

Cambridge AS & A Level · Biology 9700 · Notes

Gas exchange AS

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Read first: [Cell structure](#), [Cell membranes and transport](#), [Transport in mammals](#)

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What you need to know

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

1. **Describe the structure of the human gas exchange system:** the two lungs, the trachea, the two bronchi, the bronchioles, the alveoli and the network of capillaries around the alveoli.
2. **Say where each tissue is found** along the airways: cartilage, ciliated epithelium, goblet cells, the squamous epithelium of the alveoli, smooth muscle and capillaries.
3. **Recognise those tissues** in microscope slides, photomicrographs (light micrographs) and electron micrographs.
4. **Recognise the trachea, bronchi, bronchioles and alveoli** in slides and micrographs, and **draw plan diagrams** of the wall of the trachea and the wall of a bronchus in transverse section.
5. **Describe how ciliated epithelial cells, goblet cells and mucous glands keep the system healthy.**
6. **Describe what cartilage, smooth muscle, elastic fibres and squamous epithelium do** in the gas exchange system.
7. **Describe gas exchange** between the air in the alveoli and the blood in the capillaries.

Breathing movements (the diaphragm and intercostal muscles), lung volumes and lung diseases are not listed in this topic. Questions still describe diseases such as asthma or emphysema, and pollution, and expect you to apply the ideas below to them.

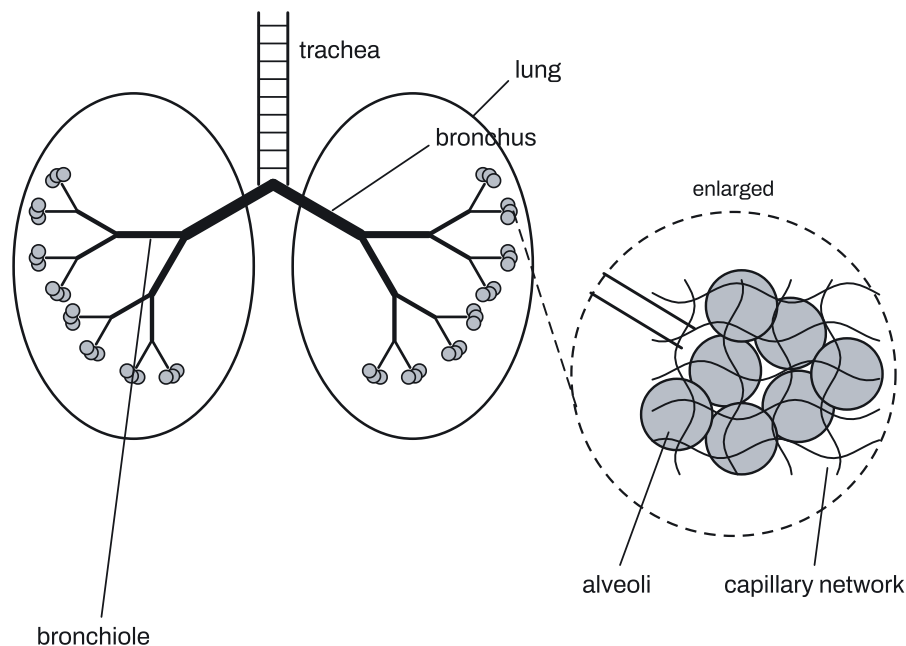
Understand it

Why the body needs a gas exchange system

Every cell respire, so every cell needs a supply of oxygen and has to get rid of carbon dioxide. A large animal has a small surface area compared with its volume, and diffusion is far too slow over more than a fraction of a millimetre. So mammals have a special **gas exchange surface** inside the lungs: a huge area of very thin wall, with air on one side and blood on the other. The airways bring air to it, and the blood carries the oxygen away to the rest of the body.

The route air takes

Air enters through the nose or mouth, passes the larynx and goes down the **trachea** (windpipe). The trachea divides into two **bronchi** (singular: bronchus), one for each **lung**. Inside the lung each bronchus divides again and again into narrower tubes called **bronchioles**. The smallest bronchioles end in clusters of tiny air sacs, the **alveoli** (singular: alveolus). Each alveolus is wrapped in a dense **capillary network**.



Only the alveoli exchange gases. The trachea, bronchi and bronchioles are just the delivery pipes: their walls are too thick for diffusion to be fast enough, and the blood that feeds their own cells is already oxygenated, so there is no gradient to use.

Which tissues are where

The walls of the airways change gradually as the tubes get narrower. This table sums up what you need to learn. It is the basis of about a third of all the questions on this topic.

Tissue	Trachea	Bronchus	Bronchiole	Alveolus
Cartilage	✓ C-shaped rings	✓ irregular plates	✗	✗
Ciliated epithelium	✓	✓	✓ in all but the very smallest	✗
Goblet cells	✓ many	✓ many	very few in the larger ones, none in the smallest	✗
Mucous glands	✓	✓	✗	✗
Smooth muscle	✓	✓	✓	✗
Elastic fibres	✓	✓	✓	✓

Tissue	Trachea	Bronchus	Bronchiole	Alveolus
Squamous epithelium	✗	✗	✗	✓
Capillaries (blood vessels)	✓	✓	✓	✓ a dense network

Four rules capture most of it:

- **Cartilage is in the trachea and bronchi only.** It is always there in both, and never in any bronchiole, not even the largest.
- **Epithelium and smooth muscle are in every airway**, including every bronchiole. Only the alveoli have neither ciliated epithelium nor smooth muscle.
- **Goblet cells and mucous glands thin out:** many in the trachea and bronchi, very few in the larger bronchioles, none in the smallest bronchioles or the alveoli. So "all bronchioles have goblet cells" is **false**.
- **Squamous epithelium is found only in the alveoli.** The lining of the trachea and bronchi is tall, column-shaped (columnar) ciliated epithelium, never squamous.

