

Exchange and transport in animals revision notes

Large animals cannot get everything they need by diffusion alone, so they have exchange surfaces such as the alveoli and a transport system made of blood, blood vessels and a heart. This topic also covers how cells release energy by aerobic and anaerobic respiration.

For Edexcel GCSE Biology 1BI0 and Combined Science 1SC0. **Triple only** is not in Combined Science. **Higher tier** is only on the Higher paper.

1 Transport and exchange surfaces Spec 8.1-8.3

The need to transport substances Spec 8.1

Every cell in an organism needs a supply of some substances and must get rid of others. These substances have to be **transported into and out of** the organism and its cells.

Substances that are transported and why

Substance	Direction	Why it is needed
Oxygen	Into cells	Used in aerobic respiration to release energy
Carbon dioxide	Out of cells	Waste product of respiration. It must be removed from the body
Water	Into and out of cells	Needed for cell reactions and to keep cells working. Water is also lost from the body, for example in urine and sweat
Dissolved food molecules	Into cells	Provide a source of energy and the materials for growth and repair, for example glucose and amino acids
Mineral ions	Into cells	Needed for many cell processes
Urea	Out of cells	A waste product that is made in the body. It is carried in the blood to the kidneys and removed in urine

In a single-celled organism these substances can simply diffuse across the cell surface. In a large animal many cells are far from the outside world, so substances have to be moved over long distances. Blood is the transport medium in humans.

Exam tip: When asked to describe the need for transport, name the substance, say whether it goes in or out, and give the reason. For example: carbon dioxide is a waste product of respiration, so it must be removed.

Exchange surfaces, transport systems and surface area : volume ratio Spec 8.2

The **surface area : volume ratio** tells you how much surface an organism has compared with its size. The bigger the organism, the smaller this ratio becomes.

$$\text{surface area : volume ratio} = \text{surface area} \div \text{volume}$$

Surface area : volume ratio of a cube

A cube-shaped block of tissue has sides of 3 cm. Calculate its surface area : volume ratio.

1. A cube has 6 faces. Area of one face = $3 \times 3 = 9 \text{ cm}^2$.
2. Surface area = $6 \times 9 = 54 \text{ cm}^2$.
3. Volume = $3 \times 3 \times 3 = 27 \text{ cm}^3$.
4. Ratio = 54 : 27. Divide both sides by 27.

Answer: 2 : 1

As a cube gets bigger, its surface area : volume ratio gets smaller

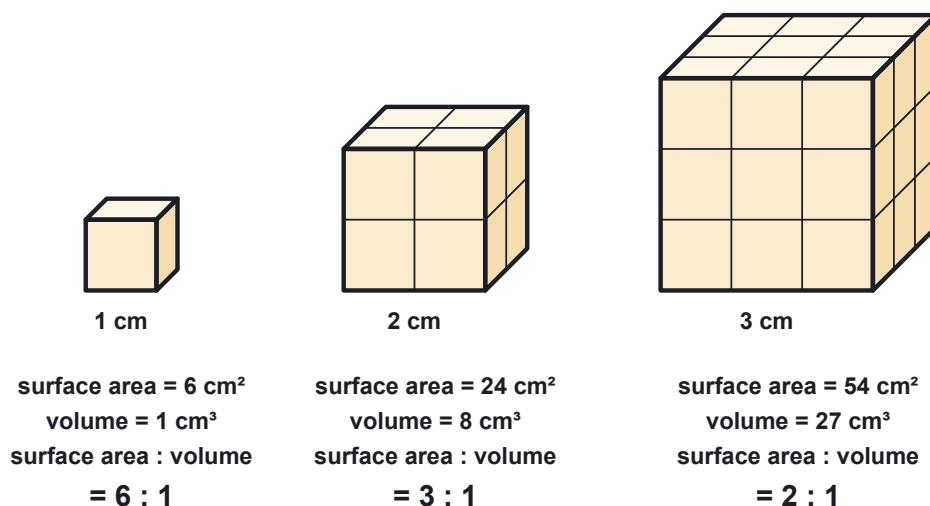
Side of cube	Surface area	Volume	Surface area : volume
1 cm	6 cm ²	1 cm ³	6 : 1
2 cm	24 cm ²	8 cm ³	3 : 1
3 cm	54 cm ²	27 cm ³	2 : 1

