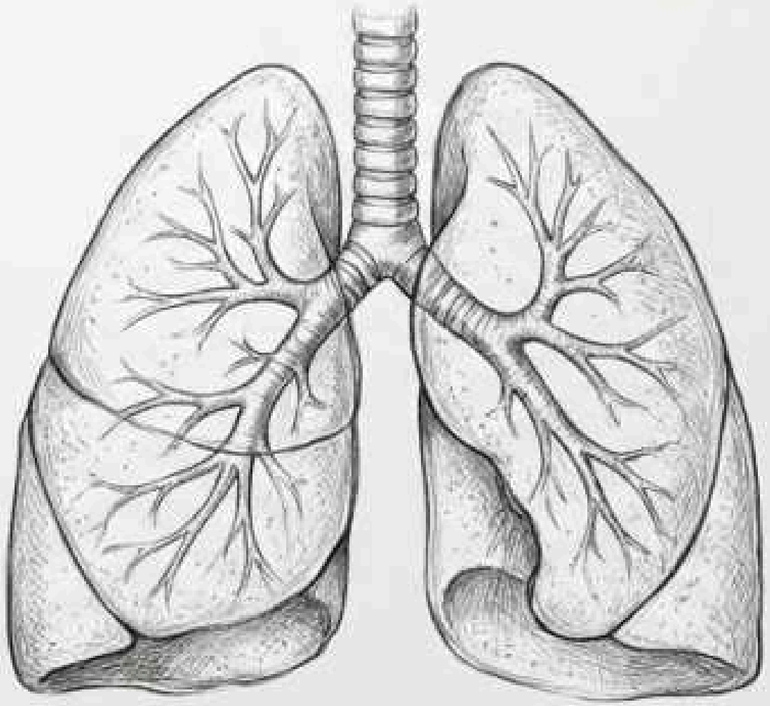
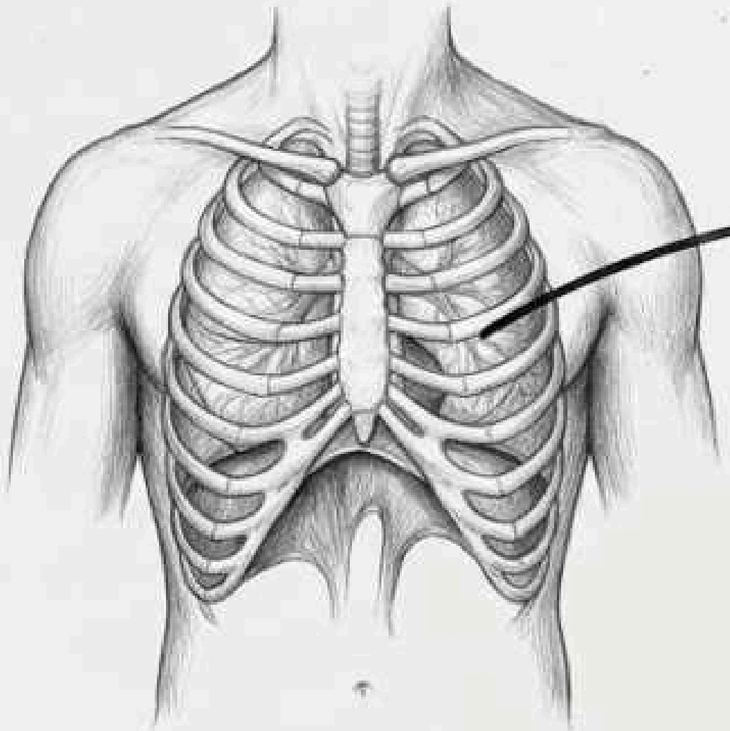
BIO 110 B Lecture 4: Breathing and Gas Exchange

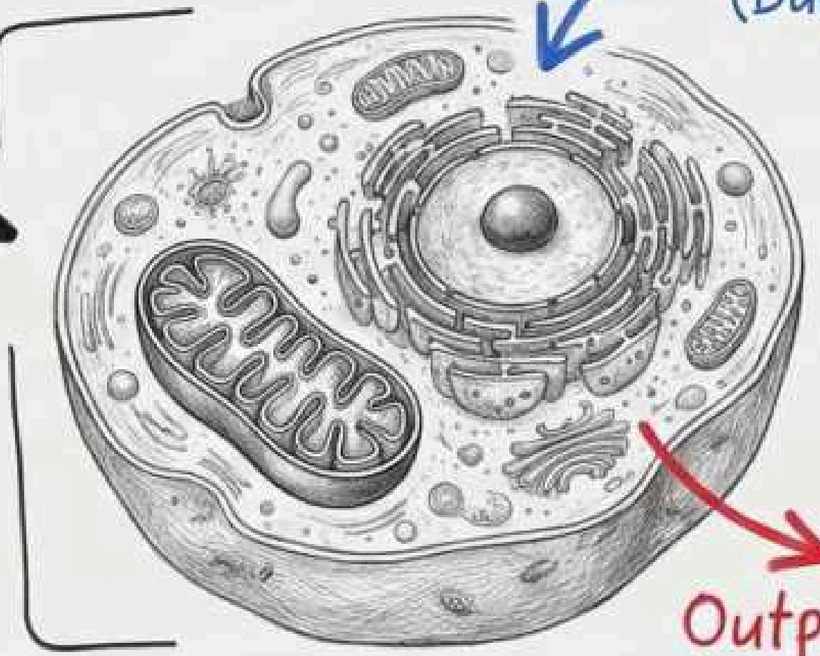


At a glance

- Airways & mechanics of breathing
- Ventilation & gas exchange
- Hemoglobin function
- Neural control of breathing

The respiratory system exists to fuel cellular respiration





$$\text{Fuel} + O_2 \rightarrow \text{Energy} + CO_2$$

The respiratory system supplies the first and removes the second.
We will track this path from the airways to the blood.

