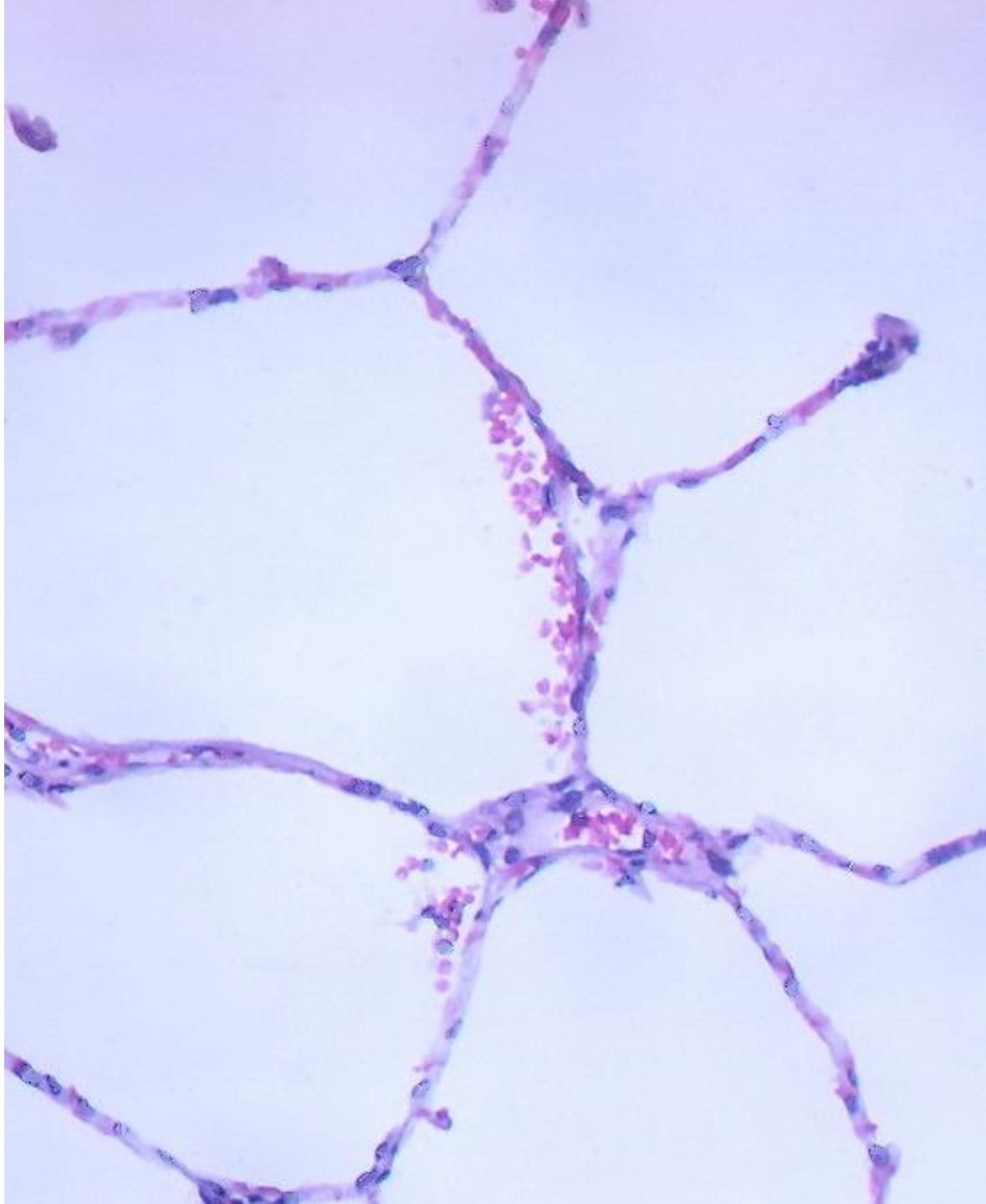
DP Biology – B3.1

Gas exchange

- What adaptations let multicellular organisms exchange gases?
- How do flowering plants and mammals differ, and resemble each other, in gas exchange?

Animal statements B3.1.1–6, SL and HL. Textbook pp. 273–283. Plants are in Plant Systems.

Image: human lung tissue, stained section. Yale Rosen, CC BY-SA 2.0.



Objectives for each class

Class	Statements	By the end of the class, you can...
1	B3.1.1–3	Explain why size makes gas exchange harder, and how surfaces and gradients overcome this
2	B3.1.4	Explain how alveoli, bronchioles, capillary beds and surfactant suit the lungs to gas exchange
3	B3.1.5–6	Describe how muscles ventilate the lungs, and determine lung volumes from a spirometer trace

