

Gas exchange in humans

Read online at pastopic.com/cambridge/biology-0610/notes/gas-exchange-in-humans

Last checked 30 September 2026

Read first: [Movement into and out of cells](#), [Blood vessels and blood](#)

© 2026 Pastopic. Free for personal study. Please share the link, not the file.

What you need to know

This topic appears on almost every paper. Papers 1 and 2 ask one-mark multiple choice (muscle actions when breathing in, how expired air differs, which structure is which); Papers 3 and 4 build longer questions around a diagram of the breathing system, a table of gases or a graph of breathing during exercise. Outcomes marked **Extended only** are tested on Papers 2 and 4 only. By the end of this topic you should be able to:

Core

1. **Describe the features of gas exchange surfaces in humans:** a large surface area, a thin surface, a good blood supply and good ventilation with air.
2. **Identify the parts of the breathing system** in diagrams and photographs: lungs, diaphragm, ribs, intercostal muscles, larynx, trachea, bronchi, bronchioles, alveoli and the capillaries around them.
3. **Investigate the differences between inspired and expired air**, using limewater as the test for carbon dioxide.
4. **Describe how inspired and expired air differ** in oxygen, carbon dioxide and water vapour.
5. **Investigate and describe how physical activity affects** the rate and depth of breathing.

Extended only

6. **Identify the internal and external intercostal muscles** in diagrams and photographs.
7. **State the function of the cartilage** in the trachea.
8. **Explain how the ribs, the internal and external intercostal muscles and the diaphragm** change the volume and pressure in the thorax, so that air moves into and out of the lungs.
9. **Explain why inspired and expired air differ** in composition.
10. **Explain the link between physical activity and breathing:** more carbon dioxide in the blood is detected by the brain, which makes breathing faster and deeper.
11. **Explain how goblet cells, mucus and ciliated cells** protect the breathing system from pathogens and particles.

Respiration itself (the equations, and lactic acid and oxygen debt after hard exercise) is in the Respiration topic; diffusion is in Movement into and out of cells; capillaries and red blood cells are in Blood vessels and blood. This note uses them only where questions on this topic do.

Understand it

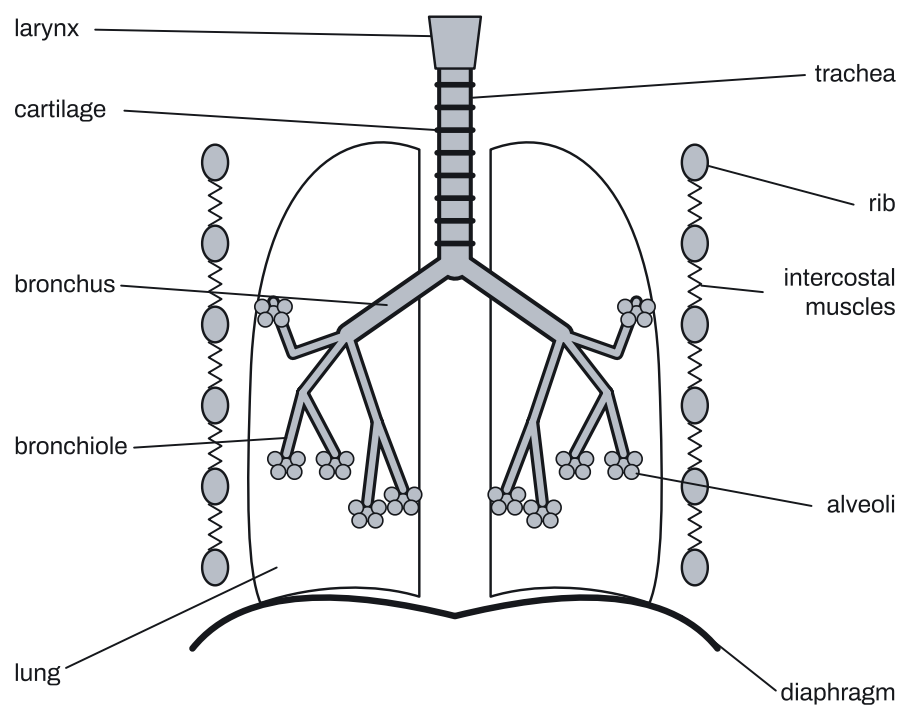
Why we breathe

Every living cell respire. Aerobic respiration uses **oxygen** and makes **carbon dioxide**:

glucose + oxygen → carbon dioxide + water (in symbols, **Extended:** $\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O}$)

It happens in the **mitochondria**. The blood brings oxygen to the cells and takes carbon dioxide away, so the blood has to pick up oxygen and get rid of carbon dioxide somewhere. That place is the **gas exchange surface** in the lungs: the **alveoli**. Breathing (**ventilation**) is the movement of air in and out that keeps fresh air at that surface. Carbon dioxide is a waste product of metabolism, so breathing it out is **excretion**.