Air descends through 23 levels of branchig airways

Nose / Mouth

↓

Larynx (Voice Box)

↓

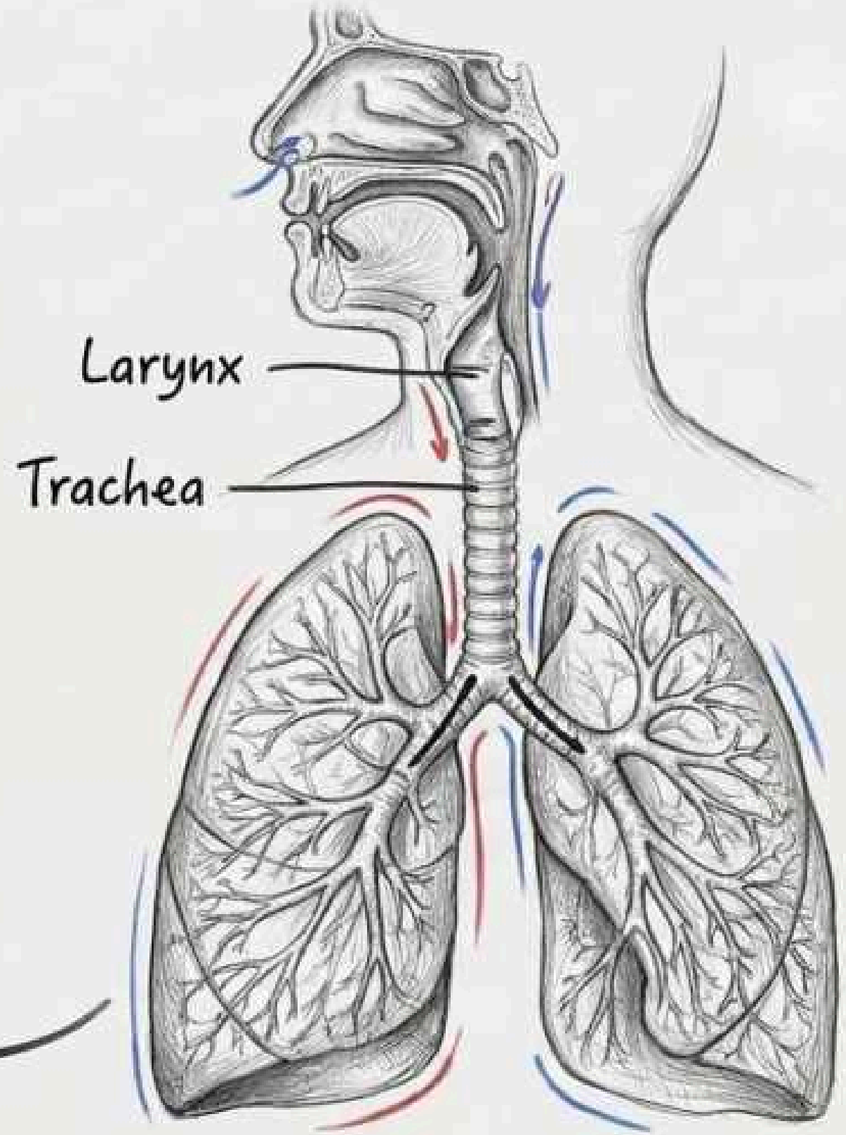
Trachea (Windpipe)

2 Bronchi (one per lung) — 2 Bronchi (one per lung)

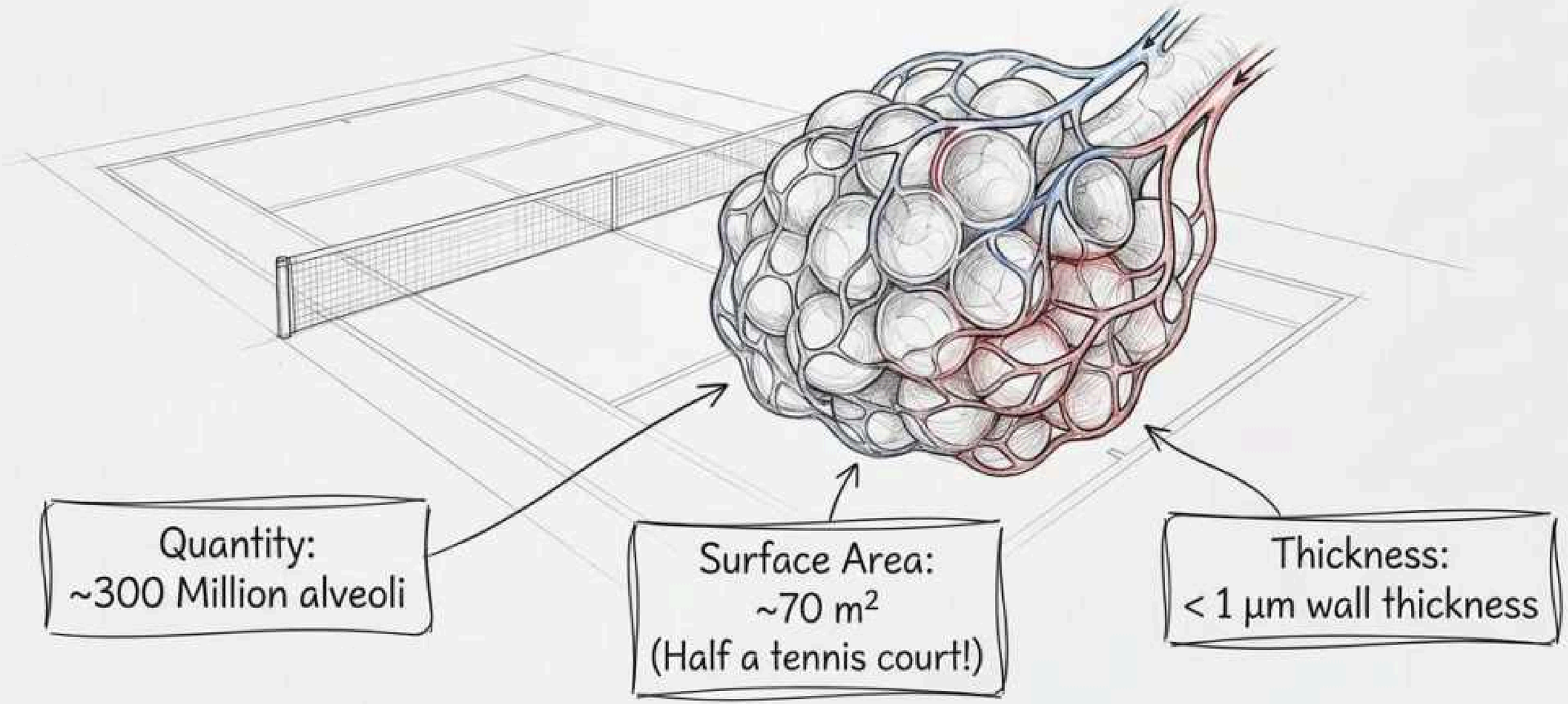
23 levels of branching

Bronchioles

Alveoli (tiny sacs for gas exchange)