Elastic fibres are everywhere, but there are the most in the alveolar walls.

What each tissue does

Cartilage is a firm, slightly flexible tissue. Its collagen fibres make it strong. In the trachea and bronchi it **holds the airway open**, so it doesn't collapse when the air pressure inside falls as you breathe in. It is still **flexible**, so the neck can bend and the tube can lengthen a little as you breathe. The trachea's cartilage rings are C-shaped, with the gap at the back next to the oesophagus, so swallowed food can pass. In the bronchi the cartilage is in separate irregular plates. Bronchioles need no cartilage: they are small enough to be held open by the tissue around them and their own smooth muscle, and without rigid cartilage they can change diameter.

Smooth muscle can **contract and relax**. When it contracts, it **narrows the airway**; when it relaxes, the airway widens. This **regulates the flow of air** to the alveoli. Smooth muscle does not pump air, and it does not stretch and recoil (that is what elastic fibres do). In the bronchioles, smooth muscle makes up a large share of the thin wall, which is why narrowing of the bronchioles matters so much in asthma.

Elastic fibres (made of the protein elastin) **stretch** when you breathe in, so the alveoli can expand without bursting, and then **recoil** when you breathe out, helping to push air out. They do not contract, and they are not what keeps the alveoli from collapsing. A liquid called **surfactant**, secreted by some alveolar cells, does that by lowering the surface tension of the moisture lining the alveoli.

Squamous epithelium is made of very thin, flat cells. The alveolar wall is one layer of them, so the **diffusion distance is very short**.

Keeping the airways clean

The air you breathe carries dust, pollen, bacteria and viruses. Three parts of the airway lining deal with them.

- **Goblet cells** are cup-shaped cells scattered among the ciliated cells of the epithelium. They make **mucus** and release it onto the surface by exocytosis. Mucus is sticky, made of glycoproteins (mucins) and water. To make so much of it, a goblet cell has lots of **rough endoplasmic reticulum** (to make the protein), a large **Golgi body** (to add the carbohydrate and package it) and many secretory vesicles.
- **Mucous glands** lie in the tissue beneath the epithelium of the trachea and bronchi. They secrete more mucus onto the surface through ducts.
- **Ciliated epithelial cells** have many **cilia** on the surface that faces the lumen. The cilia beat together in waves (a synchronised, or metachronal, rhythm) and **move the layer of mucus up the airways towards the throat**, where it is swallowed. Beating uses a lot of ATP, so these cells have many **mitochondria**.

So the **mucus traps** the particles and pathogens, and the **cilia move** the mucus, with what it has trapped, away from the alveoli. Mucus also acts as a barrier between pathogens and the epithelial cells. If the cilia stop working (tar in cigarette smoke paralyses them, for example), the mucus stays in the airways, bacteria multiply in it, and infections become more likely.

There are no goblet cells in the smallest bronchioles or the alveoli for good reasons: mucus there would block the tiny airways, would add to the diffusion distance, and there would be few or no cilia to clear it away.

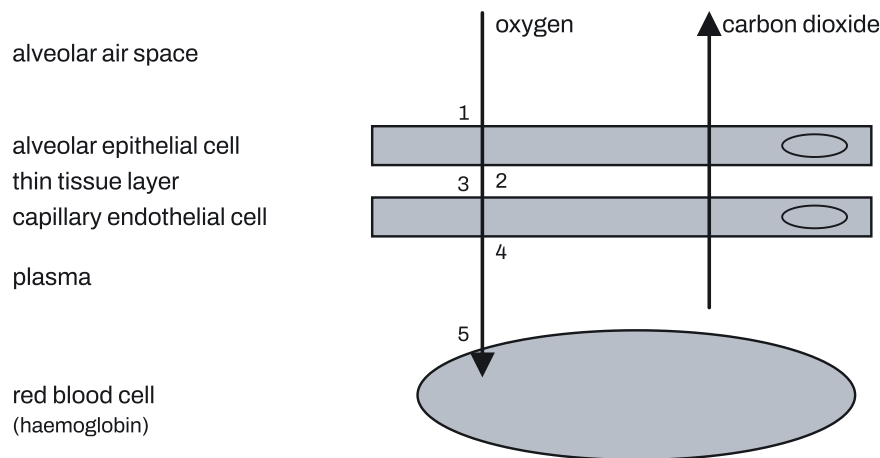
Gas exchange in the alveoli

The alveoli are where oxygen enters the blood and carbon dioxide leaves it. Both gases move by **diffusion**, each down its own concentration gradient (usually given as a **partial pressure**, in kPa):

- **Oxygen diffuses from the alveolar air into the blood**: the air in the alveoli has a higher partial pressure of oxygen than the deoxygenated blood arriving.
- **Carbon dioxide diffuses from the blood into the alveolar air**: the blood arriving has a higher partial pressure of carbon dioxide than the alveolar air.