The breathing system



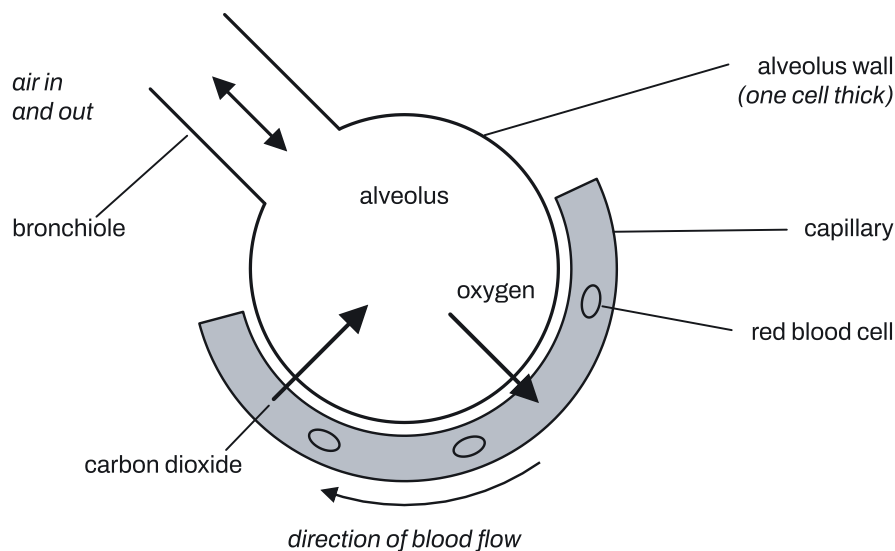
Follow a breath of air in:

Structure	What it is	What it does
Nose (or mouth)	entrance	nose hairs and mucus trap dust; air is warmed and moistened
Larynx	the voice box at the top of the trachea	air passes through it; it makes sounds
Trachea	the windpipe, with C-shaped rings of cartilage	carries air to the chest
Bronchi (one bronchus)	two branches of the trachea, one to each lung; also with cartilage	carry air into each lung

Structure	What it is	What it does
Bronchioles	many narrow, branching tubes	carry air to the alveoli
Alveoli (one alveolus)	tiny air sacs at the ends of the bronchioles, covered in capillaries	the gas exchange surface
Lungs	the two organs that contain the bronchi, bronchioles and alveoli	
Ribs	bones around the lungs	protect the lungs; move in breathing
Intercostal muscles	muscles between the ribs	move the ribs
Diaphragm	a sheet of muscle under the lungs, dome-shaped at rest	changes the volume of the thorax

The path of air in is **nose or mouth** → **larynx** → **trachea** → **bronchus** → **bronchiole** → **alveolus**, then oxygen crosses into the **capillary**. Air breathed out, and carbon dioxide leaving the blood, go the same way in reverse: **alveolus** → **bronchiole** → **bronchus** → **trachea** → **larynx**. The tubes get **narrower** and more numerous the further in you go, and only the trachea and bronchi have cartilage. The **thorax** is the chest cavity: the space inside the ribs and above the diaphragm.

The gas exchange surface

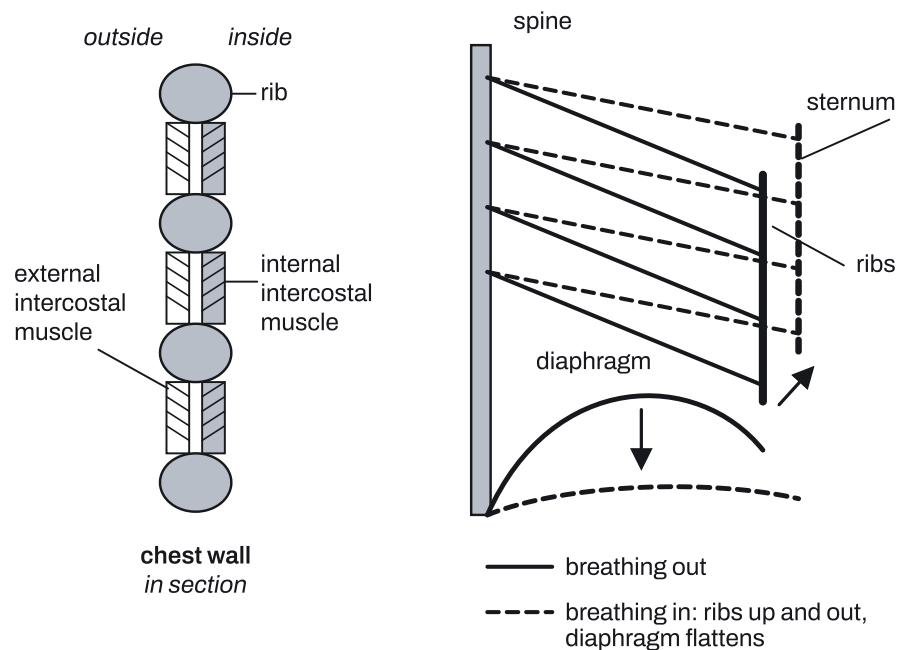


Gases cross the alveolus wall by **diffusion**, from a higher to a lower concentration. Air in the alveolus has more oxygen than the blood arriving in the capillary, so **oxygen diffuses into the blood** (into the red blood cells). The blood arriving has more carbon dioxide than the alveolar air, so **carbon dioxide diffuses out of the blood into the alveolus**, and is breathed out. No energy is needed for this.