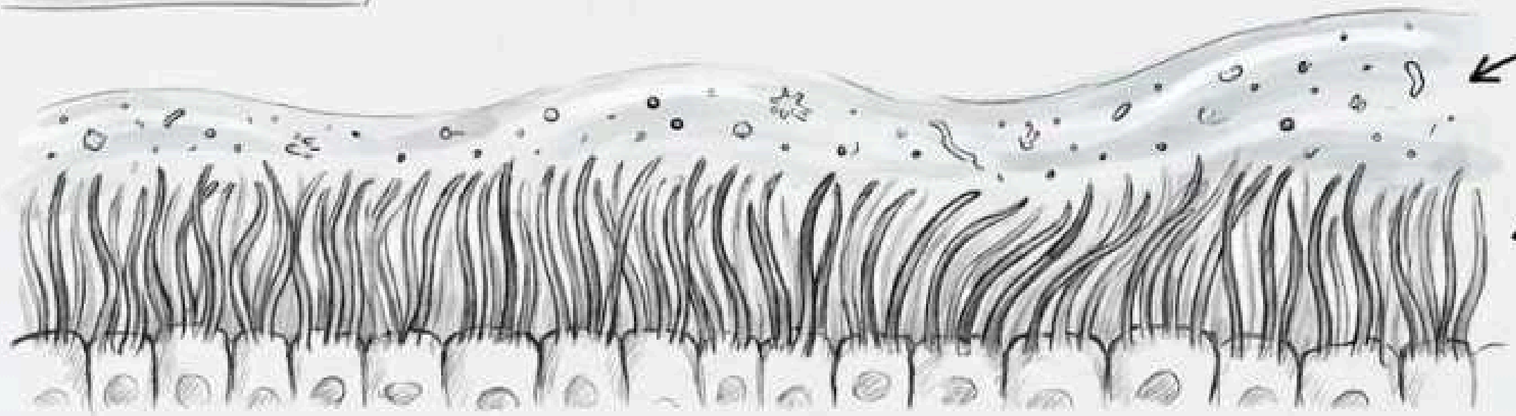
300 million alveoli create massive surface area for exchange



This architecture brings air and blood within a hair's breadth of each other.

The airway defense system cleans, warms, and moistens air

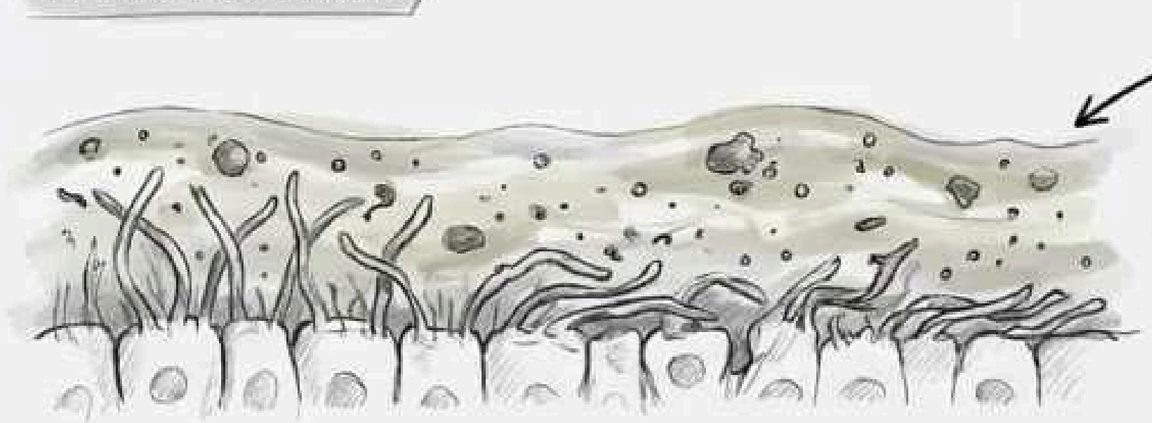
HEALTHY STATE



Mucus: Traps dust and microbes.

Cilia: Sweep mucus upward to the throat to be swallowed or coughed out.