Single-celled and multicellular organisms

- A single-celled organism has a **large surface area : volume ratio**. Substances only have a short distance to diffuse, so diffusion across the surface is fast enough.
- A multicellular organism has a **small surface area : volume ratio**. Many cells are deep inside the body, so the diffusion distance is long and diffusion across the body surface is far too slow.

Multicellular organisms therefore need two things. An **exchange surface** has a large surface area so that enough oxygen can enter and enough carbon dioxide can leave. A **transport system** (the circulatory system in humans) then carries substances between the exchange surface and all the cells in the body.

Maths skill: Write the ratio in its simplest form, in the form $x : 1$, unless the question asks otherwise. Check that the surface area is in cm² and the volume in cm³.



As the cube gets bigger, its **surface area : volume ratio gets smaller**.

Alveoli and gas exchange Spec 8.3

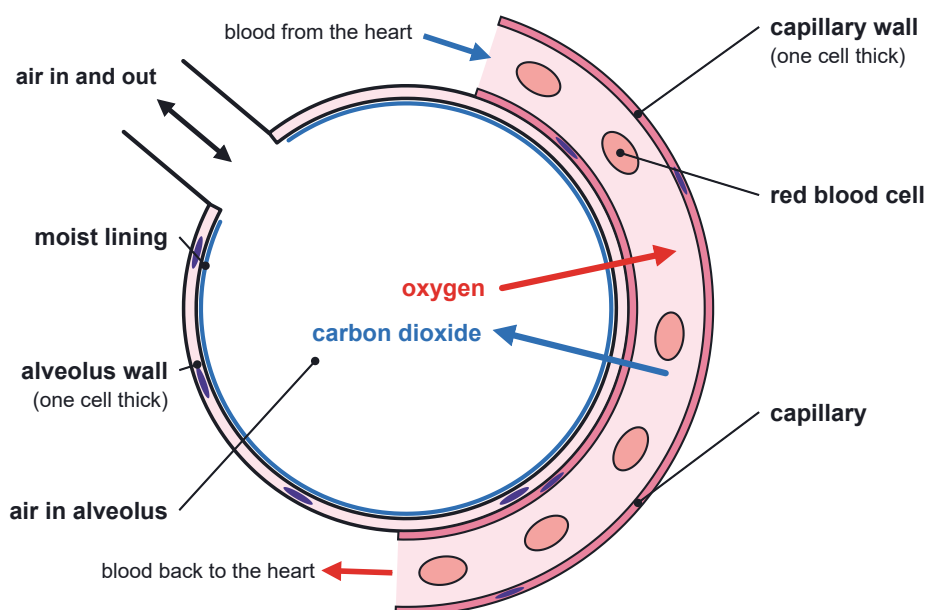
The lungs are the exchange surface for oxygen and carbon dioxide. Each lung contains millions of tiny air sacs called **alveoli**. Gases move between the air in the alveoli and the blood in the capillaries around them by **diffusion**.

- Oxygen diffuses from the air in the alveoli (high concentration) into the blood (low concentration).
- Carbon dioxide diffuses from the blood (high concentration) into the air in the alveoli (low concentration), and is breathed out.

How alveoli are adapted for gas exchange

Adaptation	Why it helps
Millions of alveoli	Gives a very large surface area for diffusion
Walls only one cell thick	Short diffusion distance, so gases diffuse quickly
Capillary walls only one cell thick	Short diffusion distance between the air and the blood
Rich network of capillaries (good blood supply)	Blood carries oxygen away and brings carbon dioxide, keeping a steep concentration gradient
Moist lining	Gases dissolve, which helps them to diffuse
Ventilation (breathing in and out)	Keeps a high oxygen concentration in the alveoli and a low carbon dioxide concentration, which maintains the concentration gradient

Exam tip: Do not stop at the adaptation. Link every feature to its effect: for example, thin walls means a short diffusion distance, so faster diffusion.