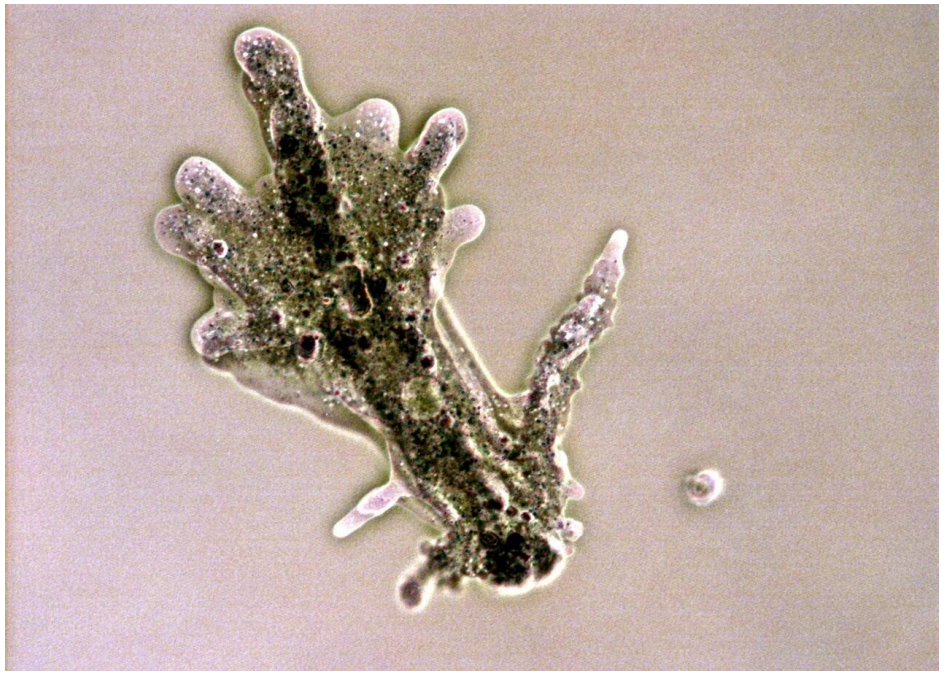
Overview of this chapter

Part	Statements	What it covers
The problem	B3.1.1	Why getting bigger makes gas exchange harder
Good surfaces	B3.1.2	The four properties that speed up diffusion
Keeping gradients	B3.1.3	Blood vessels, blood flow and ventilation
The mammal lung	B3.1.4	Surfactant, bronchioles, capillary beds, surface area
Breathing	B3.1.5	Diaphragm, intercostal and abdominal muscles, ribs
Measuring	B3.1.6	Tidal volume, vital capacity and the reserves

Every organism must exchange gases

B3.1.1

- Cells respire all the time to release energy as ATP
- Aerobic respiration uses **oxygen** and produces **carbon dioxide**
- Both gases cross cell membranes by **diffusion**
- Plants also exchange gases for photosynthesis
- In a single cell, the whole membrane is the exchange surface



Amoeba proteus, a single cell. Gases diffuse straight across its membrane. Cymothoa exigua, CC BY-SA 3.0.

Key idea

Gas exchange happens at the surface, but the cells using the gases fill the volume. Size changes the balance between these two.

Size makes gas exchange harder

Cube side	Area	Volume	Area : volume
1 cm	6 cm^2	1 cm^3	6 : 1
2 cm	24 cm^2	8 cm^3	3 : 1
4 cm	96 cm^2	64 cm^3	1.5 : 1

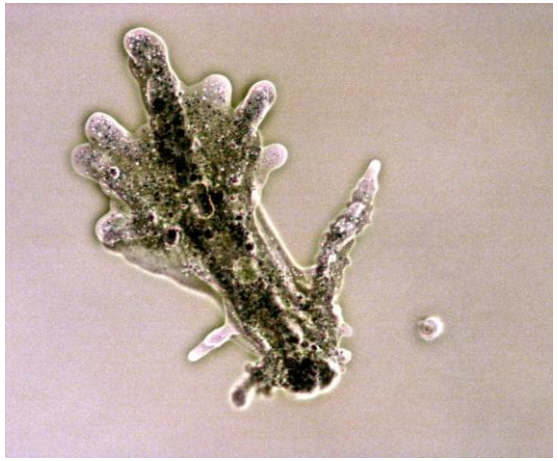
Model cubes: each doubling of length halves the ratio.

- **Surface area-to-volume ratio** falls as size increases
- The **distance** from the centre to the outside increases
- Diffusion alone becomes too slow
- Tough outer skin is often not gas-permeable

Key idea

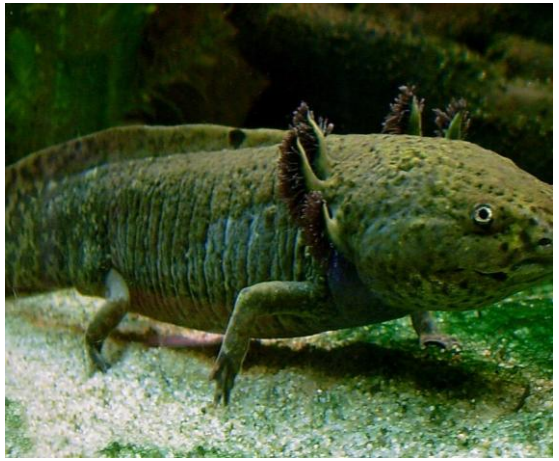
Large, active animals have a high demand for oxygen and a small surface for their volume. They solve this with a specialized exchange organ and a transport system.