DAMAGED STATE

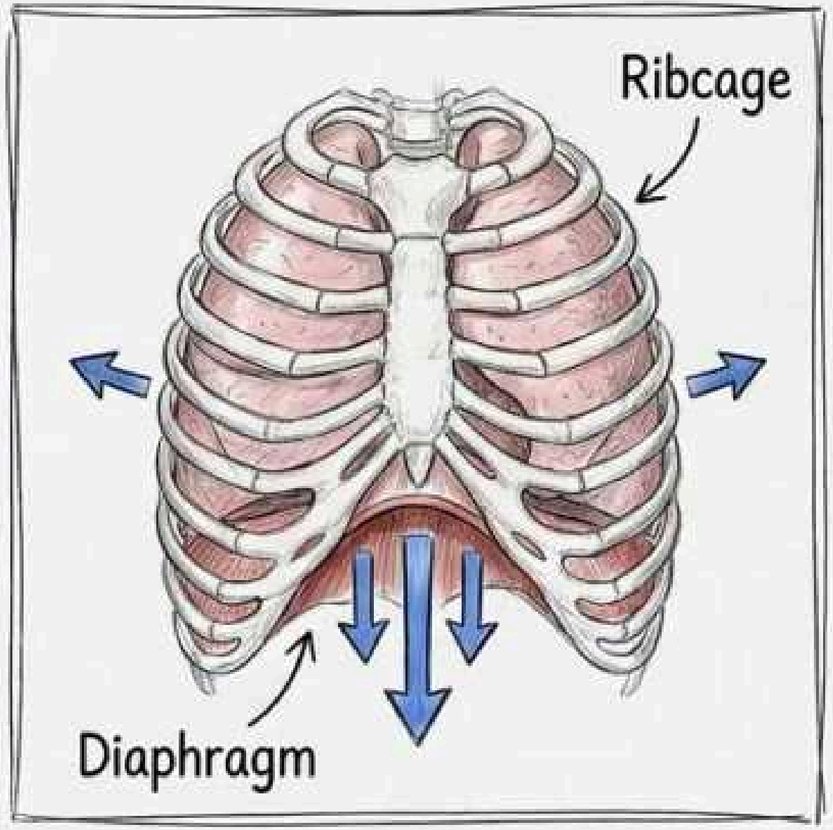


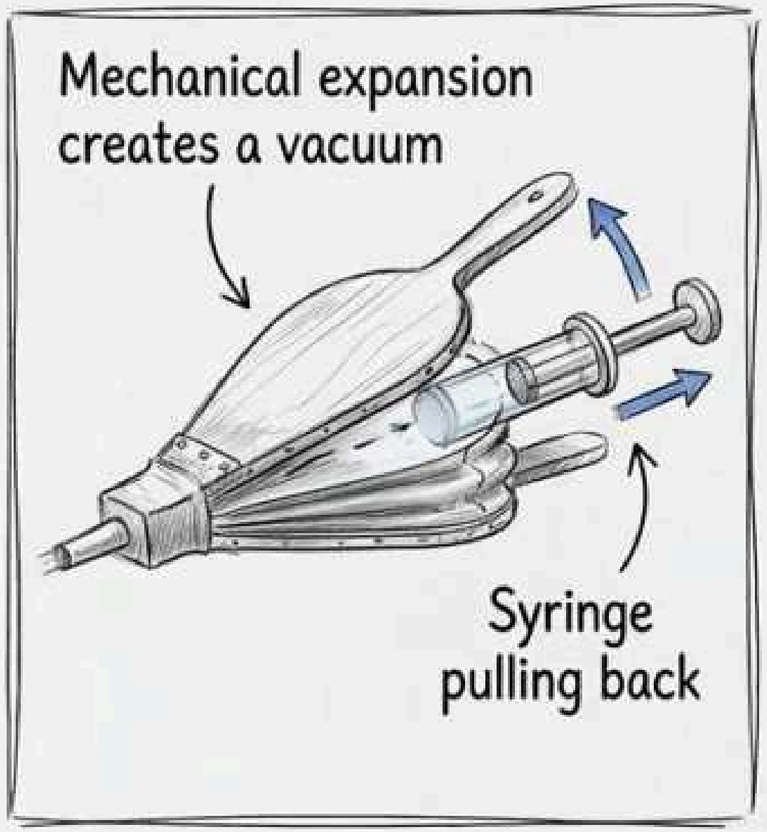


Smoking paralyzes the cilia and damages this upward-sweeping defense, directly leading to increased lung infections.

The lungs have no muscle; they expand via a vacuum

Warning: Lungs do not pull themselves.



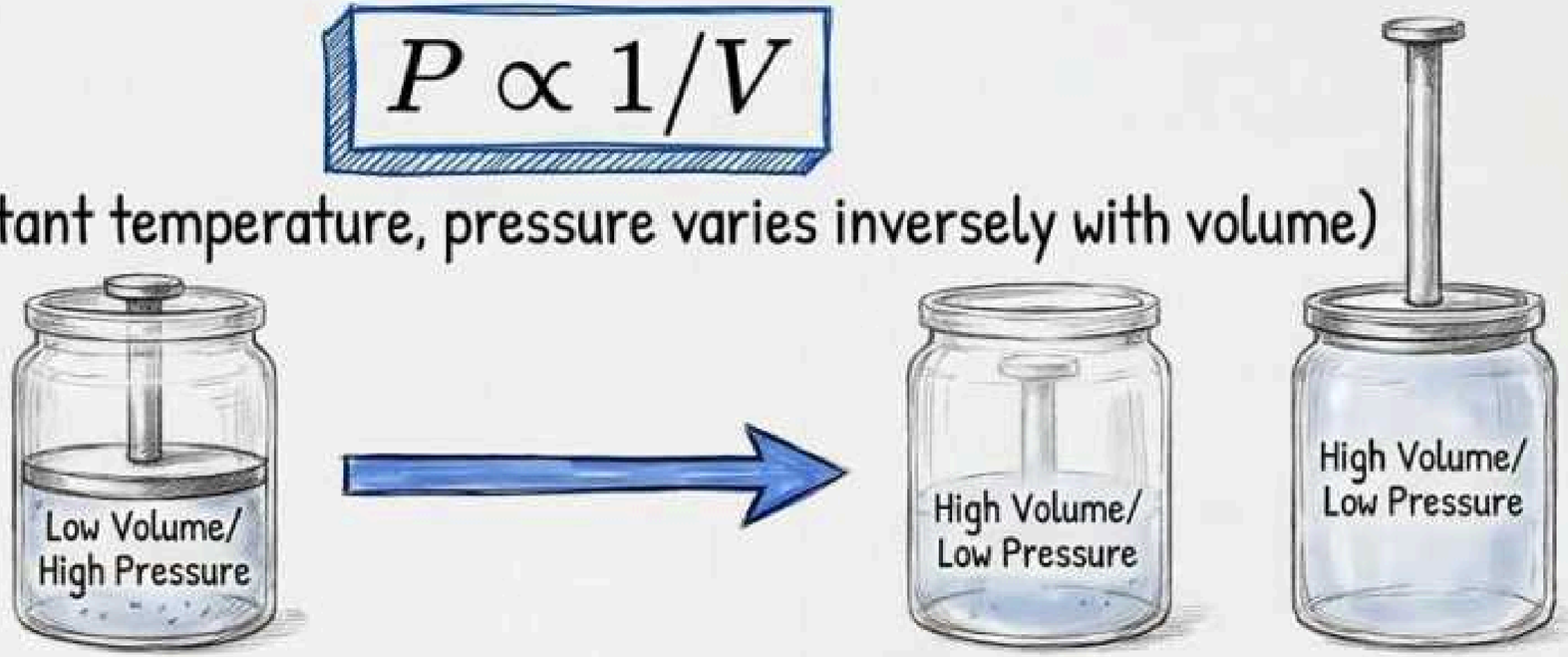


1. Diaphragm (muscle under lungs) contracts & flattens.
2. Rib muscles lift the chest.
3. Chest cavity expands.
4. Lungs expand with the cavity, held to the chest wall by a thin film of fluid.