Typical values are below. The numbers can change from question to question, but the pattern (oxygen higher in the air, carbon dioxide higher in the blood arriving) is always the same.

	Oxygen / kPa	Carbon dioxide / kPa
Air in the alveoli	13.3	5.3
Blood arriving in the pulmonary artery	5.3	6.0
Blood leaving in the pulmonary vein	13.3	5.3



Three things make the diffusion fast:

1. **A very large surface area.** Each lung has hundreds of millions of alveoli, which together give a surface area about the size of a tennis court. The capillary network covers almost all of it.
2. **A very short diffusion distance.** The gases cross only **two thin cells**: the **squamous epithelial cell** of the alveolar wall and the **endothelial cell** of the capillary wall. Together they are less than a micrometre thick. The capillaries are so narrow that the red blood cells squeeze through, pressed against the wall.
3. **Steep concentration gradients**, kept steep all the time:
 - **Ventilation** (breathing in and out) keeps replacing the alveolar air with fresh air, which is high in oxygen and low in carbon dioxide.
 - **Blood flow** keeps bringing **deoxygenated** blood (low in oxygen, high in carbon dioxide) from the pulmonary artery and carries the newly oxygenated blood away to the pulmonary vein.
 - **Haemoglobin** in the red blood cells takes up oxygen from the plasma as soon as it arrives, keeping the concentration of dissolved oxygen in the plasma low.

Keep these apart: a thin wall shortens the **distance**, a large area gives more **surface**, and only ventilation and blood flow (helped by haemoglobin) keep the **gradient** steep. A thin wall does not make the gradient steeper. Also, air and blood do not flow in opposite directions in the lungs: there is no countercurrent system here.

The alveoli are also lined with a **thin film of water**. The gases dissolve in it before they diffuse across the wall.

Counting membranes on the diffusion path

Each cell the gas passes through has a membrane on each side, and each membrane is a **phospholipid bilayer** (two layers of phospholipids). For oxygen going from the alveolar air to haemoglobin (diagram 2):

Crossing	Membranes
Squamous epithelial cell of the alveolus (in and out)	2
Endothelial cell of the capillary (in and out)	2
Red blood cell (in)	1

Crossing	Membranes
Total	5 membranes = 10 phospholipid layers

Carbon dioxide dissolved in the plasma crosses only the two cells: **4 membranes**. Carbon dioxide inside a red blood cell crosses 5.

Two blood supplies to the lungs

The lungs get blood from two circulations.

- The **pulmonary circulation** (pulmonary artery, from the right ventricle) brings **deoxygenated** blood at **low pressure** to the alveolar capillaries, to pick up oxygen and get rid of carbon dioxide. This is the blood that takes part in gas exchange.
- The **systemic circulation** (the bronchial arteries, branches of the aorta, from the left ventricle) brings **oxygenated** blood at **higher pressure** to the cells of the airways and lung tissue themselves. These cells need oxygen and glucose for their own aerobic respiration.

Recognising tissues in micrographs

In a light micrograph (photomicrograph):

- **Cartilage** looks like a smooth, pale, glassy background (the matrix) with scattered rounded cells (**chondrocytes**) sitting in small spaces called **lacunae**. A layer of fibrous tissue, the **perichondrium**, surrounds it. It is found as a C-shaped band (trachea) or in blocks (bronchus).
- **Ciliated epithelium** lines the lumen. The cells are tall and packed tightly, with nuclei at different heights, so it can look like several layers. The edge facing the lumen looks **fuzzy or blurred**; that is the cilia.
- **Goblet cells** sit among the ciliated cells. They are cup-shaped and filled with mucus, so they stain differently from their neighbours (paler or darker, depending on the stain). In a **scanning** electron micrograph of the lining, a goblet cell is a smooth rounded dome among a carpet of cilia.
- **Mucous glands** are clusters of small, rounded groups of secretory cells in the tissue beneath the epithelium.
- **Smooth muscle** is a band of long, narrow cells with long nuclei, often wrapped around the airway.
- **Squamous epithelium** is so thin that the alveolar walls are just fine lines, with the nucleus of each cell making a small bulge.
- **Alveoli** give lung tissue a lacy, net-like look: many empty air spaces separated by very thin walls. Much smaller spaces than bronchioles.
- **Capillaries** are tiny vessels with a wall of one flat cell, often with red blood cells inside in single file.

A **scanning electron micrograph (SEM)** shows surfaces in 3-D, such as cilia seen from above. A **transmission electron micrograph (TEM)** shows a thin section with internal detail, such as the ring of 9 pairs of microtubules around 2 single ones inside a cilium cut across, or the thin alveolar wall between an air space and a capillary.