Different animals, different solutions



Single cell

Across the membrane



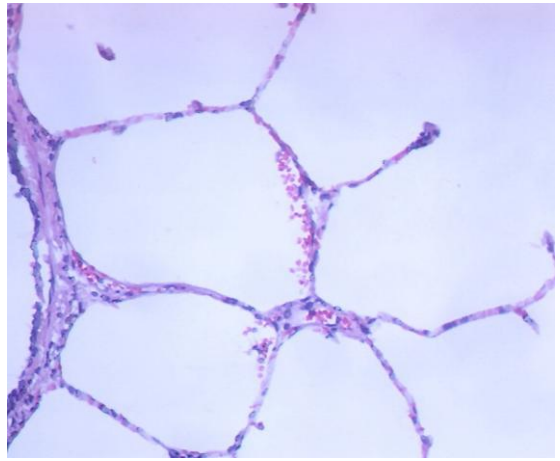
Salamander

External gills, and also the skin



Bony fish

Internal gills



Mammal

Lungs with alveoli

Images, left to right: Cymothoa exigua, CC BY-SA 3.0; LoKiLeCh, CC BY-SA 3.0; Krishna satya 333, CC BY-SA 4.0; Yale Rosen, CC BY-SA 2.0.

Activity

For each organism, suggest how its size and its habitat explain the way it exchanges gases. What would happen to the axolotl if its gills were dry?

Four properties of an exchange surface

B3.1.2

Property	How it helps
Permeable	Oxygen and carbon dioxide can pass across it
Thin	The diffusion distance is as short as possible
Moist	Gases dissolve first, which helps them pass across
Large surface area	More gas can cross at the same time

Link

The rate of diffusion depends on three things: surface area, the concentration gradient and the distance. Every adaptation in this chapter acts on one of these.

Diffusion needs a concentration gradient

B3.1.3



- The steeper the gradient, the faster the net diffusion
- Diffusion evens out concentrations, so the gradient would soon disappear
- Exchange would then stop, unless the gradient is maintained

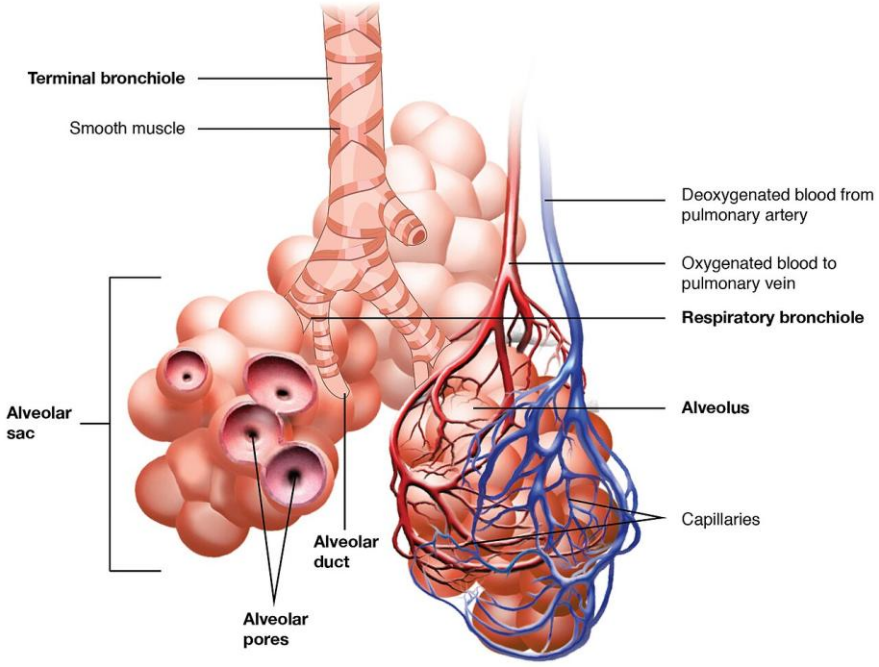
Question

Oxygen is about 14% of the air in the alveoli and the blood arriving is low in oxygen. What must happen on each side of the surface for this difference to last?

Three ways to maintain the gradients

B3.1.3

Feature	What it does
Dense network of blood vessels	Keeps a large area of blood close to the surface
Continuous blood flow	Removes oxygen and brings carbon dioxide
Ventilation	Brings in fresh air or water and removes used air or water



Blood vessels around alveoli. OpenStax College, CC BY 3.0.

Key idea

Both sides of the surface keep moving. Blood takes oxygen away, and ventilation replaces what has been used.