Boyle's Law drives the inward flow of air

$$P \propto 1/V$$

(At constant temperature, pressure varies inversely with volume)



The Application: Chest Expands (Volume ⇧) → Lung Pressure Drops (⇩)

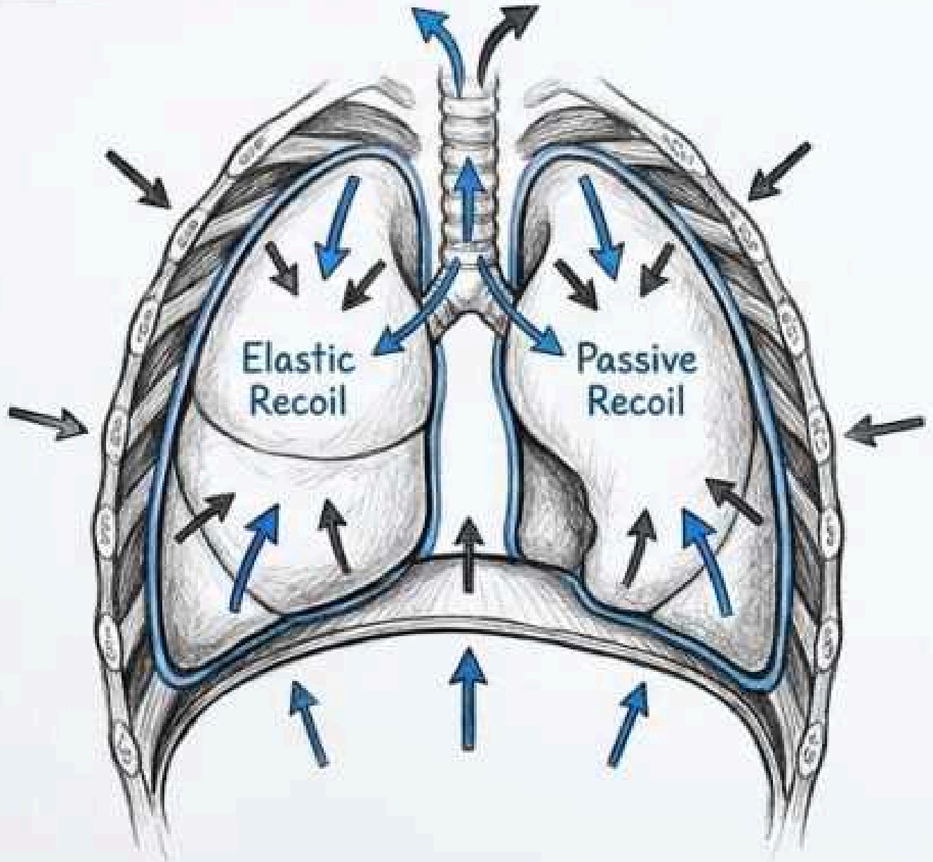
The Result: Pressure drops just ~1 mmHg below atmospheric pressure.
Air flows from higher outside pressure to lower inside pressure.

Volume Moved: This tiny 1 mmHg drop is enough to move 0.5 Liters of air.

Exhalation relies on elastic recoil, but the fluid seal is vulnerable

¶ 4.8

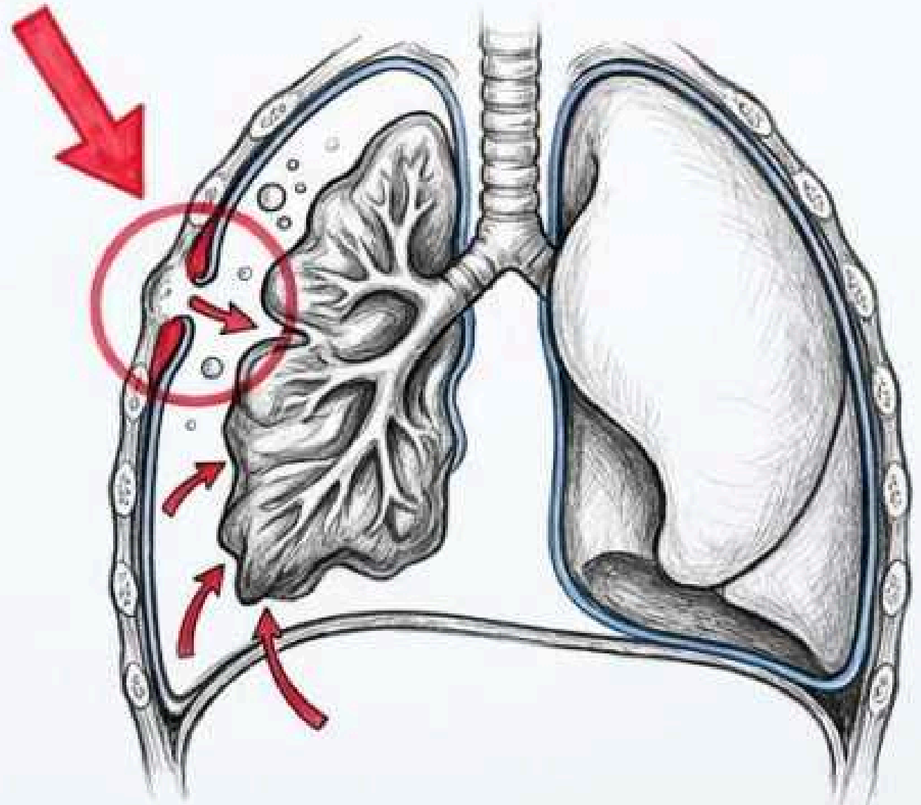
Quiet Exhalation (Passive):



Diaphragm relaxes -> elastic lungs recoil -> volume falls -> pressure rises above atmospheric -> air flows out.