Oxygen diffuses into the blood and carbon dioxide diffuses out, across **two walls that are each one cell thick**.

Quick check

1. Why must urea be transported out of the body's cells?
2. Does a large animal have a larger or smaller surface area : volume ratio than a single cell?
3. Why do multicellular organisms need a transport system?
4. State two ways alveoli are adapted for gas exchange.

2 Factors affecting the rate of diffusion Spec 8.4B-8.5B Triple only

Factors affecting the rate of diffusion Spec 8.4B

Three factors affect how fast particles diffuse across an exchange surface.

Factors affecting the rate of diffusion		
Factor	Effect on rate of diffusion	Example in the body
Surface area	Larger surface area means a faster rate, because more particles can cross at once	Millions of alveoli in the lungs
Concentration gradient	A steeper gradient (bigger difference in concentration) means a faster rate	Blood flow and breathing keep the oxygen concentration lower in the blood than in the alveoli
Diffusion distance (thickness of the membrane)	A shorter distance means a faster rate	Alveolus and capillary walls are one cell thick

Diffusion is the net movement of particles from a region of higher concentration to a region of lower concentration. The bigger the difference, the faster the net movement.

Common mistake: A short diffusion distance means a thin membrane. Do not say that a thin membrane gives a larger surface area, because these are two separate factors.

Fick's law Spec 8.5B

Fick's law combines the three factors. The rate of diffusion is **proportional to** the surface area multiplied by the concentration difference, divided by the thickness of the membrane.

$$\text{rate of diffusion} \propto (\text{surface area} \times \text{concentration difference}) \div \text{thickness of membrane}$$

The symbol $\propto$ means is proportional to. So doubling the surface area doubles the rate, doubling the concentration difference doubles the rate, and doubling the thickness halves the rate.

Using Fick's law

A membrane has a surface area of 30 units and a thickness of 2 units. The concentration difference across it is 5 units. Calculate the rate of diffusion in arbitrary units.

1. Multiply surface area by concentration difference: $30 \times 5 = 150$.
2. Divide by thickness: $150 \div 2 = 75$.

Answer: 75 arbitrary units

Maths skill: Because the law uses proportionality, the answer is a relative rate and is often given in arbitrary units. Show each step of your working to get method marks.

Quick check

1. Name the three factors that affect the rate of diffusion.
2. What happens to the rate of diffusion if the membrane becomes twice as thick?
3. Write Fick's law in words.

3 Blood and blood vessels Spec 8.6-8.7

The structure and function of blood Spec 8.6

Blood is a tissue made of **plasma** with red blood cells, white blood cells and platelets suspended in it.

Components of blood		
Component	Structure	Function
Red blood cells (erythrocytes)	Biconcave disc shape, no nucleus, full of haemoglobin	Carry oxygen from the lungs to the cells. Haemoglobin combines with oxygen to form oxyhaemoglobin
White blood cells: phagocytes	Flexible, so they can change shape to surround a pathogen	Engulf (take in) pathogens and digest them. This is phagocytosis
White blood cells: lymphocytes	Make and release antibodies into the blood	Antibodies attach to specific pathogens and help to destroy them
Plasma	Pale yellow liquid	Transports blood cells and dissolved substances: carbon dioxide, urea, digested food molecules, mineral ions and hormones
Platelets	Small fragments of cells, with no nucleus	Help the blood to clot at a wound

Red blood cells

- The **biconcave disc** shape gives a large surface area for oxygen to be absorbed.
- **Haemoglobin** binds to oxygen, so the cell can carry a lot of oxygen.
- There is **no nucleus**, which leaves more room for haemoglobin.