Gills do the same job in water

B3.1.3



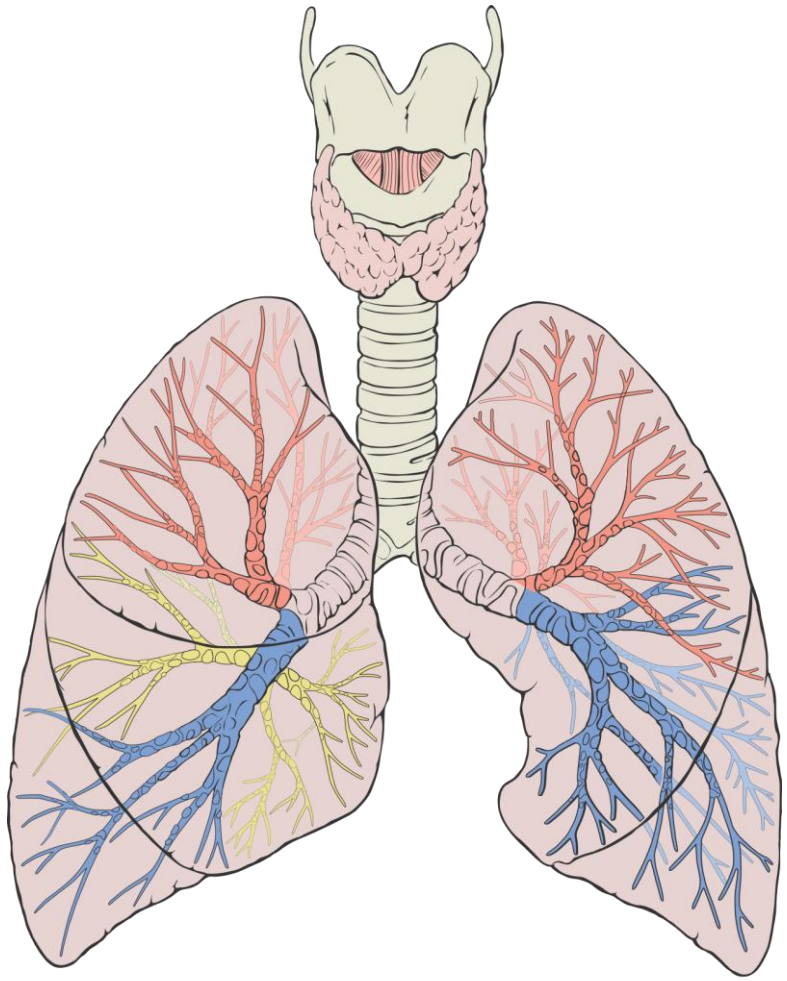
Gills removed from a bony fish: many thin filaments, with a dense blood supply. Krishna satya 333, CC BY-SA 4.0.

- Thin filaments give a large surface area
- A dense network of capillaries runs through each one
- Water is pumped over the gills, which is **ventilation with water**
- Moving water brings oxygen and carries away carbon dioxide

Question

Water holds far less dissolved oxygen than the same volume of air holds. Explain why continuous ventilation matters so much for a fish, and suggest why many fish die in warm, still water.

From trachea to alveoli



1. Air enters through the **trachea**, held open by rings of cartilage
2. The trachea divides into two **bronchi**, one for each lung
3. Bronchi divide into a **branched network of bronchioles**
4. The finest bronchioles end in clusters of **alveoli**
5. Gas exchange happens in the alveoli