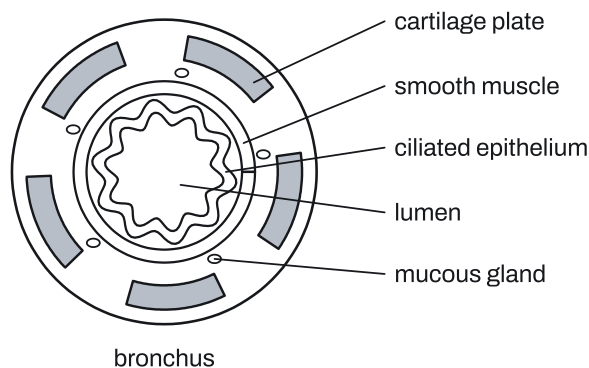
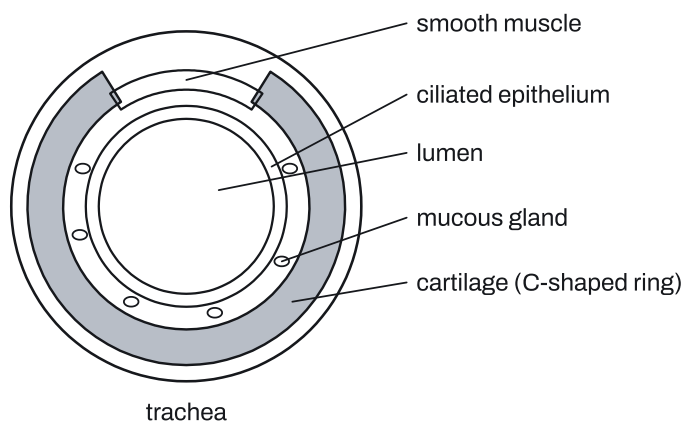
To name the airway in a section:

Airway	How to tell
Trachea	One big lumen; a large C-shaped ring of cartilage; many goblet cells; mucous glands
Bronchus	Irregular plates of cartilage; ciliated epithelium with goblet cells; a band of smooth muscle; mucous glands; lining often folded
Bronchiole	No cartilage ; folded (wavy) lining; few or no goblet cells; no mucous glands; a thin wall with a thin layer of smooth muscle (though a large share of the thin wall)
Alveoli	Many tiny air spaces with walls one flat cell thick; no cartilage, cilia or muscle

A bronchiole has less smooth muscle in total than a bronchus, but its wall is so thin that the muscle is a larger proportion of it. Both statements are credited by mark schemes, so say which you mean.

Plan diagrams of the trachea and a bronchus

A **plan diagram** shows the **outlines of the tissue layers** and where they are, with **no individual cells**. Draw with a sharp pencil, in single clean lines, keeping the proportions (how thick each layer is compared with the others) as they are in the slide. Label with ruled lines that touch the layer.



Key facts and formulas

None of these are in the syllabus's list of mathematical formulae, so they are all "Learn it".

Formula	Status
Magnification = $\frac{\text{image size}}{\text{actual size}}$, so actual size = $\frac{\text{image size}}{\text{magnification}}$	Learn it
1 mm = 1000 μm and 1 μm = 1000 nm	Learn it
Percentage change = $\frac{\text{new} - \text{original}}{\text{original}} \times 100$	Learn it
Oxygen, alveolus to haemoglobin: 2 + 2 + 1 = 5 membranes = 10 phospholipid layers	Learn it
Carbon dioxide, plasma to alveolus: 2 + 2 = 4 membranes = 8 phospholipid layers	Learn it
Faster diffusion: larger surface area, shorter distance, steeper gradient	Learn it
Oxygen: air → blood; carbon dioxide: blood → air (down their partial pressure gradients)	Learn it
Cartilage: trachea and bronchi only. Squamous epithelium: alveoli only	Learn it

How to do it

We have tagged 104 questions on this topic (2021–2025): 82 multiple-choice questions from Paper 1 and 22 structured questions from Paper 2. The types came up this often. 23 of the 104 questions mix more than one type, so the counts add up to more than 104.

Question type	Questions
Which tissues and cells are in which airway	30
Identify tissues, cells and airways in micrographs and diagrams	28
Describe or explain the function of a tissue or cell	25
Explain gas exchange at the alveolus	25
Apply the ideas to disease, pollution or new data	10
Count membranes or add distances on the diffusion path	8
Name or order the airways	5
Link a cell's organelles to its function	3

1. Which tissues and cells are in which airway (30 questions)

- Read the question's exact words.** "The trachea **and** the bronchus" means ticks only for tissues in **both**; "**all** bronchioles" means even the smallest; "**always** contains cartilage" means every one of that airway.
- Go through the table in "Which tissues are where" one tissue at a time**, and cross out every option with a wrong tick or cross.
- For a structured question asking what **identifies** an airway, give **visible** features (see step 4 of type 2).