Four features make the surface efficient:

Feature	In the lungs	Why it speeds up diffusion
Large surface area	millions of alveoli	more gas can cross at once
Thin surface	the alveolus wall and the capillary wall are each one cell thick	a short diffusion distance
Good blood supply	a dense network of capillaries around every alveolus	blood keeps carrying oxygen away and bringing carbon dioxide, so a steep concentration gradient is kept
Good ventilation with air	breathing replaces the air in the alveoli	keeps the oxygen concentration in the alveoli high and carbon dioxide low: the gradient is kept

Extended: how breathing works



Air moves because of **pressure differences**: it always flows from higher pressure to lower pressure. The muscles change the **volume** of the thorax, and the volume change causes the pressure change. The lungs follow the chest wall, so they get bigger and smaller with it.

Breathing in (inspiration):

1. The **external intercostal muscles contract** (the internal ones relax), pulling the **ribs up and out**.
2. The **diaphragm contracts** and **flattens** (moves down).
3. Both make the **volume of the thorax increase**.
4. So the **pressure in the thorax (and lungs) decreases**, below atmospheric pressure.

5. **Air is drawn in** from outside, down the pressure gradient, until the pressures are equal.

Breathing out (expiration) at rest is the reverse:

1. The **external intercostal muscles relax**, so the **ribs move down and in**.
2. The **diaphragm relaxes** and goes back to its **dome** shape (moves up).
3. The **volume of the thorax decreases**, so the **pressure increases** above atmospheric.
4. **Air is forced out**.

Forced expiration (coughing, blowing hard, heavy exercise): the **internal intercostal muscles contract** to pull the ribs down and in harder, so more air is pushed out faster.

The two sets of intercostal muscles are **antagonistic**: when one contracts, the other relaxes. When breathing in, the external set contracts and the internal set relaxes; the diaphragm contracts at the same time. The diaphragm and the external intercostals never contract to breathe out.

Cartilage in the trachea and bronchi is **C-shaped rings** of stiff tissue. When the pressure falls during inspiration, the rings **keep the airway open** and stop it **collapsing**, so air can still flow.

Inspired and expired air

Gas	Inspired air	Expired air
Oxygen	21%	16%
Carbon dioxide	0.04%	4%
Water vapour	variable	saturated
Nitrogen	78%	78%

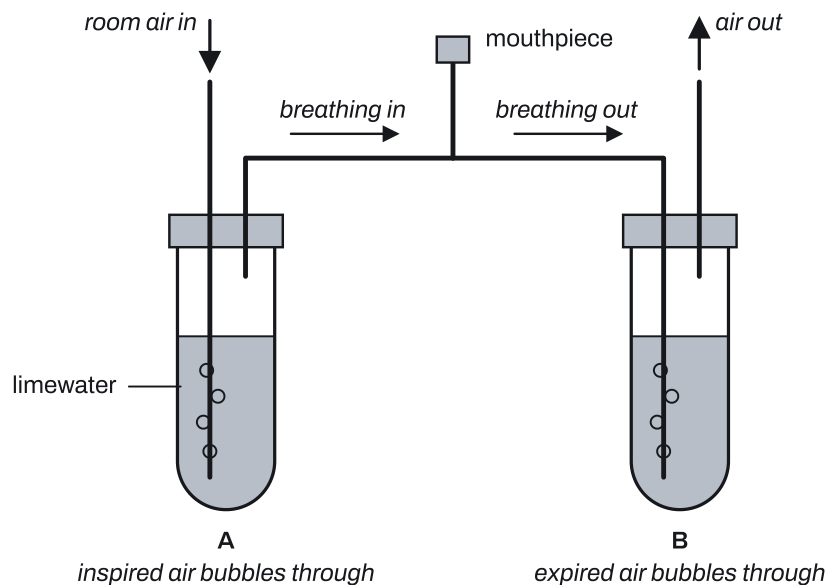
Expired air has **less oxygen**, **more carbon dioxide** (about 100 times more) and **more water vapour** than inspired air. Nitrogen does not change. Expired air is also warmer.

Extended: why they differ.

- **Less oxygen**: oxygen diffuses from the alveoli into the blood and is carried to the body's cells, which **use it in aerobic respiration**.
- **More carbon dioxide**: cells **make carbon dioxide in respiration**; the blood carries it to the lungs, where it diffuses into the alveoli and is breathed out (excreted).
- **More water vapour**: water **evaporates from the moist lining of the alveoli** into the air before it is breathed out.
- **Nitrogen** is not used or made by the body, so its percentage stays the same.