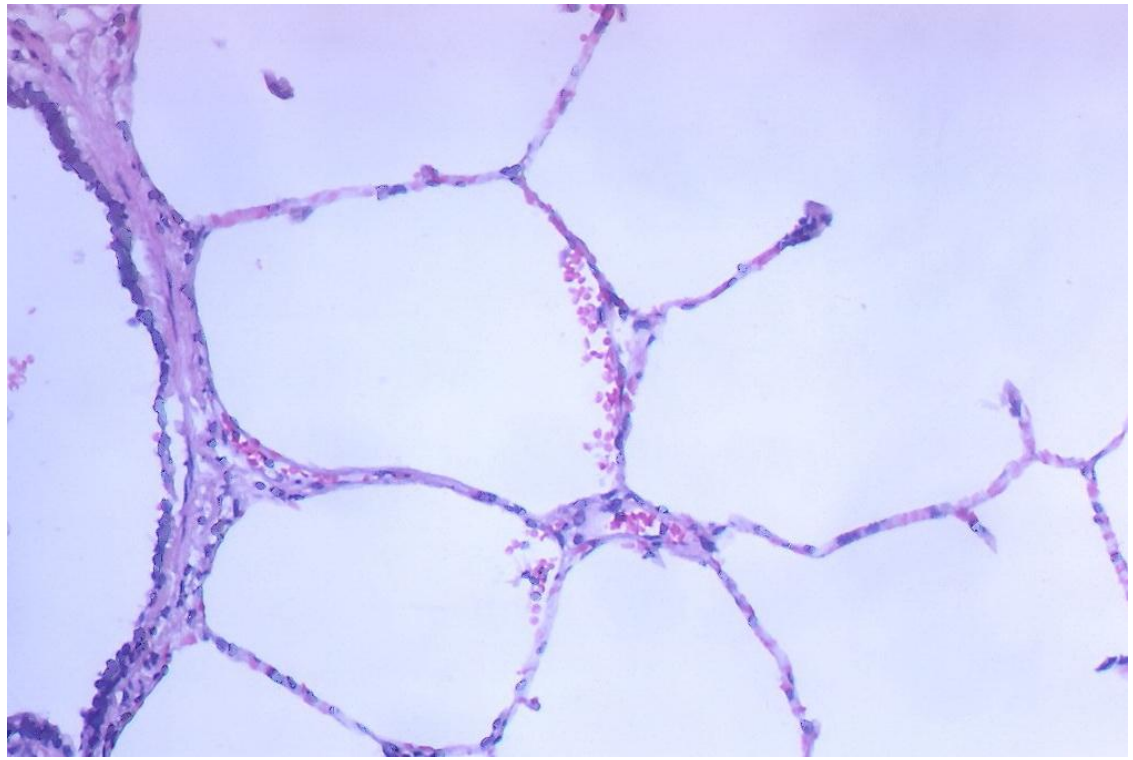
Key idea

The branching spreads air evenly through the whole lung, so every alveolus is ventilated. Air enters and leaves by the same route, so some stale air always remains and mixes with fresh air.

Human lungs. Patrick J. Lynch, CC BY 2.5.

Alveoli give a huge surface area

B3.1.4



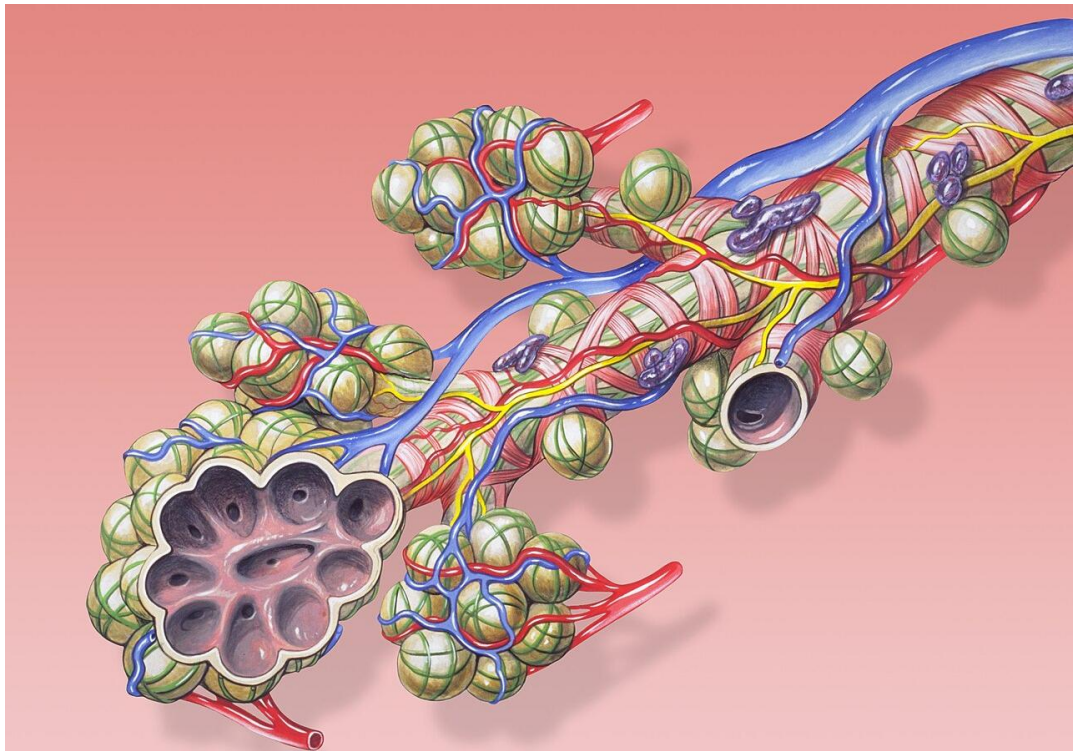
Human lung tissue: spaces are alveoli, separated by very thin walls. Blood cells are in the capillaries in the walls. Yale Rosen, CC BY-SA 2.0.

- Millions of tiny sacs, each about 0.25 mm wide
- Total area is about 50 m^2 in an adult
- **Wall one cell thick**, of flattened cells: a short diffusion distance
- Moist lining lets oxygen dissolve
- Elastic tissue stretches and recoils with each breath

Common mistake

Their round shape does not give the large area. It is their small size and huge number. Write ‘alveolar wall’ rather than ‘membrane’, and do not confuse it with a cell wall.

Extensive capillary beds



Bronchioles ending in alveoli, each cluster wrapped in capillaries. Patrick J. Lynch, CC BY 2.5.

- Capillaries wrap around each cluster of alveoli
- **Pulmonary artery** branches bring blood low in oxygen, from the right side of the heart
- **Pulmonary vein** branches take oxygen-rich blood to the left side of the heart
- Oxygen dissolves, then diffuses across the wall and into red blood cells
- Carbon dioxide diffuses the other way

Key idea

The capillaries add to the surface area and keep the concentration gradients steep.