Variations you will meet:

- **Tick tables** (trachea, bronchus, bronchiole, alveolus against cartilage, ciliated epithelium, goblet cells, smooth muscle, squamous epithelium, elastic fibres). The traps are cartilage in bronchioles (never), squamous epithelium outside the alveoli (never), smooth muscle in alveoli (never) and goblet cells in all bronchioles (no).
- **Terminal bronchioles:** no cartilage, but cilia and smooth muscle are present.
- **Matching or Venn diagrams:** "ciliated epithelium, goblet cells **and** cartilage" together means the trachea and the bronchi.
- **Why an airway lacks something.** No goblet cells in the respiratory bronchioles: mucus would block narrow airways close to the alveoli, would lengthen the diffusion path, there are few or no cilia to clear it, and trapped pathogens would cause infection. No cartilage in bronchioles: the smooth muscle and surrounding tissue support them, and they need to change diameter.
- **Compare the epithelium of a bronchiole with that of an alveolus:** the bronchiole's is ciliated and columnar or cuboidal (taller cells); the alveolus's is squamous (flat, very thin cells) with no cilia.
- **"Suggest how the bronchiole wall differs from the bronchus wall"** for two named tissues: no cartilage in the bronchiole; smooth muscle a larger proportion of its wall (though a thinner layer in absolute terms).

2. Identify tissues, cells and airways in micrographs and diagrams (28 questions)

1. **Find the lumen** (the empty space the air moves through). The epithelium lines it.
2. **Name the labelled part** from what it looks like (see "Recognising tissues in micrographs"). Use the exact name asked for: a **tissue** ("ciliated epithelium", "smooth muscle", "cartilage") or a **cell** ("ciliated epithelial cell", "goblet cell").
3. **Name the airway** from the cartilage: C-shaped ring = trachea, plates = bronchus, none = bronchiole; walls one cell thick = alveoli.
4. If asked for **features that helped you identify it**, describe only what you can **see**: "blurred edge on the lumen side, so cilia", "cells in spaces in a pale matrix, so cartilage", "a single layer of flat cells with red blood cells inside, so a capillary".

Variations you will meet:

- **Plan diagram of a trachea** with lettered layers: the tissue that prevents collapse is the shaded C-shaped band (cartilage); the one that changes diameter is the smooth muscle.
- **SEM of the lining** with goblet cells among cilia; or a TEM of a cilium's microtubules. Say which kind of electron micrograph: a 3-D surface view is SEM.
- **"Which structures are present in this section of lung tissue?"** A section through lung tissue can show bronchi, bronchioles, arteries and veins, but never the trachea, which is outside the lungs.
- **Annotated labels:** check both the name and that the pointer is on that tissue, and that the function is right. "Squamous epithelium allows gas exchange" is wrong in a bronchus, because a bronchus has no squamous epithelium.
- **Smooth muscle wording.** To **identify a bronchiole from a micrograph**, write "a thin layer of smooth muscle" or "less smooth muscle than a bronchus". To **compare its wall with a bronchus's**, write "smooth muscle is a larger proportion of the wall".

- **Measuring:** a line across a structure in a micrograph. Alveoli are far smaller than any airway, so a line across a larger lumen with a thick wall is a bronchiole.

3. Describe or explain the function of a tissue or cell (25 questions)

Give **what it does**, then the **consequence**:

- **Cartilage:** keeps the trachea and bronchi **open** (stops them collapsing when the pressure falls on breathing in) **so air flows freely**; flexible, so the neck can bend and the tube can lengthen during breathing.
- **Smooth muscle:** **contracts and relaxes** to **change the diameter** of the airway, **regulating the flow of air** to the alveoli.
- **Elastic fibres:** **stretch** as the alveoli fill, so they don't burst; **recoil** to help push air out when breathing out.
- **Squamous epithelium:** one layer of thin, flat cells, so a **short diffusion distance** for oxygen and carbon dioxide.
- **Goblet cells and mucous glands:** **secrete mucus**, which **traps** dust and pathogens.
- **Cilia:** **beat** in a synchronised rhythm to **move the mucus** up to the throat, away from the alveoli.

Variations you will meet:

- **"Explain why ciliated epithelial cells are also important"** (after being told mucus traps particles): they move the mucus away; if it stayed, pathogens would build up and cause infection, and it would block airflow.
- **"Suggest why ciliated cells would not suit the alveolar wall"**: they are much taller (thicker) than squamous cells, so the diffusion distance would be longer and diffusion slower; beating cilia would also use oxygen.
- **Properties of collagen in cartilage:** collagen gives cartilage high tensile strength and some flexibility; it is the **cartilage** (not collagen on its own) that holds the trachea and bronchi open.
- **"Collagen in the bronchi prevents them collapsing"** is marked **false** in [9700/12/F/M/24 Q37](#): credit the cartilage, not the collagen alone.
- **Cilia do not trap or make mucus, and do not increase surface area.** Goblet cells **release** mucus; they do not move it.
- **Surfactant:** questions may tell you that some alveolar cells secrete it to stop alveoli collapsing. It lowers surface tension; it is not what the elastic fibres do.
- **Why bronchioles have no cartilage:** smooth muscle and the surrounding tissue give enough support.

4. Explain gas exchange at the alveolus (25 questions)

1. **State the direction:** oxygen from the alveolar air into the blood; carbon dioxide from the blood into the alveolar air; both by **diffusion**.
2. **Use the numbers** if given: say which partial pressure is higher for each gas.
3. **Explain the gradient:** ventilation brings in air high in oxygen and low in carbon dioxide; blood flow brings deoxygenated blood and removes oxygenated blood; haemoglobin takes up oxygen.

4. **Link the structure to the rate:** large surface area (many alveoli, capillary network); short distance (two thin cells: squamous epithelium and endothelium).