White blood cells

Phagocytes can change shape, so they can surround and **engulf** pathogens and then digest them. Lymphocytes make **antibodies** that attach to specific pathogens and help to destroy them.

Plasma and platelets

Plasma is the liquid part of blood and carries many dissolved substances around the body. **Platelets** make the blood clot where there is a cut. This stops blood loss and stops pathogens entering the body.

Higher tier

Standard form with blood cell counts

A sample of blood has 5×10^6 red blood cells in each mm^3 . How many red blood cells are there in 2 mm^3 ? Give your answer in standard form.

1. Multiply: $2 \times 5 \times 10^6 = 10 \times 10^6 = 10\,000\,000$.
2. Write as a number between 1 and 10 multiplied by a power of ten: 1×10^7 .

Answer: 1×10^7 red blood cells

Common mistake: Do not say red blood cells 'carry haemoglobin' as their job. They carry oxygen. Haemoglobin is the substance inside them that binds to oxygen.

The structure and function of blood vessels Spec 8.7

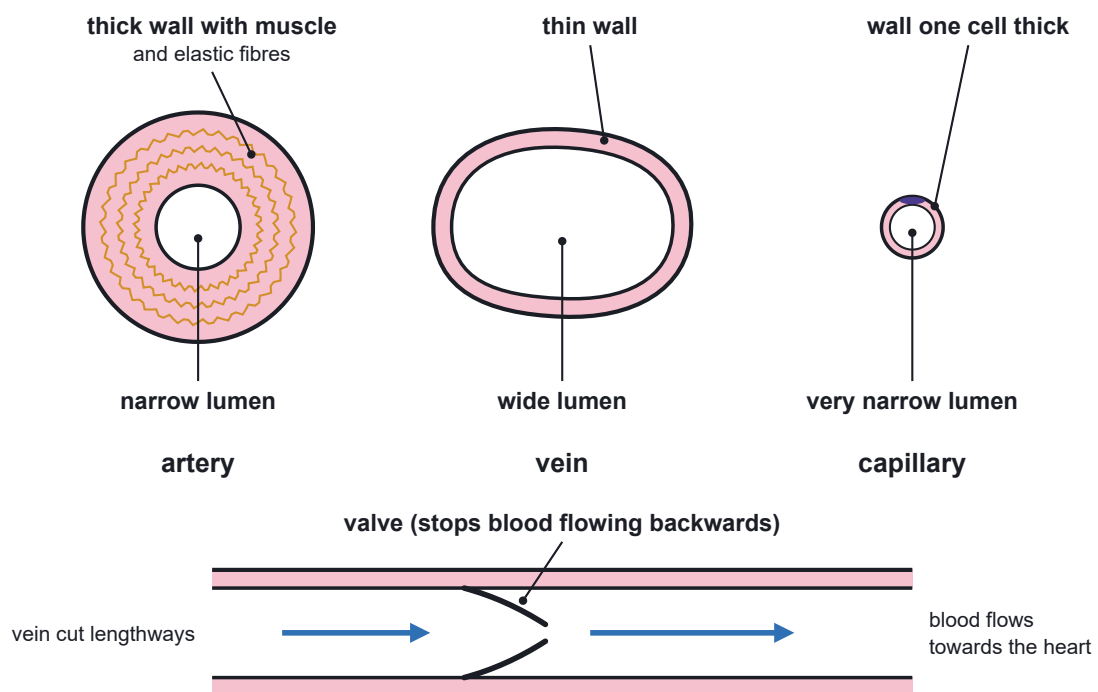
There are three types of blood vessel. Each is adapted to its job.