Surfactant keeps alveoli open

- Secreted by cells in the alveolar wall
- Lines the moist inner surface of each alveolus
- Made mainly of **phospholipids**
- **Reduces surface tension** in the film of water
- Stops the walls sticking together and the alveolus collapsing during exhalation

Why it matters

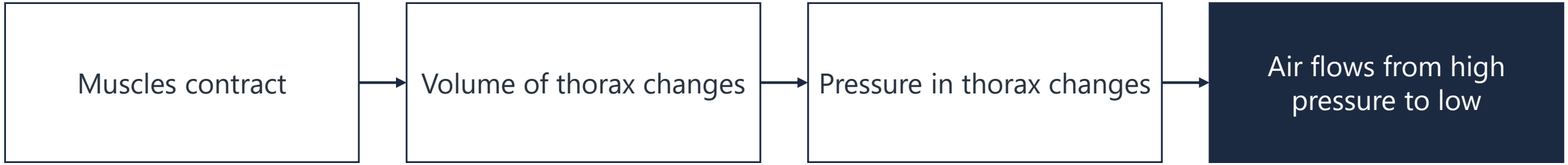
Foetal lungs start making enough surfactant at about five months of pregnancy. Babies born very early can have stiff lungs and may need ventilation support and surfactant treatment.

Exam note

The adaptations you should be able to give are surfactant, a branched network of bronchioles, extensive capillary beds and a high surface area.

Ventilation depends on pressure

B3.1.5



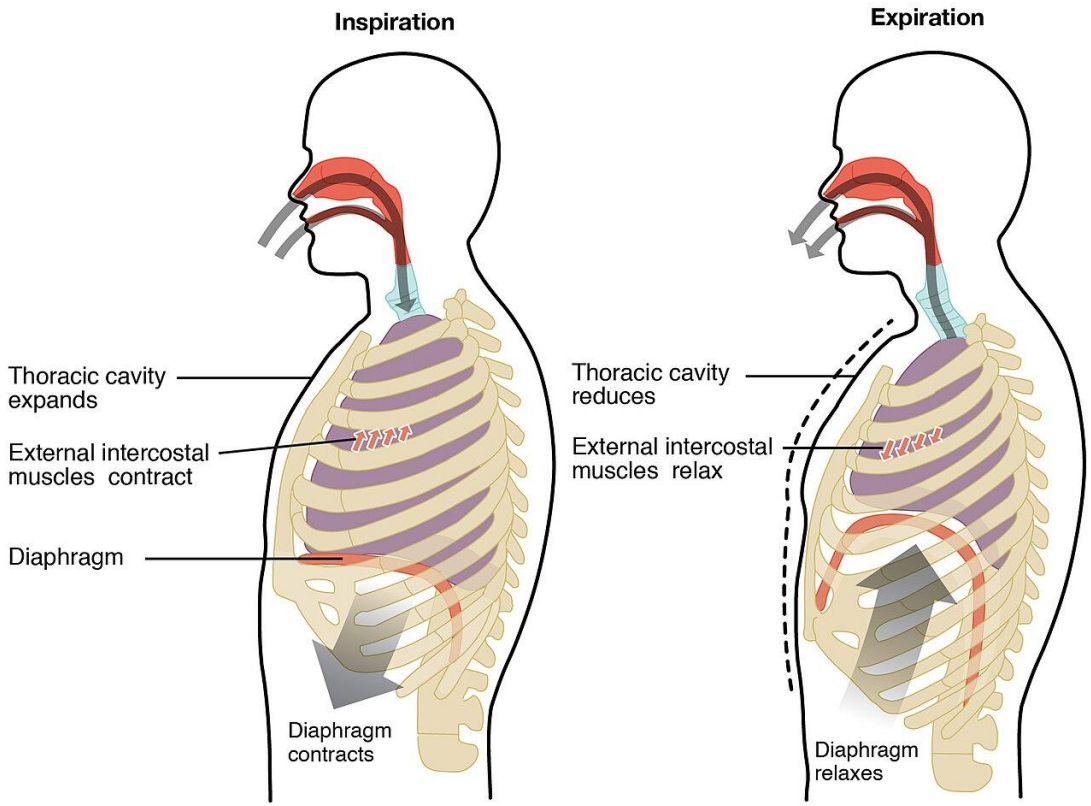
- The thorax is an airtight chamber: its volume decides the pressure inside
- **Ventilation** moves air in and out, to maintain the concentration gradients
- Muscles can only pull when they contract, so moving ribs both ways takes two sets: an **antagonistic pair**

Common mistake

Get cause and effect the right way round. Air coming in does not push the diaphragm down. The diaphragm moves down, pressure falls, and then air enters. Refer to the volume of the thorax, not of the lungs.