Variations you will meet:

- **"Which of these maintains the gradient?"** Only ventilation (fresh air) and blood flow (fresh deoxygenated blood) do. A thin lining or flattened endothelium shortens the **distance**; many alveoli increase the **area**. If only one option can be right, the blood flow is the usual answer; haemoglobin binding oxygen helps, but as part of that.
- **"Which partial pressures allow exchange?"** Pick the row where oxygen is higher in the alveolar air than in the blood **and** carbon dioxide is higher in the blood than in the air.
- **Arrows on a TEM:** oxygen from the alveolar air space into the capillary; carbon dioxide from the capillary into the air space. Label each arrow.
- **Why the airways (trachea to terminal bronchioles) can't exchange gases:** walls too thick (several layers, ciliated epithelium, smooth muscle, mucus), so diffusion is too slow; and their blood comes from the systemic circulation, already oxygenated, so there is no gradient.
- **Why the lungs need both circulations:** see "Two blood supplies to the lungs".
- **Effect of shallow, slow breathing** (at rest): less fresh air, so a lower partial pressure of oxygen in the alveoli, a less steep gradient and slower diffusion. Oxygen still moves by diffusion, never active transport.
- **A machine that oxygenates blood** (such as an ECMO oxygenator): the membrane does the job of the alveolar wall; oxygen diffuses into the blood and carbon dioxide out, and if blood and gas flow in opposite directions, the gradient stays steep along the whole membrane.

5. Apply the ideas to disease, pollution or new data (10 questions)

1. **Find what has changed** (thicker mucus, narrower airways, fewer alveoli, less oxygen in the air, a new molecule binding haemoglobin).
2. **Link it to one of:** surface area, diffusion distance, concentration gradient, airflow, or the clearing of mucus.
3. **Give the consequence** for oxygen uptake (and carbon dioxide removal), with the direction of each gas.

Variations you will meet:

- **Asthma:** smooth muscle in the bronchi and bronchioles contracts, narrowing the airways, and extra mucus is made. A reliever drug **relaxes the smooth muscle**, widening the airways.
- **Emphysema:** elastic fibres are lost and alveolar walls break down into larger air sacs, so a **smaller surface area** and **poor recoil**, which makes breathing out difficult.
- **Chronic bronchitis and tar:** cilia are damaged or paralysed, goblet cells and mucous glands enlarge and make more mucus, and mucus builds up with trapped bacteria, so infections follow.
- **Thick, sticky mucus** (as in cystic fibrosis): the cilia can't move it, so pathogens aren't removed and infections are more likely.
- **Air pollution** lowering the oxygen saturation of blood leaving the lungs in a healthy person: polluted air has a lower proportion of oxygen, so a lower partial pressure in the alveoli and a less steep gradient, so less oxygen diffuses in; some pollutants (such as carbon monoxide) bind haemoglobin more strongly than

oxygen does, leaving fewer binding sites for oxygen and changing haemoglobin's shape so the cooperative binding of oxygen is less effective.

- **Data tables and graphs:** describe the trend, quote figures with units, and don't claim cause from a correlation ("associated with").
- **Other animals** (such as insects, whose air tubes take oxygen straight to the cells): compare with humans, where gases must be carried by the blood.

6. Count membranes or add distances on the diffusion path (8 questions)

1. **List the cells in order:** alveolar squamous epithelial cell, (tissue fluid or basement membrane), capillary endothelial cell, plasma, red blood cell.
2. **Count 2 membranes for each cell passed through** and **1 for entering** a red blood cell.
3. **Double for phospholipid layers** (each membrane is a bilayer).
4. **For a distance**, add up every membrane and every layer of cytoplasm and tissue on the path, using the thicknesses given.

Variations you will meet:

- Oxygen, alveolar air to haemoglobin: **5** membranes, **10** phospholipid layers.
- Oxygen or carbon monoxide, alveolar air into a red blood cell: also **5**.
- Carbon dioxide, plasma to alveolar air: **4**.
- **Pores:** if a gas can leak between or through gaps in the endothelium, it skips that cell. Carbon dioxide leaving a red blood cell then crosses 1 (red cell) + 2 (alveolar cell) = **3** membranes at least.
- **Which layers?** Oxygen crosses the **squamous epithelium** of the alveolus first, then the **endothelium** of the capillary.

7. Name or order the airways (5 questions)

1. Order: nose or mouth, larynx, **trachea**, **bronchus**, **bronchiole**, **alveolus**.
2. The trachea branches into two **bronchi**; each bronchus branches into **bronchioles**; the gas exchange surface is the **alveolar wall**. Spell "bronchus" (one) and "bronchi" (two) carefully; "bronchiole" is a different airway.

8. Link a cell's organelles to its function (3 questions)

- **Goblet cell:** lots of **rough ER**, a large **Golgi body** and many vesicles, because it makes, packages and secretes large amounts of mucus (a glycoprotein). It also has many ribosomes and mitochondria.
- **Ciliated epithelial cell:** many **mitochondria**, making ATP for the beating cilia.
- **Smooth muscle cell:** many mitochondria, for ATP for contraction.
- **Squamous epithelial cell:** very little cytoplasm and few organelles; it is thin so the distance is short.

