multicellular organisms adapted to carry out gas exchange?
- What are the similarities and differences in gas exchange between a flowering plant and a mammal?

With these questions in mind, take a moment to reflect on your learning so far and type your reflections into the space provided.

You can use the following questions to guide you:

- What main points have you learned from this subtopic?
- Is anything unclear? What questions do you still have?
- How confident do you feel in answering the guiding questions?
- What connections do you see between this subtopic and other parts of the course?

⚠ Once you submit your response, you won't be able to edit it.

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