Breathing in: inhalation

B3.1.5

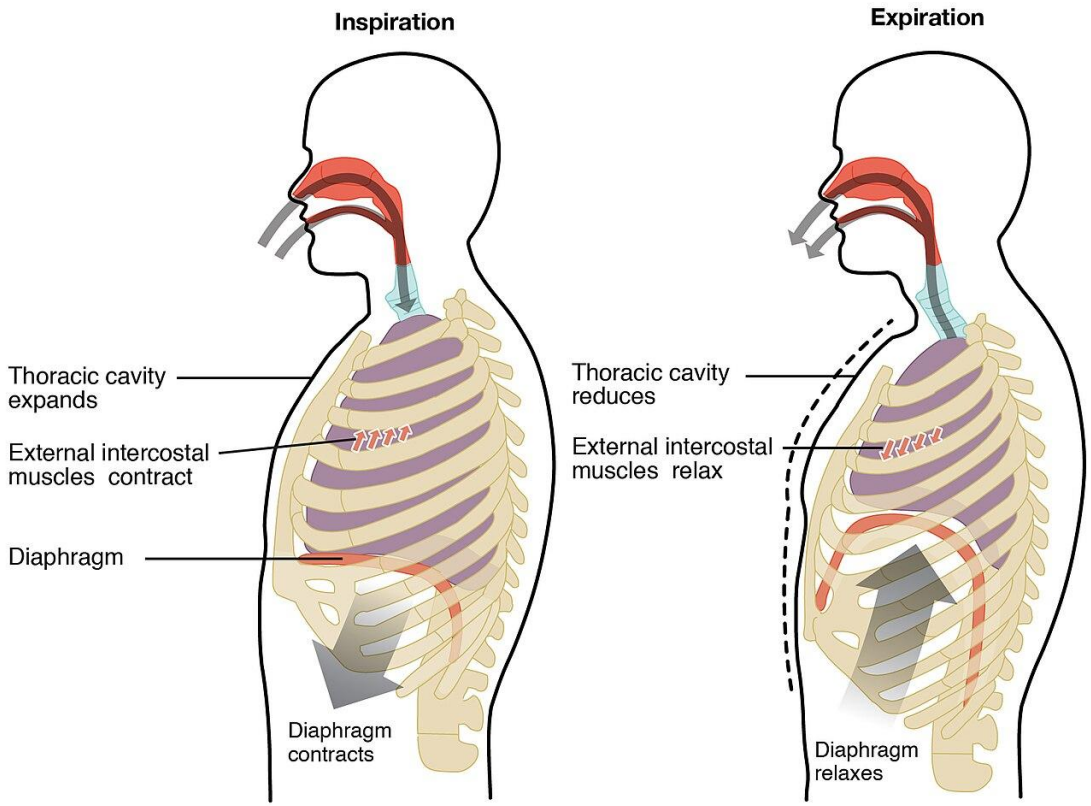


Inspiration (left) and expiration (right). OpenStax College, CC BY 3.0.

1. **Diaphragm** contracts and flattens, moving down
2. **Abdominal muscles** relax, so abdominal contents can move down
3. **External intercostal muscles** contract, and **internal** ones relax
4. **Ribcage** moves up and out
5. Volume of the thorax increases
6. Pressure falls below atmospheric pressure
7. Air flows in

Breathing out: exhalation

B3.1.5



Inspiration (left) and expiration (right). OpenStax College, CC BY 3.0.

1. **Diaphragm** relaxes and returns to a dome
2. **Abdominal muscles** contract, pushing the abdominal contents up, especially in a forced breath
3. **Internal intercostal muscles** contract, and **external** ones relax
4. **Ribcage** moves down and in
5. Volume of the thorax decreases
6. Pressure rises above atmospheric pressure
7. Air flows out

Inhalation and exhalation compared

B3.1.5

	Inhalation	Exhalation
Diaphragm	Contracts, moves down	Relaxes, moves up
Abdominal muscles	Relax	Contract
External intercostals	Contract	Relax
Internal intercostals	Relax	Contract
Ribcage	Up and out	Down and in
Thorax volume	Increases	Decreases
Pressure in thorax	Below atmospheric	Above atmospheric
Air flow	In	Out