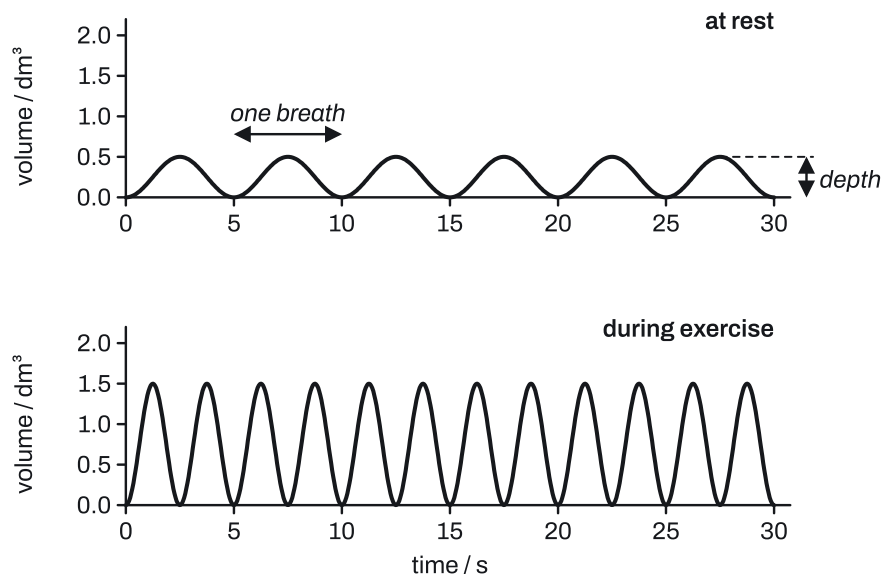
Testing for carbon dioxide

Limewater is the test. It starts **clear (colourless)** and turns **cloudy (milky)** when carbon dioxide bubbles through it. More carbon dioxide makes it go cloudy **faster**.



With two tubes on one mouthpiece, air always bubbles through the tube whose **long tube** (the one reaching under the limewater) it enters by. When the person **breathes in**, room air is sucked down the long tube of A and bubbles through it. When they **breathe out**, the air goes down the long tube of B and bubbles through it. So **B (expired air) turns cloudy quickly; A (inspired air) stays clear**, or turns cloudy only very slowly, because room air has only 0.04% carbon dioxide.

Physical activity and breathing



During physical activity **both the rate and the depth of breathing increase**. The **rate** is the number of breaths per minute; the **depth** is the volume of air in one breath. On the traces above, the rate doubles from 12 to 24 breaths per minute and the depth triples from 0.5 to 1.5 dm³, so the volume breathed each minute rises from $12 \times 0.5 = 6$ dm³ to $24 \times 1.5 = 36$ dm³, six times as much. After the activity stops, breathing stays fast and deep for a while, then slowly falls back to the resting rate (the extra oxygen is needed to deal with the lactic acid made, the **oxygen debt**; see Respiration).

To investigate it: count breaths for a minute at rest, do a fixed activity (such as step-ups for 2 minutes), then count again straight away and every minute until breathing is back to normal. Keep the activity and the person the same, and repeat.

Extended: why breathing speeds up.

1. Working **muscles respire faster** to release more energy for contraction.
2. So they make **more carbon dioxide**, which diffuses into the blood: the **carbon dioxide concentration in the blood increases**.
3. The **brain detects** the higher carbon dioxide concentration.
4. The brain sends **more nerve impulses** to the **diaphragm and intercostal muscles**.
5. They contract **more often and more strongly**, so breathing becomes **faster and deeper**.
6. This removes carbon dioxide faster and brings in more oxygen for aerobic respiration.

The trigger is the **rise in carbon dioxide**, not a fall in oxygen. The same happens if a person breathes air containing extra carbon dioxide while sitting still.

Extended: protecting the airways

The air we breathe carries dust, pollen and **pathogens** (bacteria and viruses). The trachea and bronchi are lined with two kinds of cell that stop them reaching the alveoli:

- **Goblet cells** secrete **mucus**, which is sticky and **traps** pathogens and dust particles.
- **Ciliated cells** have **cilia**, tiny hair-like structures that **beat** and **sweep the mucus up** the airways to the **throat**, where it is swallowed (and stomach acid kills the pathogens).

So pathogens and particles are trapped **and** removed. If the cilia stop working, mucus collects in the airways and bacteria can multiply there, causing chest infections. Very thick, sticky mucus can also **narrow or block the airways**, so less air reaches the alveoli, less oxygen diffuses into the blood and less aerobic respiration is possible in the muscles.

Key facts and formulas

There is no formula list in the IGCSE Biology exam. Everything below must be learnt.

Formula	Status
Features of gas exchange surfaces: large surface area, thin surface, good blood supply, good ventilation with air	Learn it
Path of air: nose/mouth → larynx → trachea → bronchi → bronchioles → alveoli	Learn it
Oxygen diffuses from the alveoli into the blood; carbon dioxide diffuses from the blood into the alveoli	Learn it

Formula	Status
Inspired air: O ₂ 21%, CO ₂ 0.04%, water vapour variable. Expired air: O ₂ 16%, CO ₂ 4%, water vapour saturated	Learn it
Limewater: clear → cloudy (milky) with carbon dioxide	Learn it
Physical activity: rate and depth of breathing both increase	Learn it
Extended: inspiration: external intercostals and diaphragm contract → ribs up and out, diaphragm flattens → thorax volume up → pressure down → air in	Learn it
Extended: expiration: external intercostals and diaphragm relax → volume down → pressure up → air out; internal intercostals contract in forced expiration	Learn it
Extended: cartilage (C-shaped rings) keeps the trachea open	Learn it
Extended: more respiration → more CO ₂ in blood → detected by the brain → faster, deeper breathing	Learn it
Extended: goblet cells make mucus that traps; cilia sweep mucus up to the throat	Learn it
Breaths per minute = breaths counted × (60 ÷ seconds counted); volume per minute = breaths per minute × volume per breath	Learn it

How to do it

We tagged 106 questions for this topic (2021–2025, Papers 1–4; 91 different, since some multiple-choice questions appear on more than one paper). 24 of them mix types, so the counts add up to 159.