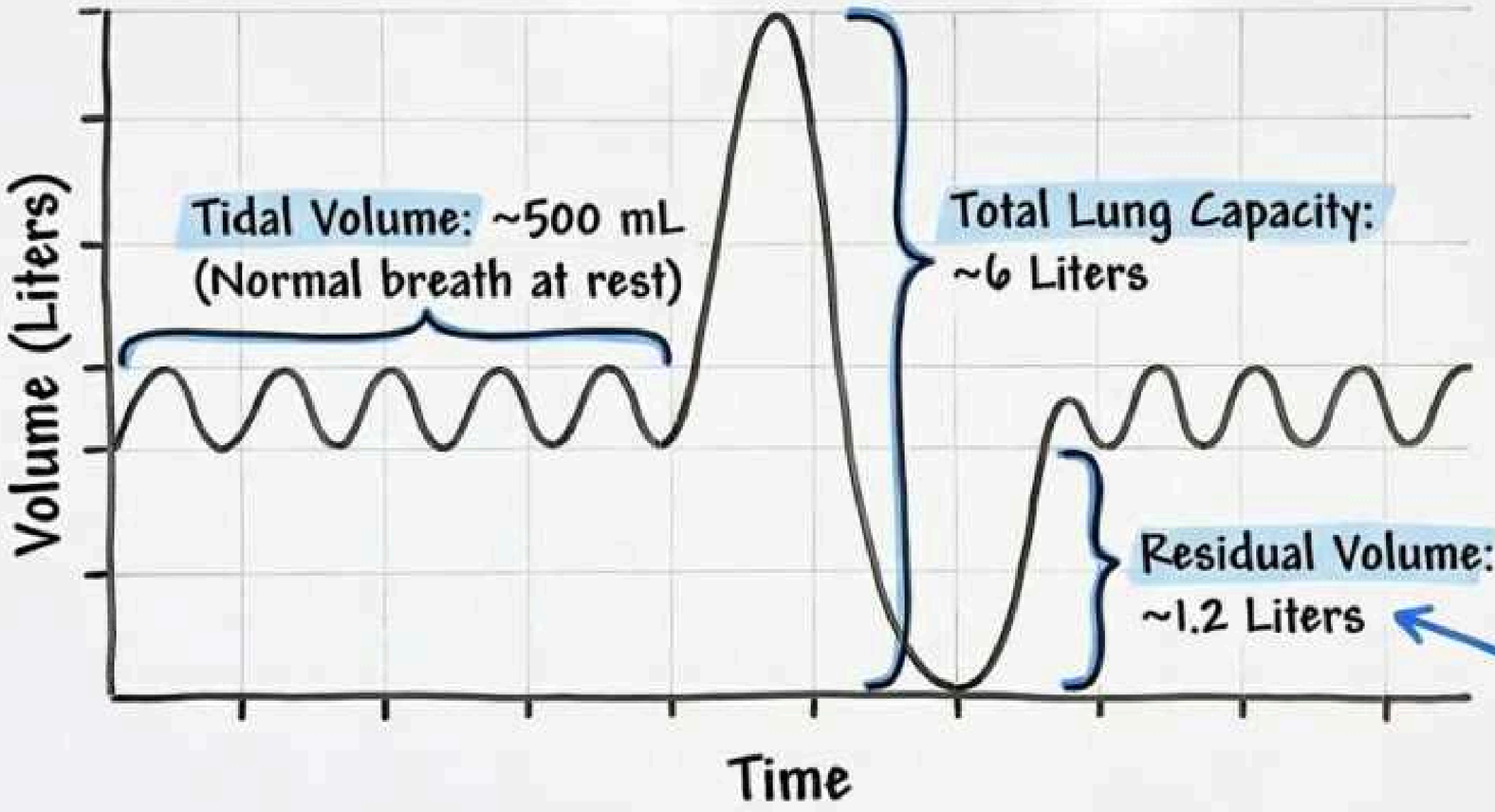
Active Exhalation: Abdominal and chest muscles actively force air out (during exercise or coughing).

Clinical Pathology (Collapsed Lung):



Occurs when air leaks into the thin fluid film, breaking the suction. The lung can no longer be held against the chest wall.

Measuring lung volumes from resting breath to maximum capacity



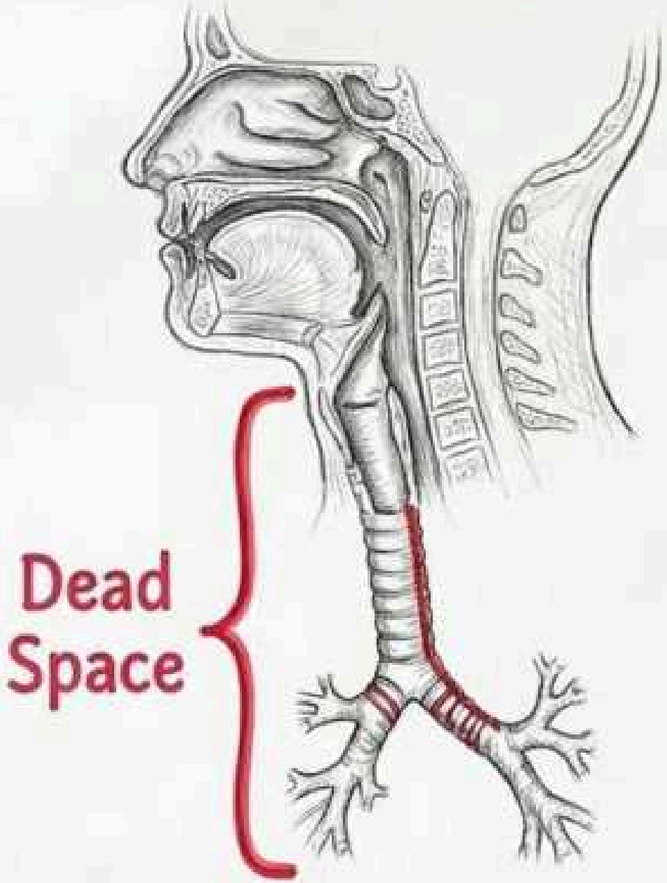
Must stay in the lungs even after the deepest exhalation to prevent the alveoli from collapsing.

Minute ventilation calculates total air, but ignores dead space

Minute Ventilation Calculation:

500 mL (Tidal Volume)
x 12 breaths/min
= 6,000 mL/min (6 L/min)

The Catch: Not all 6 liters reach the alveoli.



Dead Space: The first 150 mL of every breath fills the structural airways. These are useless for gas exchange.

Alveolar ventilation reveals the true volume of exchanged air

Alveolar Ventilation = (Tidal Vol. − Dead Space) × Rate

Normal Deep Breaths	Shallow Rapid Breaths
(500 − 150) × 12	(250 − 150) × 24
⇒ 350 × 12	⇒ 100 × 24
⇒ 4,200 mL/min reaching alveoli.	⇒ 2,400 mL/min reaching alveoli.

(Note: Total ventilation is 6 Liters for both, but effective air air drops massively with shallow breathing).

The Clinical Lesson: Depth matters more than speed



The Core Insight:
Deep breaths are vastly more effective than quick, shallow ones. The same total volume of air yields very different physiological results.