How lung volumes are measured

B3.1.6



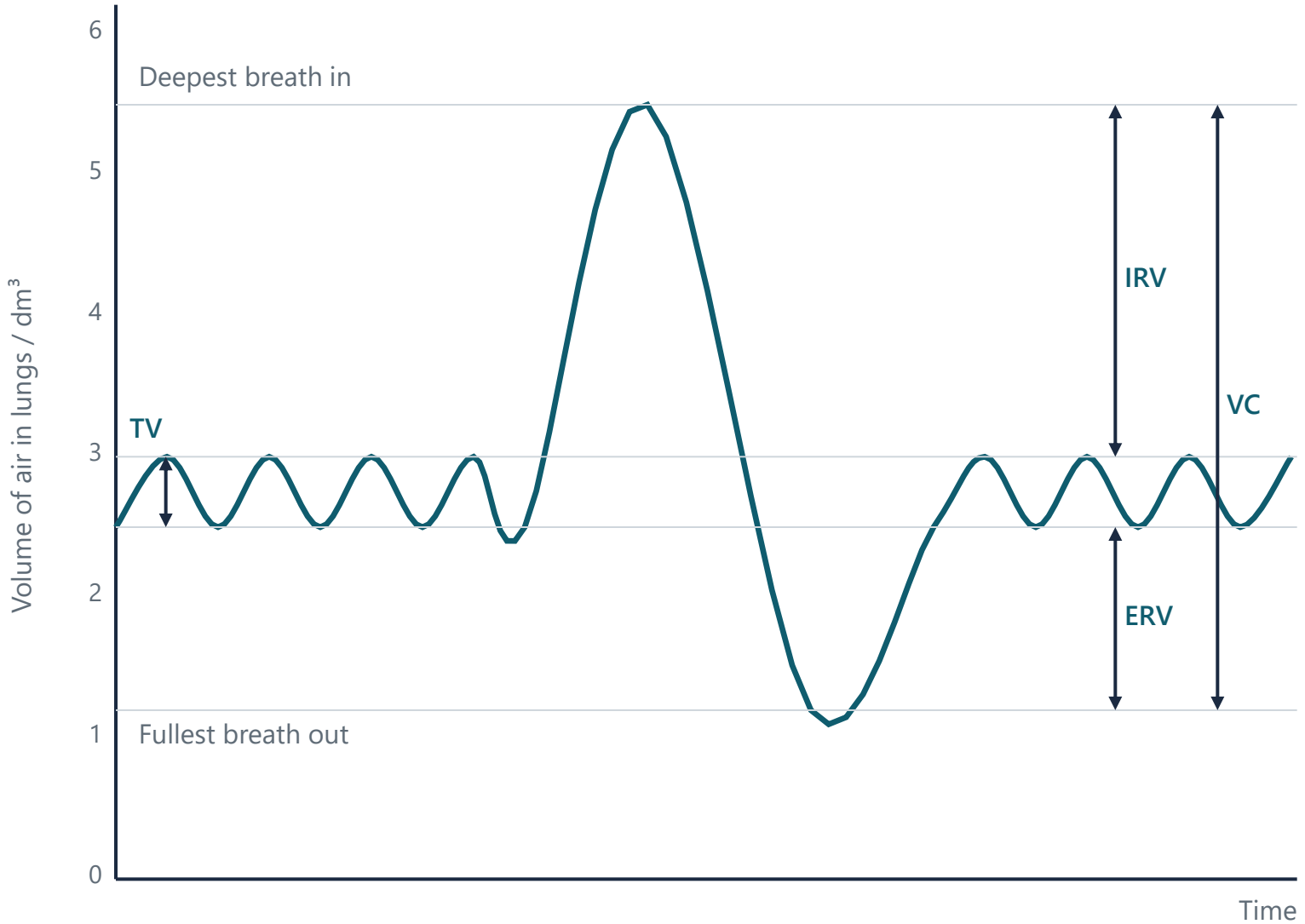
A portable spirometer with disposable mouthpieces. Biswarup Ganguly, CC BY 3.0.

- A **spirometer** records air flow and volume over time
- A data logger with a chest belt can record breathing rate
- A **lung volume bag** collects one breath
- A balloon gives a low-cost estimate
- Breathing out into an inverted, water-filled container: the volume displaced is the volume of air

Why measure?

To compare people at rest and during exercise, to follow lung conditions such as asthma, or to see the effect of training.

Reading a spirometer trace



Schematic trace with typical values.

- **Tidal volume**: one normal breath. About 0.5 dm^3
- **Inspiratory reserve**: extra air breathed in after a normal breath in
- **Expiratory reserve**: extra air breathed out after a normal breath out
- **Vital capacity**: the deepest breath in to the fullest breath out

Equation

VC = TV + IRV + ERV

Here: 0.5 + 2.5 + 1.3 = 4.3 dm^3

Measure your own lung volumes

B3.1.6

1. Breathe out one normal breath into your own balloon
2. Measure the diameter, then find the volume of the sphere: $V = 4/3 \times 3.14 \times r^3$
3. Repeat three times and calculate the mean: this estimates **tidal volume**
4. Take the deepest breath you can and breathe out fully: this estimates **vital capacity**
5. Count breaths for one minute to find the **ventilation rate**

Evaluate

Vital capacity varies with age, body size and activity. How accurate is a balloon? Why are several repeats needed? What might change after exercise?

Safety

Volunteers only. Never share a balloon or a mouthpiece. Stop and sit down if you feel dizzy.

Check that you can explain

1. Why size makes gas exchange harder
2. The four properties of an exchange surface
3. Three ways gradients are maintained
4. How gills are ventilated
5. Four adaptations of the lungs
6. What surfactant does
7. Muscle actions during inhalation and exhalation
8. Cause and effect in ventilation
9. How to read a spirometer trace
10. How to calculate vital capacity

Exit activity: 5 minutes

On your own and without notes. Hand this in as you leave.

1. State two properties of a gas-exchange surface, and how each one helps.

2. A student writes: "Air rushes in and pushes the diaphragm down." Correct this in one sentence.

3. Tidal volume is 0.5 dm^3, inspiratory reserve is 3.0 dm^3 and expiratory reserve is 1.0 dm^3. Calculate the vital capacity.

Image credits

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