Question type	Questions
Compare the composition of inspired and expired air	31
Describe the ventilation mechanism (Extended)	30
Identify parts of the breathing system and the path of air	27
State features of the gas exchange surface and the direction of diffusion	20
Describe and explain the effect of physical activity on breathing	19
Explain how the airways are protected and kept open	14
Test for carbon dioxide with limewater	12
Read or calculate from breathing data	6

1. Compare the composition of inspired and expired air (31 questions)

1. **Core:** expired air has **less oxygen**, **more carbon dioxide** and **more water vapour**; nitrogen is **the same**. Say "more/less" or "higher/lower" for each gas, and name the gas.
2. **Extended:** learn the numbers (O_2 21 → 16%, CO_2 0.04 → 4%, water vapour variable → saturated) and **explain** each difference with the reasons in "Inspired and expired air".

Variations you will meet:

- **Multiple choice** with rows of "higher/lower" or four percentage tables: check oxygen goes **down** and carbon dioxide goes **up**. The one number most candidates don't know is **16% oxygen** in expired air.
- **A bar chart** of several air samples: expired air is the one with about 16% oxygen and about 4% carbon dioxide.
- **Name the gases** in a table from their percentages: 78 is nitrogen, 21 → 16 is oxygen, 0.04 → 4 is carbon dioxide, variable → saturated is water vapour.
- **Explain** the differences (up to 4 marks): a figure alone earns nothing; the marks are for **respiration** using oxygen and making carbon dioxide, with **diffusion** between alveoli and blood as the route.
- **Fewer dust particles** in expired air: dust was **trapped by mucus** in the airways.
- **"The gas excreted by the lungs"**: carbon dioxide.

2. Describe the ventilation mechanism (30 questions, Extended)

1. **Muscles first:** which contract and which relax (external intercostals and diaphragm contract to breathe in).
2. **Movement:** ribs **up and out**; diaphragm **flattens / moves down**.
3. **Volume** of the thorax **increases**.
4. **Pressure** in the thorax **decreases** (below atmospheric).
5. **Air is drawn in** to equalise the pressure.

For expiration, reverse every step. Write the steps **in this order**: the volume change causes the pressure change, never the other way round.

Variations you will meet:

- **Rows of muscle actions** (multiple choice): inspiration = external intercostals **contract**, internal **relax**, diaphragm **contracts**. Expiration at rest = both external intercostals and diaphragm **relax**. A row where the diaphragm "contracts and moves up" is always wrong.
- **Putting the stages in order**: muscles contract → ribs and diaphragm move → volume increases → pressure falls → air rushes in.
- **A table to complete** for each feature (diaphragm, external intercostals, ribs, volume, pressure): one word or phrase per box, such as "contracts", "move up and out", "increases", "decreases".
- **Graphs**: a lung-volume trace that is **falling** means breathing out (muscles relaxing); a lung pressure graph for one breath in **dips below** atmospheric pressure first, then returns to it.

- **Which muscles lower the ribs in forced expiration?** The **internal** intercostal muscles. Always say internal or external.
- **Only the diaphragm:** if asked just the effect of the diaphragm contracting, give flattens → **thorax** volume increases → pressure falls. Don't describe the whole of breathing.

3. Identify parts of the breathing system and the path of air (27 questions)

1. Use diagram 1: from the top, larynx → trachea (rings) → two bronchi → many bronchioles → alveoli; ribs and intercostal muscles around the outside; diaphragm below.
2. For the **path**, start outside the body (nose or mouth), not at the lungs.

Variations you will meet:

- **Word lists and letter boxes:** put nose, larynx, trachea, bronchus, bronchiole, alveolus in order; for expired air or carbon dioxide, reverse it.
- **"Which structure connects directly to the alveoli?"** Bronchioles (not bronchi).
- **The organ containing alveoli** is the lung; the **site of gas exchange** is the alveoli (not "the lungs").
- **Name from function:** prevents collapse → cartilage; site of gas exchange → alveoli; contracts to lower pressure → diaphragm or external intercostal muscles; protects the lungs from damage → ribs.
- **Draw a label line** to an external intercostal muscle (Extended): use a ruler and make the line **touch** the outer muscle between two ribs.
- **Graphs of airway width:** the further from the larynx, the narrower the tubes; the widest (trachea, bronchi) have cartilage, the narrowest (bronchioles) lead to alveoli.
- **Part that also works in digestion:** the mouth (physical digestion by chewing).
- **The organ system** the alveoli belong to is the gas exchange (breathing) system.

4. State features of the gas exchange surface and the direction of diffusion (20 questions)

1. **Name the surface:** alveoli.
2. **Features:** large surface area; thin (one cell thick, short diffusion distance); good blood supply (capillary network); good ventilation.
3. **Explain** (Extended): pair each feature with **why** it speeds up diffusion, from the table in "The gas exchange surface".