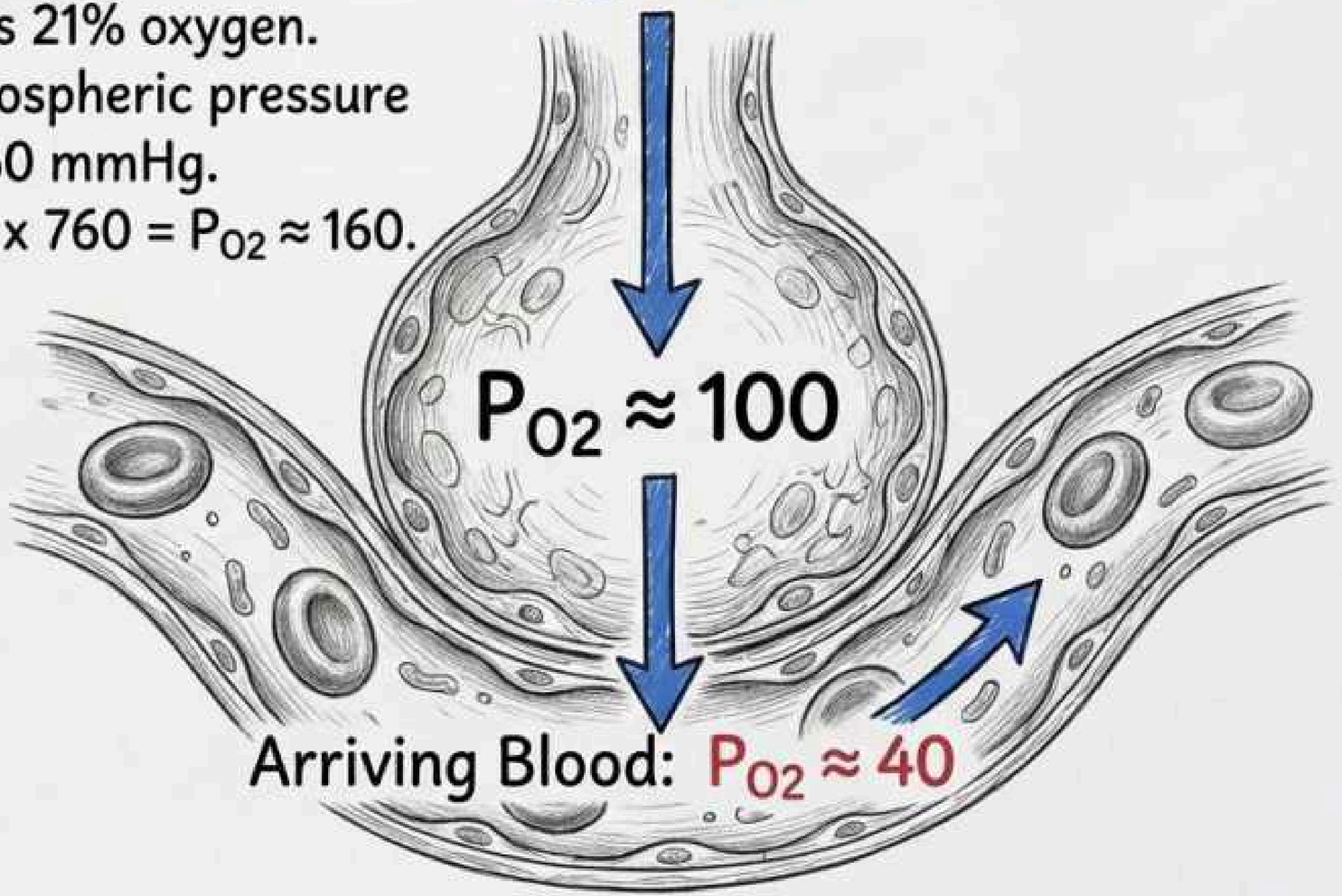
The True Metric:
What matters is not how much total air moves, but how much fresh air actually reaches the exchange surface.

Application:
Doctors utilize this principle when judging whether a patient is truly breathing well, looking past mere chest rise and fall.

Oxygen diffuses down a steep pressure gradient

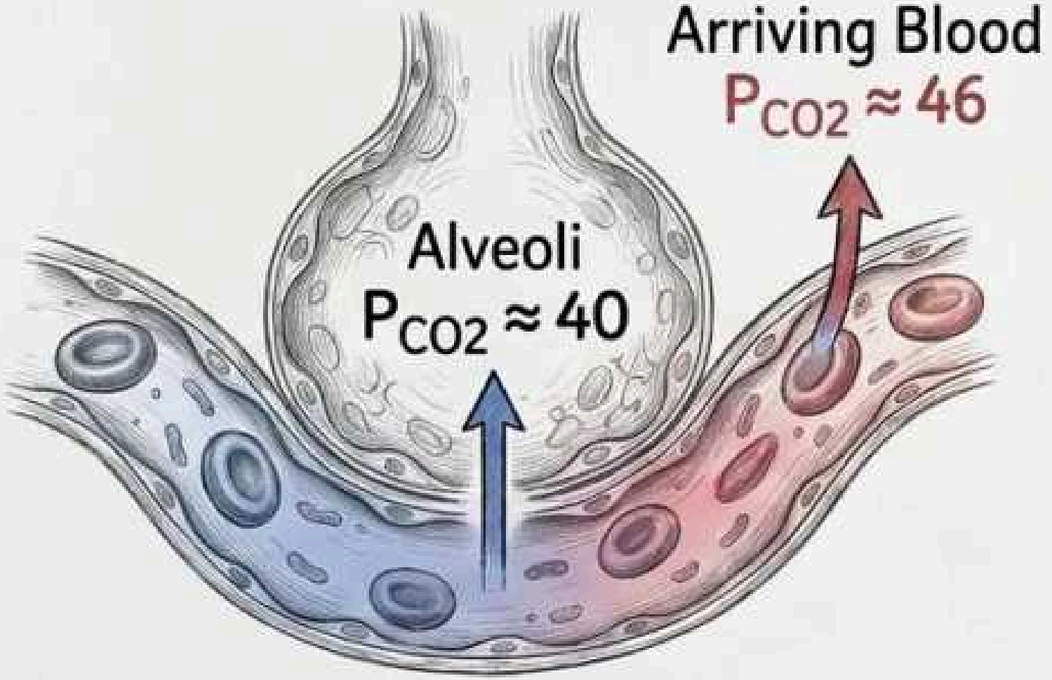
The Rule:
Gases move entirely by diffusion, from High partial pressure to Low.

Atmosphere (Sea Level): $P_{O2} \approx 160$
Air is 21% oxygen.
Atmospheric pressure is 760 mmHg.
$0.21 \times 760 = P_{O2} \approx 160$.