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

(a) State **two** differences between the wall of the trachea and the wall of a bronchiole. **[2]**

(b) Describe how goblet cells and ciliated epithelial cells work together to keep the gas exchange system healthy. **[3]**

(c) Explain the function of the smooth muscle in the wall of a bronchiole. **[2]**

(a) Any two of: the trachea has **cartilage** (C-shaped rings) but the bronchiole has none; the trachea has **many goblet cells** and **mucous glands**, the bronchiole few or no goblet cells and no glands; the trachea wall is **much thicker**. **B1 B1**

(b) Goblet cells **secrete mucus** onto the surface of the epithelium. **B1** The mucus **traps** dust and pathogens such as bacteria, keeping them away from the alveoli. **B1** The **cilia** beat in a synchronised rhythm and **move the mucus**, with what it has trapped, **up to the throat**, where it is swallowed. **B1**

(c) Smooth muscle **contracts and relaxes**, which **changes the diameter** of the bronchiole. **B1** This **regulates the flow of air** into and out of the alveoli. **B1**

Example 2

A student looks at a slide of part of a lung. She sees an airway with a folded lining of ciliated epithelium containing goblet cells, a ring of smooth muscle, some mucous glands, and several separate blocks of cartilage near the outside of the wall.

(a) Identify the airway, and give **two** visible features that show it is not the trachea and not a bronchiole. **[3]**

(b) The image of the airway's lumen in her drawing is 36 mm across, and the drawing is at a magnification of $\times 40$. Calculate the actual width of the lumen in micrometres. **[2]**

(c) Describe how a plan diagram of this airway should be drawn. **[2]**

(a) A **bronchus**. **B1** Not the trachea: its cartilage is in **irregular plates**, not a C-shaped ring. **B1** Not a bronchiole: it **has cartilage** (and mucous glands). **B1**

(b) $36 \text{ mm} = 36\,000 \text{ }\mu\text{m}$. **M1** Actual size = $36\,000 \div 40 = 900 \text{ }\mu\text{m}$. **A1**

(c) Show only the **outlines of the tissue layers** (lining, smooth muscle, cartilage plates) in their correct positions and proportions, with **no individual cells**. **B1** Use clear, continuous lines and ruled label lines that touch each layer. **B1**

Example 3

The table gives the thickness of each layer that an oxygen molecule crosses between the air in an alveolus and the haemoglobin in a red blood cell. The red blood cell is touching the capillary wall.

Layer	Thickness / nm
Each cell surface membrane	8
Cytoplasm of the alveolar epithelial cell	160
Tissue between the alveolar wall and the capillary wall	220
Cytoplasm of the capillary endothelial cell	110

(a) State how many membranes, and how many phospholipid layers, the oxygen molecule crosses. **[2]**

(b) Calculate the shortest distance the oxygen molecule diffuses. Give your answer in μm . **[2]**

(c) In a lung disease the tissue between the two walls thickens to $1.5 \text{ }\mu\text{m}$. Calculate the percentage increase in the diffusion distance, and explain the effect on gas exchange. **[4]**

(a) $2 \text{ (alveolar cell)} + 2 \text{ (endothelial cell)} + 1 \text{ (red blood cell)} = 5 \text{ membranes}$. **B1** Each is a bilayer, so 10 phospholipid layers. **B1**

(b) $5 \times 8 + 160 + 220 + 110 = 530 \text{ nm}$ **M1** $= 0.53 \text{ }\mu\text{m}$. **A1**

(c) New distance = $530 - 220 + 1500 = 1810 \text{ nm}$. **M1** Increase = $\frac{1810 - 530}{530} \times 100 = 241.5\%$. **A1** The **diffusion distance is longer**, so oxygen diffuses into the blood (and carbon dioxide out of it) **more slowly**. **B1** Blood leaving the lungs is less oxygenated, so less oxygen reaches the respiring cells. **B1**

Example 4

The table shows partial pressures of oxygen in a person breathing normally and later breathing shallowly and slowly while resting.

	Normal breathing / kPa	Shallow breathing / kPa
Air in the alveoli	13.3	10.1
Blood arriving in the lung capillaries	5.3	5.3

(a) Calculate the difference in the partial pressure of oxygen between the alveolar air and the blood arriving, for each type of breathing, and the percentage decrease in this difference. **[3]**

(b) Explain why shallow breathing changes the rate of oxygen uptake. [3]

(c) Explain how the flow of blood through the lung capillaries helps to keep the oxygen gradient steep. [2]

(a) Normal: $13.3 - 5.3 = 8.0$ kPa. Shallow: $10.1 - 5.3 = 4.8$ kPa. **B1** Decrease = $\frac{8.0 - 4.8}{8.0} \times 100 = 40\%$.