Variations you will meet:

- **Don't repeat the stem:** if the question gives "large surface area", give two **other** features. "Many alveoli" is the same point again.
- **"Good blood supply"** is the phrase; "next to blood" or "has blood" is too vague.
- **Arrows on an alveolus diagram:** oxygen from alveolus **into** capillary; carbon dioxide from capillary **into** alveolus. Air coming in from the bronchiole is **air**, not just oxygen.

- **Highest concentrations along a capillary:** carbon dioxide is highest in blood **arriving** at the alveolus; oxygen is highest in blood **leaving** it.
- **The process** is **diffusion** (not active transport or osmosis), and it needs no energy from respiration.
- **Other animals** (skin as a gas exchange surface): thin, moist skin with a large surface area and a good blood supply.

5. Describe and explain the effect of physical activity on breathing (19 questions)

1. **Core:** the **rate and depth both increase**; after exercise they fall gradually back to resting values.
2. **Extended:** the chain in "Extended: why breathing speeds up": more respiration → more CO₂ in the blood → detected by the **brain** → more impulses to the breathing muscles → faster, deeper breathing.

Variations you will meet:

- **Tables or traces** to pick from: the right one rises during activity and falls back slowly afterwards, peaking during or just after the activity. Look at both rate **and** depth.
- **Completing sentences:** the stimulus is **increased carbon dioxide concentration** in the blood; the organ that detects it is the **brain**; the result is greater **depth** and rate of breathing.
- **Ordering steps:** muscle respiration → CO₂ into blood → brain detects → impulses to muscles → faster, deeper breathing.
- **Why it stays high after exercise:** lactic acid built up in the muscles gives an **oxygen debt**; the extra oxygen is used to break it down (Respiration).
- **Sketch a trace for exercise** on a resting one: more peaks, closer together (faster), and taller ones (deeper).
- **Air with extra CO₂** breathed at rest: rate and depth rise while it is breathed, then fall back; describe with figures and units.

6. Explain how the airways are protected and kept open (14 questions)

1. **Cartilage** (Extended): C-shaped rings in the trachea and bronchi; **keeps the airway open / stops it collapsing**. "Protects" or "supports" alone is too vague.
2. **Goblet cells** secrete **mucus** that **traps** pathogens and particles.
3. **Ciliated cells:** **cilia** move the mucus **up** and **out of** the airways, to the throat.

Variations you will meet:

- **"Which cells produce mucus?"** Goblet cells, not ciliated cells.
- **How a ciliated cell is adapted:** it has many cilia, which beat to move mucus.
- **Cilia move mucus**, not the pathogens directly; say the pathogens are **in** the mucus.
- **Name two cell types that protect the airways:** goblet cells and ciliated cells (white blood cells are also accepted: phagocytes engulf, lymphocytes make antibodies).
- **Thick, sticky mucus** (as in cystic fibrosis): blocks or narrows the airways → less air reaches the alveoli → less oxygen into the blood → less aerobic respiration, less energy for muscles → exercise is harder.

- **The context matters:** in a photo of the trachea lining, the mucus traps pathogens; don't write about lubricating food.

7. Test for carbon dioxide with limewater (12 questions)

1. **Name it: limewater.** (Benedict's, biuret, iodine, ethanol and DCPIP test for other things.)
2. **Result:** clear/colourless → **cloudy/milky.**

Variations you will meet:

- **Two tubes on one mouthpiece:** find which tube's **long tube** each breath enters through. The tube receiving **expired air** goes cloudy (quickly); the one receiving **inspired air** stays clear or goes cloudy much more slowly.
- **Photographs of a positive test:** clear at the start, cloudy at the end, so the reagent is limewater.
- **Match a gas with its test:** carbon dioxide with limewater.

8. Read or calculate from breathing data (6 questions)

1. **Breaths per minute:** count the peaks (or complete breaths) and scale to 60 s: 7 breaths in 30 s is $7 \times 2 = 14$ breaths per minute.
2. **Volume of one breath** (depth): read the **trough and the peak** of one breath and subtract: a trough at 0.5 dm^3 and a peak at 2.0 dm^3 give 1.5 dm^3 . Give units.
3. **Volume per minute** = breaths per minute $\times$ volume of one breath. To find the depth from a volume per minute, divide by the rate.
4. **Rate of decrease** = change $\div$ time taken, with units (for example beats per minute per second).
5. **Evidence for and against a claim:** quote two data points for, and two points that break the pattern against, each with the numbers.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **M1** method mark: for a correct method, even if the numbers slip.
- **A1** accuracy mark: for a correct answer; it needs the M mark before it.
- **B1** mark for a correct result on its own, with no method needed.

Example 1

Core. A student breathed out gently through a straw into a test-tube of limewater and timed how long it took to turn cloudy. At rest it took 40 seconds. Straight after two minutes of skipping it took 16 seconds.

- (a) Describe the change in the limewater that shows carbon dioxide is present. [1]
- (b) Calculate the percentage decrease in the time taken. [2]
- (c) Suggest why the limewater turned cloudy more quickly after skipping. [2]
- (d) To check that the result was caused by breath, the student used a pump to bubble air from the room through a fresh tube of limewater in the same way. After 5 minutes it was still clear. Explain this result. [2]
- (e) State one other way, apart from carbon dioxide, in which the student's expired air differs from the air in the room. [1]

(a) It turns from clear to cloudy (milky) **B1**.