Arteries, veins and capillaries

	Artery	Vein	Capillary
Direction of blood	Away from the heart	Towards the heart	Between arteries and veins, through the tissues
Blood pressure	High	Low	Falls as blood passes through
Wall	Thick, muscular, with elastic fibres	Thinner wall	One cell thick
Lumen	Narrow	Wide	Very narrow
Valves	No	Yes	No
Function	Carry blood at high pressure to the organs	Carry blood back to the heart	Exchange substances with cells

- **Arteries** have thick, muscular walls and elastic fibres. The wall can stand the high pressure and stretches and springs back with each heartbeat.
- **Veins** carry blood at low pressure. They have a wide lumen to let blood flow easily, and **valves** to stop the blood flowing backwards.
- **Capillaries** have walls only one cell thick, giving a short diffusion distance. They form a huge network so there is a large surface area for exchange, and they are narrow so they can reach every cell.

Exam tip: Do not say that arteries always carry oxygenated blood and veins always carry deoxygenated blood. The pulmonary artery and pulmonary vein are the exceptions.



Arteries have **thick walls**, veins have a **wide lumen and valves**, capillaries have walls **one cell thick**. (The capillary is drawn much larger than its real size.)

Quick check

- 1 . Which part of the blood carries oxygen, and what is the name of the substance that binds to it?
- 2 . What is the job of phagocytes?
- 3 . Which blood vessels have valves?
- 4 . Why are capillary walls only one cell thick?

4 The heart and circulation Spec 8.8, 8.12

The heart and circulatory system Spec 8.8

Humans have a **double circulatory system**. In one circuit the blood goes from the heart to the lungs and back. In the other the blood goes from the heart around the body and back. Blood passes through the heart twice on each complete circuit of the body.

1. Deoxygenated blood from the body enters the right atrium through the vena cava.
2. The right atrium contracts and pushes blood into the right ventricle.
3. The right ventricle contracts and pumps blood to the lungs through the pulmonary artery.
4. Oxygenated blood returns from the lungs through the pulmonary vein into the left atrium.
5. The left atrium contracts and pushes blood into the left ventricle.
6. The left ventricle contracts and pumps blood around the body through the aorta.

Major blood vessels of the heart		
Blood vessel	Carries blood	Between
Vena cava	Deoxygenated	Body → right atrium
Pulmonary artery	Deoxygenated	Right ventricle → lungs
Pulmonary vein	Oxygenated	Lungs → left atrium
Aorta	Oxygenated	Left ventricle → body