M1 A1

(b) With shallow breathing, **less fresh air** reaches the alveoli, so the alveolar air is not replaced as often and its **partial pressure of oxygen falls**. **B1** The **gradient** between the alveolar air and the blood is **less steep**. **B1** So oxygen **diffuses into the blood more slowly**. **B1**

(c) Blood arriving from the pulmonary artery is **deoxygenated** (low partial pressure of oxygen). **B1** Blood that has taken up oxygen is **continually carried away** to the pulmonary vein and replaced, so the blood next to the alveolus always has less oxygen than the air. **B1**

Common mistakes

- **Putting smooth muscle or cilia in the alveoli.** The alveolar wall is squamous epithelium, elastic fibres and capillaries. Examiners see "alveoli contain smooth muscle" often.
- **Putting cartilage in bronchioles.** Almost two thirds of candidates in one year said terminal bronchioles have cartilage. No bronchiole has any.
- **Calling the lining of the trachea or bronchi squamous.** It is ciliated columnar epithelium. Squamous epithelium is found only in the alveoli.
- **Giving the bronchi C-shaped rings.** Only the trachea has C-shaped rings; the bronchi have irregular plates.
- **Saying the cilia trap particles.** The mucus traps them; the cilia **move** the mucus. Write "the cilia move the mucus", not "the ciliated cells move": the cells stay still.
- **Mixing up muscle and elastic fibres.** Smooth muscle **contracts and relaxes**; elastic fibres **stretch and recoil**. Examiners penalise "smooth muscle stretches" and "elastic fibres contract".
- **Saying collagen keeps the airways open.** A statement that collagen on its own prevents the bronchi collapsing is marked false ([9700/12/F/M/24 Q37](#)). The **cartilage** does; its collagen makes it strong.
- **Saying elastic fibres keep the alveoli open.** They stop them bursting and help push air out. Cartilage keeps the larger airways open.
- **Naming a cell when a tissue is asked for (or the other way round).** "Ciliated epithelium" is a tissue; "ciliated epithelial cell" is a cell. "Muscle" alone is not enough: write "smooth muscle".
- **Crediting goblet cells when the question is about the glands.** Mucous glands are in the tissue under the epithelium; goblet cells are in the epithelium. Both make mucus.
- **Leaving out the alveolar wall when counting,** or counting only one membrane per cell. Each cell passed through has two.
- **Saying which gas moves but not where.** "Gas exchange is reduced" earns little; say that less oxygen diffuses **into the blood** and less carbon dioxide diffuses **out**.

- **Saying thick mucus restricts airflow** when the question is about keeping the surfaces healthy. The credited idea is that the cilia can't move it, so pathogens aren't removed and infection is more likely.

How to get the marks

- **"Identify" or "name"**: one precise term. "Epithelium" is too vague when "ciliated epithelium" is meant, and "muscle" when "smooth muscle" is.
- **"State the features that help to identify"**: only features you can **see** in that image, each in a few words ("no cartilage", "folded lining", "few goblet cells").
- **"Describe the function" or "describe the role"**: what the tissue does plus the result ("contracts to narrow the airway, **so** regulating airflow"). Put it in the context asked: smooth muscle in the **bronchioles**, not the trachea.
- **"Explain" a gradient**: give both sides (what arrives and what leaves) and name the gas and its direction. Use "partial pressure" or "concentration", not "amount".
- **"Suggest"**: use the ideas here on a new situation (a disease, a pollutant, a machine). Link to surface area, distance, gradient, airflow or mucus clearance.
- **Calculations**: convert units first (mm to μm to nm), show the working, and give the unit. Round only at the end, to the accuracy asked.
- **Data**: quote figures with units, compare, and describe correlations as associations.
- **Plan diagrams**: layers only, no cells; correct proportions; clear lines; ruled labels that touch the layer.
- **Paper 1 tick tables**: work tissue by tissue and eliminate; read "and", "all" and "always" carefully.

Quick check

1. Which of the trachea, bronchus, bronchiole and alveolus contain (a) cartilage, (b) goblet cells, (c) squamous epithelium?
2. A molecule of carbon dioxide diffuses from the plasma, through a cell of the capillary wall and a cell of the alveolar wall, into the alveolar air. How many membranes, and how many phospholipid layers, does it cross?
3. An alveolus in a photomicrograph measures 18 mm across. The magnification is $\times 75$. Calculate the actual diameter of the alveolus in μm .
4. During an asthma attack the bronchioles narrow. Explain why, and how a drug that relaxes smooth muscle helps.
5. In a study, the mean number of goblet cells per mm of airway lining was 20 in non-smokers and 47 in smokers. Calculate the percentage increase.

Answers

1. (a) Trachea and bronchus. (b) Trachea, bronchus and the larger bronchioles (very few there). (c) Alveolus only.
2. 2 (endothelial cell) + 2 (alveolar cell) = 4 membranes = 8 phospholipid layers.
3. 18 mm = 18 000 µm; actual size = $18\,000 \div 75 = 240\text{ }\mu\text{m}$.
4. The **smooth muscle** in the bronchiole walls **contracts**, narrowing the lumen (and extra mucus is made), so less air reaches the alveoli. A drug that **relaxes the smooth muscle** widens the bronchioles, so air flows to the alveoli more easily.
5. $\frac{47 - 20}{20} \times 100 = 135\%$.

Past questions to try

- [9700/22/O/N/22 Q4](#): why the smallest bronchioles have no goblet cells, and the bronchiole's epithelium.
- [9700/23/O/N/24 Q1](#): where cartilage is, its role, and identifying regions from micrographs.
- [9700/22/O/N/23 Q4](#): how blood flow keeps the gradients steep, and the elastic fibres.
- [9700/12/M/J/23 Q37](#): adding up the diffusion distance from given thicknesses.