(b) $\frac{16 - 40}{40} \times 100$ **M1** = -60%, a decrease of 60% **A1**. (It went cloudy 2.5 times as fast.)

(c) Muscles respired faster during skipping, making more carbon dioxide **B1**, so the air breathed out after exercise contained more carbon dioxide (and more was breathed out each second) **B1**.

(d) Room air (inspired air) contains very little carbon dioxide, about 0.04% **B1**, compared with about 4% in expired air, so not enough carbon dioxide passed through to turn the limewater cloudy **B1**.

(e) Less oxygen, or more water vapour **B1**.

Example 2

Core, with an Extended part. A cyclist rode an exercise bike at different power outputs. At each one, her breathing rate and the volume of air in each breath were measured.

Power output / watts	0	50	100	150
Breathing rate / breaths per minute	14	18	24	32
Volume of each breath / dm ³	0.5	1.2	1.9	2.4

- (a) Describe how the rate and depth of her breathing change as the power output increases. Use data in your answer. [3]
- (b) Calculate the volume of air she breathed per minute at 100 watts and at 150 watts. [2]
- (c) At rest she breathed 7.0 dm³ per minute. Calculate how many times more air she breathed per minute at 150 watts, to 1 decimal place. [1]
- (d) **Extended:** explain how the increase in power output causes these changes in her breathing. [4]
- (a) Both the rate and the depth increase as the power output increases **B1**. The rate rises from 14 to 32 breaths per minute **B1**; the volume of each breath rises from 0.5 to 2.4 dm³ **B1**. (Depth rises most at the start: it more than doubles between 0 and 50 watts.)

(b) At 100 W: $24 \times 1.9 = 45.6$ dm³ per minute; at 150 W: $32 \times 2.4 = 76.8$ dm³ per minute **M1 A1**.

(c) $76.8 \div 7.0 = 11.0$ times **B1**.

(d) Her leg muscles respire faster to release more energy **B1**, so more carbon dioxide passes into her blood and its concentration increases **B1**. The brain detects the higher carbon dioxide concentration **B1** and sends more nerve impulses to the diaphragm and intercostal muscles, so they contract faster and more strongly: breathing gets faster and deeper **B1**.

Example 3

Extended. During a lung-function test, a doctor asks a patient to breathe in as far as she can, then to blow the air out as hard as she can. At rest, the patient takes one breath every 5 seconds.

(a) Calculate her resting breathing rate in breaths per minute. **[1]**

(b) Name the two sets of muscles that contract when she breathes in. **[2]**

(c) Explain how the contraction of these muscles causes air to enter her lungs. **[4]**

(d) Name the muscles that contract when she blows out hard, and state their effect on the ribs. **[2]**

(e) The pressure inside her trachea falls as she breathes in. Explain why the trachea does not close. **[1]**

(a) $60 \div 5 = 12$ breaths per minute **B1**.

(b) The external intercostal muscles **B1** and the diaphragm **B1**.

(c) The ribs are pulled upwards and outwards, and the diaphragm flattens (moves down) **B1**. This increases the volume of the thorax **B1**, so the pressure in the thorax and lungs decreases **B1**, below atmospheric pressure, and air is drawn in until the pressures are equal **B1**.

(d) The internal intercostal muscles **B1**; they pull the ribs down and in **B1**.

(e) Rings of cartilage in its wall hold it open and stop it collapsing **B1**.

Example 4

Extended. A gas analyser in a hospital measured the air a patient breathed in and out.

	Oxygen / %	Carbon dioxide / %
Air breathed in	20.9	0.04
Air breathed out	16.3	4.2

(a) Calculate the fall in the percentage of oxygen, and what percentage of the oxygen breathed in this fall represents, to the nearest whole number. **[2]**

(b) Calculate how many times greater the percentage of carbon dioxide is in the air breathed out. **[1]**

(c) Explain the differences in oxygen and carbon dioxide shown in the table. **[4]**

(d) The air breathed out was also saturated with water vapour. Suggest why. **[1]**

(e) The patient has a condition in which the cilia in the airways do not beat. Explain why she often gets chest infections. **[3]**

(a) $20.9 - 16.3 = 4.6$ **B1**; $\frac{4.6}{20.9} \times 100 = 22\%$ **B1**.

(b) $4.2 \div 0.04 = 105$ times **B1**.

(c) Oxygen diffuses from the alveoli into the blood **B1** and is used by the cells in aerobic respiration **B1**. Carbon dioxide is made by respiration in the cells **B1**, carried to the lungs in the blood and diffuses into the alveoli, so it is breathed out (excreted) **B1**.

(d) Water evaporates from the moist lining of the alveoli into the air **B1**.

(e) Goblet cells still make mucus, which traps pathogens **B1**, but the cilia do not sweep the mucus up and out of the airways **B1**, so mucus containing bacteria stays in the lungs, where they can multiply **B1**.