Valves

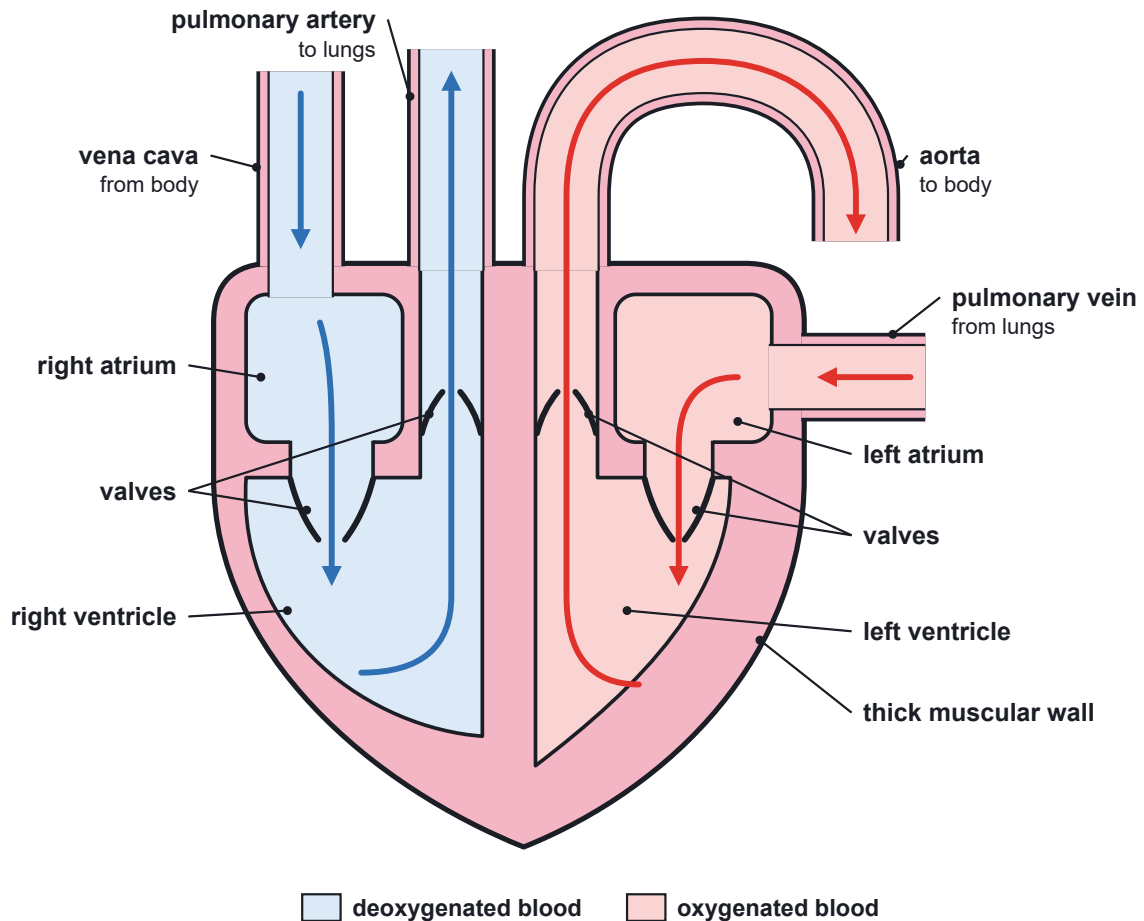
The heart has **valves** between the atria and ventricles, and where the pulmonary artery and aorta leave the ventricles. They open to let blood through in one direction and close to **prevent backflow**.

Thickness of the chamber walls

- The ventricles have thicker, more muscular walls than the atria, because they pump blood out of the heart and further.
- The **left ventricle** has a thicker wall than the right ventricle. It pumps blood around the whole body, which needs a higher pressure. The right ventricle pumps blood only to the lungs, which are close by.

The blood pressure falls as blood passes through the capillaries in the lungs. Returning the blood to the heart before it goes to the body lets the left ventricle increase the pressure again, so blood can reach the rest of the body quickly.

Common mistake: The diagram of the heart is drawn as if you are facing the person, so the left side of the heart is on the right of the page. Check which side is which before you answer.



Blood flows **vena cava** → **right atrium** → **right ventricle** → **pulmonary artery**, then **pulmonary vein** → **left atrium** → **left ventricle** → **aorta**. The left side of the heart is on the **right of the page**.

Heart rate, stroke volume and cardiac output Spec 8.12

Heart rate	The number of times the heart beats per minute (bpm).
Stroke volume	The volume of blood pumped out of the heart in each beat, in cm ³ .
Cardiac output	The volume of blood pumped out of the heart per minute, in cm ³ per minute.

$$\text{cardiac output} = \text{stroke volume} \times \text{heart rate}$$

Calculating cardiac output

A person has a resting heart rate of 70 beats per minute and a stroke volume of 75 cm³. Calculate the cardiac output.

- cardiac output = stroke volume × heart rate
- cardiac output = 75 × 70 = 5250

Answer: 5250 cm³ per minute

You may be asked to rearrange the equation. Stroke volume = cardiac output ÷ heart rate. Heart rate = cardiac output ÷ stroke volume.

You can measure heart rate by taking a pulse for a set time, for example counting beats in 30 seconds and doubling. A suggested practical is to investigate the short-term effect of exercise on heart rate and breathing rate, which both increase to supply more oxygen to the working muscles.

Maths skill: Check the units. If a question gives heart rate in beats per minute and stroke volume in cm^3 , the answer is in cm^3 per minute. Give the unit in your answer.