Common mistakes

- **Saying "lungs" for the gas exchange surface.** The surface is the **alveoli**. Examiners do not accept "lungs" or "membrane" there.
- **Getting the causes backwards in ventilation.** Muscles contract → volume increases → pressure falls → air comes in. Air coming in does not make the lungs bigger, and the pressure change does not move the ribs.
- **Writing "intercostal muscles" without saying which.** Name the **external** intercostals (breathing in) or the **internal** intercostals (forced breathing out), or you lose the mark.
- **Contradictions such as "the diaphragm contracts and rises".** When it contracts it **flattens and moves down**.
- **Writing "lung volume" when asked about the thorax**, or describing all of breathing when asked only about the diaphragm. Answer exactly what is asked.
- **Thinking the depth of breathing falls during exercise.** Both rate and depth increase.
- **Explaining gas differences with diffusion only.** The full answer needs **respiration**: oxygen is used by it and carbon dioxide is made by it.
- **Not knowing 16% oxygen and 4% carbon dioxide** in expired air. These are the numbers most often got wrong.
- **Vague cartilage answers** ("protects", "supports the lungs"). Cartilage **keeps the trachea open** and stops it collapsing.
- **Saying cilia trap or move pathogens directly, or that goblet cells move mucus.** Goblet cells **make** mucus that traps; cilia **move the mucus**, upwards.
- **Starting the path of air at the lungs**, or confusing bronchi with bronchioles. Air enters at the nose or mouth; bronchioles are the narrow ones that lead to alveoli.

- **Naming "hydrogencarbonate" without "indicator", or "calcium carbonate"** for the carbon dioxide test. Say **limewater**, and give the result: clear to **cloudy**.
- **Data quotes without units**, or describing only the overall trend. Give numbers with units and note any change in pattern.

How to get the marks

- **"State" or "name"**: one word or phrase (alveoli, cartilage, limewater, brain). Don't give alternatives; a wrong one cancels a right one.
- **"Describe" differences in air**: name each gas and say more or less (or give both percentages). "Different" earns nothing.
- **"Explain" ventilation**: a chain of linked steps in the right order (muscles → ribs/diaphragm → volume → pressure → air). Each link is a mark, and the mark schemes cap it (often 4), so be complete but brief. The best answers say air moves in until the pressures are **equal**.
- **"Explain" the effect of exercise**: carbon dioxide concentration in the blood, **brain**, impulses to named muscles, faster **and** deeper breathing.
- **"Describe and explain" features of alveoli**: give the feature **and** its effect on diffusion ("thin wall, so a short diffusion distance").
- **Label lines**: ruled, and touching the structure.
- **Data**: quote values with units, show working in calculations, and round as asked.
- **Use the exact terms**: alveoli, bronchioles, bronchi, trachea, larynx, cartilage, external and internal intercostal muscles, diaphragm, thorax, volume, pressure, diffusion, concentration gradient, respiration, goblet cells, mucus, ciliated cells, cilia, limewater.

Quick check

1. List, in order, the structures an oxygen molecule crosses between the larynx and the blood: bronchiole, capillary wall, trachea, alveolus wall, bronchus.
2. **Extended**: For each change, say whether it happens when breathing in or when breathing out: (a) the internal intercostal muscles contract; (b) the pressure in the thorax falls below atmospheric pressure; (c) the diaphragm relaxes and becomes dome-shaped; (d) the ribs move up and out.
3. A breathing trace shows 9 complete breaths in 45 seconds, each 0.6 dm³ deep. Calculate the breathing rate and the volume breathed per minute.
4. Explain how each helps gas exchange: (a) the alveolus wall is one cell thick; (b) blood flows continuously through the capillaries around the alveoli; (c) breathing keeps replacing the air in the alveoli.
5. **Extended**: A student wrote: "During exercise the brain detects that the blood is short of oxygen, so the lungs breathe faster." Correct the answer.

Answers

1. Trachea → bronchus → bronchiole → alveolus wall → capillary wall.
2. (a) Breathing out (forced expiration). (b) Breathing in. (c) Breathing out. (d) Breathing in.
3. $9 \times \frac{60}{45} = 12$ breaths per minute. $12 \times 0.6 = 7.2 \text{ dm}^3$ per minute.
4. (a) A short diffusion distance, so gases diffuse across quickly. (b) Oxygen is carried away and carbon dioxide brought in, so a steep concentration gradient is kept. (c) The oxygen concentration in the alveoli stays high and carbon dioxide low, keeping the gradient.
5. The brain detects an **increase in the carbon dioxide concentration** of the blood, made by faster respiration in the muscles. It sends more nerve impulses to the **diaphragm and intercostal muscles**, which contract faster and more strongly; the lungs don't move by themselves. Breathing becomes faster and deeper.

Past questions to try

- **0610/42/O/N/24 Q2**: parts of the breathing system, cartilage, a thorax pressure and volume graph, and carbon dioxide and breathing (Extended).
- **0610/43/O/N/23 Q3**: percentages of gases, dust in expired air, and calculating breathing rate and depth from traces (Extended).
- **0610/33/O/N/23 Q4**: the path of air, composition of air, the two-tube limewater apparatus and exercise (Core).
- **0610/41/O/N/22 Q6**: naming parts from their functions, adaptations of alveoli, and explaining the composition of air (Extended).