Quick check

1. Which vessel carries oxygenated blood from the lungs to the heart?
2. Why is the wall of the left ventricle thicker than the wall of the right ventricle?
3. What is the job of the valves in the heart?
4. State the equation for cardiac output.

5 Respiration Spec 8.9–8.11

Cellular respiration Spec 8.9

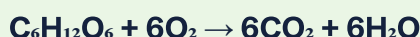
Cellular respiration is an **exothermic** reaction. It transfers energy to the surroundings, and some of this energy is released as heat. It happens **continuously** in living cells (in plants as well as animals) to release energy for **metabolic processes**.

Metabolic processes include building larger molecules from smaller ones, muscle contraction, and keeping the body warm in mammals and birds.

Aerobic respiration

Aerobic respiration uses oxygen to break down glucose.

glucose + oxygen → carbon dioxide + water



Anaerobic respiration

Anaerobic respiration happens without oxygen. In animal cells, such as muscle cells working hard, glucose is broken down to **lactic acid**. In plant cells and yeast, glucose is broken down to **ethanol** and carbon dioxide.

glucose → lactic acid

glucose → ethanol + carbon dioxide

Common mistake: Respiration is not breathing, and it is not the same as gas exchange. Respiration is a chemical reaction in cells that releases energy.

Comparing aerobic and anaerobic respiration Spec 8.10

Aerobic and anaerobic respiration compared		
	Aerobic respiration	Anaerobic respiration
Oxygen needed?	Yes	No
Glucose breakdown	Complete breakdown	Incomplete breakdown
Energy released	A large amount per glucose molecule	Much less per glucose molecule
Products in animals	Carbon dioxide and water	Lactic acid
Products in plants and yeast	Carbon dioxide and water	Ethanol and carbon dioxide
When it happens	Whenever enough oxygen is available	When oxygen is not available, for example in muscles during vigorous exercise

Aerobic respiration releases much more energy because glucose is completely broken down. Anaerobic respiration releases less energy because glucose is only partly broken down. Both types of respiration are exothermic and both release energy from glucose.

Exam tip: A comparison needs both sides in the same sentence, for example: aerobic respiration releases more energy per glucose than anaerobic respiration.

Core practical: the rate of respiration in living organisms Spec 8.11

Respiration can be investigated by measuring how fast a living organism, such as germinating seeds or small invertebrates, uses up oxygen. This is done with a **respirometer**.

1. Place the organisms in a boiling tube. Put a layer of soda lime (or another carbon dioxide absorber) in the tube, separated from the organisms by cotton wool or gauze.
2. Connect the tube to a capillary tube containing a drop of coloured liquid, and seal the apparatus so that no air can get in or out.
3. Place the tube in a water bath at a set temperature and leave it to settle.
4. Measure the distance the coloured liquid moves in a set time, for example 5 minutes.
5. Repeat at different temperatures, and repeat each temperature to calculate a mean.
6. Set up a control tube with an equal volume of an inert material, such as glass beads, instead of organisms.

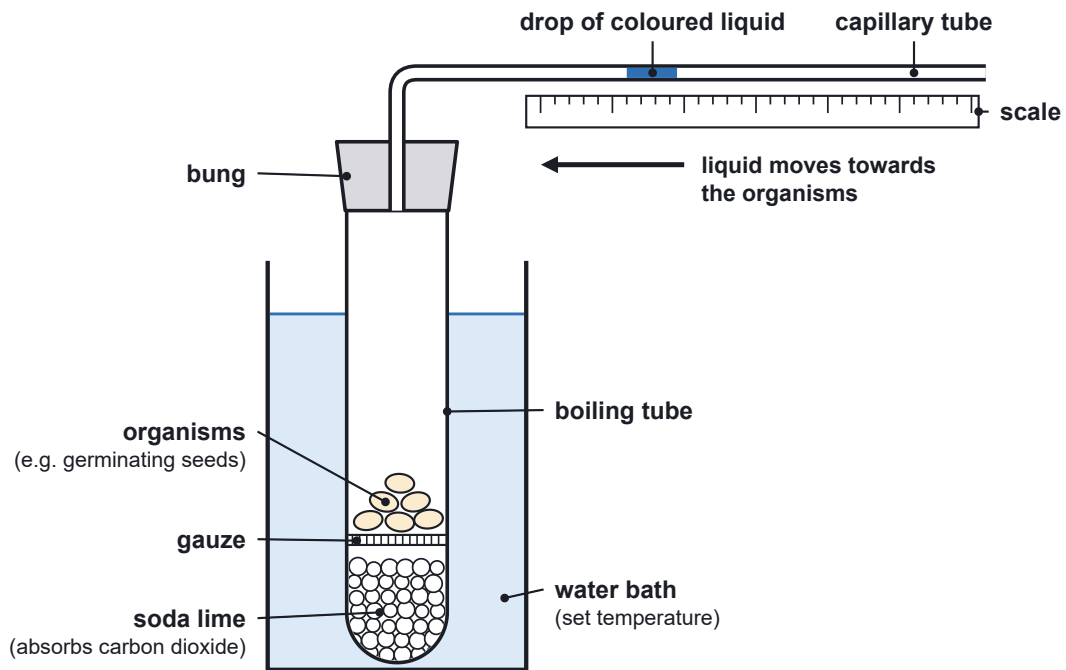
The organisms use up oxygen. The carbon dioxide they produce is absorbed, so the volume of gas in the tube falls and the coloured liquid moves **towards the organisms**. The further it moves in a given time, the faster the rate of respiration.

rate of respiration = distance moved by liquid ÷ time

Variables in the investigation	
Type of variable	Example
Independent variable	Temperature (or the type of organism, if comparing organisms)
Dependent variable	Distance moved by the liquid in a set time
Control variables	Mass of organisms, volume of soda lime, time, volume of the apparatus, start position of the liquid

Core practical: Typical result: the rate of respiration increases as temperature increases (up to a point), because enzymes in respiration work faster. Soda lime is corrosive, so wear eye protection and avoid skin contact. Handle living organisms gently and wash your hands afterwards.

A suggested practical for anaerobic respiration is to investigate the effect of glucose concentration on the rate of anaerobic respiration in yeast. The rate can be found by measuring how quickly carbon dioxide is produced, for example by counting bubbles or measuring the volume of gas collected.



As the organisms use up oxygen, the coloured liquid moves towards them. Soda lime absorbs the carbon dioxide they release.

Quick check

1. What does exothermic mean?
2. Write the word equation for aerobic respiration.
3. What are the products of anaerobic respiration in yeast?
4. Why does the coloured liquid move towards the organisms in a respirometer?

Quick check answers

Transport and exchange surfaces

1. It is a waste product that is carried in the blood to the kidneys and removed in urine.
2. Smaller.
3. Many cells are far from the surface, so diffusion alone is too slow to supply them.
4. Any two of: large surface area, walls one cell thick, moist lining, good blood supply, ventilation.

Factors affecting the rate of diffusion

1. Surface area, concentration gradient and diffusion distance.
2. It halves, if the other factors stay the same.
3. Rate of diffusion is proportional to surface area $\times$ concentration difference $\div$ thickness of membrane.

Blood and blood vessels

1. Red blood cells; haemoglobin.
2. They engulf and digest pathogens.
3. Veins.
4. To give a short diffusion distance for exchange of substances.

The heart and circulation

1. The pulmonary vein.
2. It pumps blood around the whole body, which needs a higher pressure than pumping blood to the lungs.
3. To prevent backflow and keep blood flowing in one direction.
4. Cardiac output = stroke volume $\times$ heart rate.

Respiration

1. Energy is transferred to the surroundings.
2. Glucose + oxygen $\rightarrow$ carbon dioxide + water.
3. Ethanol and carbon dioxide.
4. The organisms use up oxygen and the carbon dioxide is absorbed, so the volume of gas decreases.