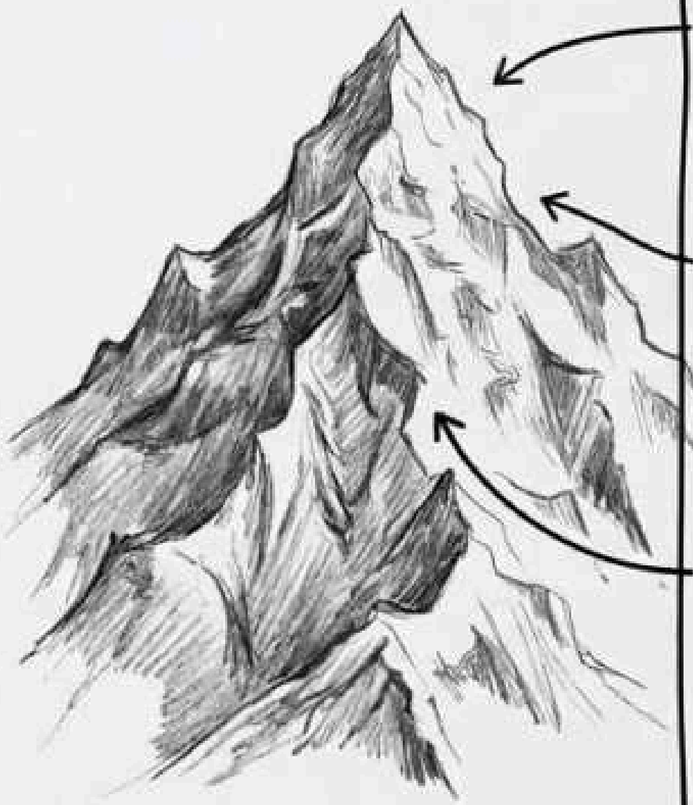
Carbon dioxide diffuses easily, but altitude destroys oxygen's drive

CO_2 Gradient



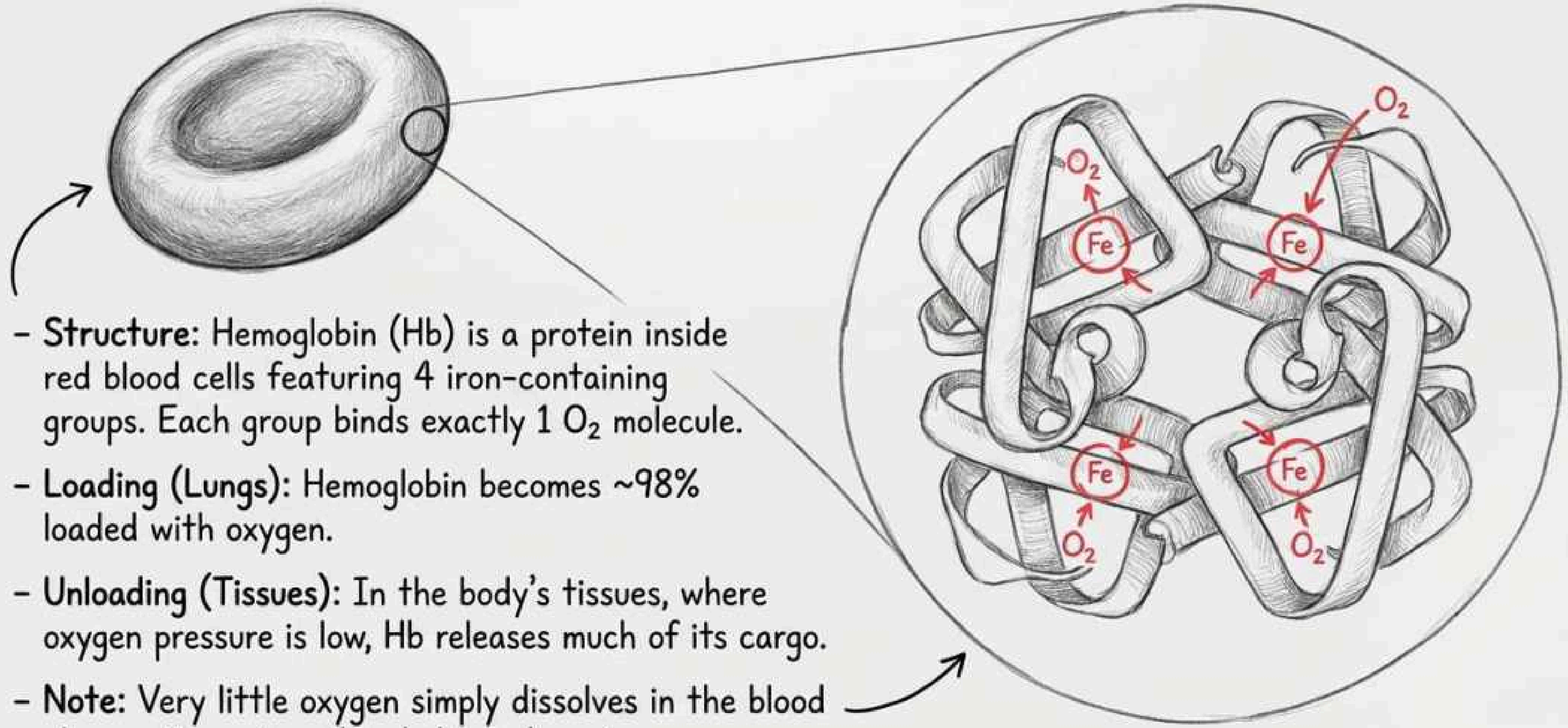
The gradient runs the other way. The 6-point difference is small, but CO_2 diffuses so easily it is enough.

The Altitude Effect



- Atop Mt. Everest, total air pressure plummets to ~250.
- Oxygen's partial pressure drops to only 53 (compared to 160 at sea level).
- Result: The difference driving oxygen into the blood is drastically reduced.

Hemoglobin acts as the blood's dedicated oxygen carrier



- **Structure:** Hemoglobin (Hb) is a protein inside red blood cells featuring 4 iron-containing groups. Each group binds exactly 1 O_2 molecule.
- **Loading (Lungs):** Hemoglobin becomes ~98% loaded with oxygen.
- **Unloading (Tissues):** In the body's tissues, where oxygen pressure is low, Hb releases much of its cargo.
- **Note:** Very little oxygen simply dissolves in the blood plasma; it requires this dedicated carrier.

Calculating the immense carrying capacity of hemoglobin

15 grams of Hb per 100 mL of blood.

1 gram carries 1.34 mL of O_2.

$$15\ g\ Hb \times 1.34\ mL\ O_2$$

$$\rightarrow = 20\ mL\ O_2 \text{ per } 100\ mL \text{ of blood}$$

$$= 200\ mL\ O_2$$

per Liter of blood

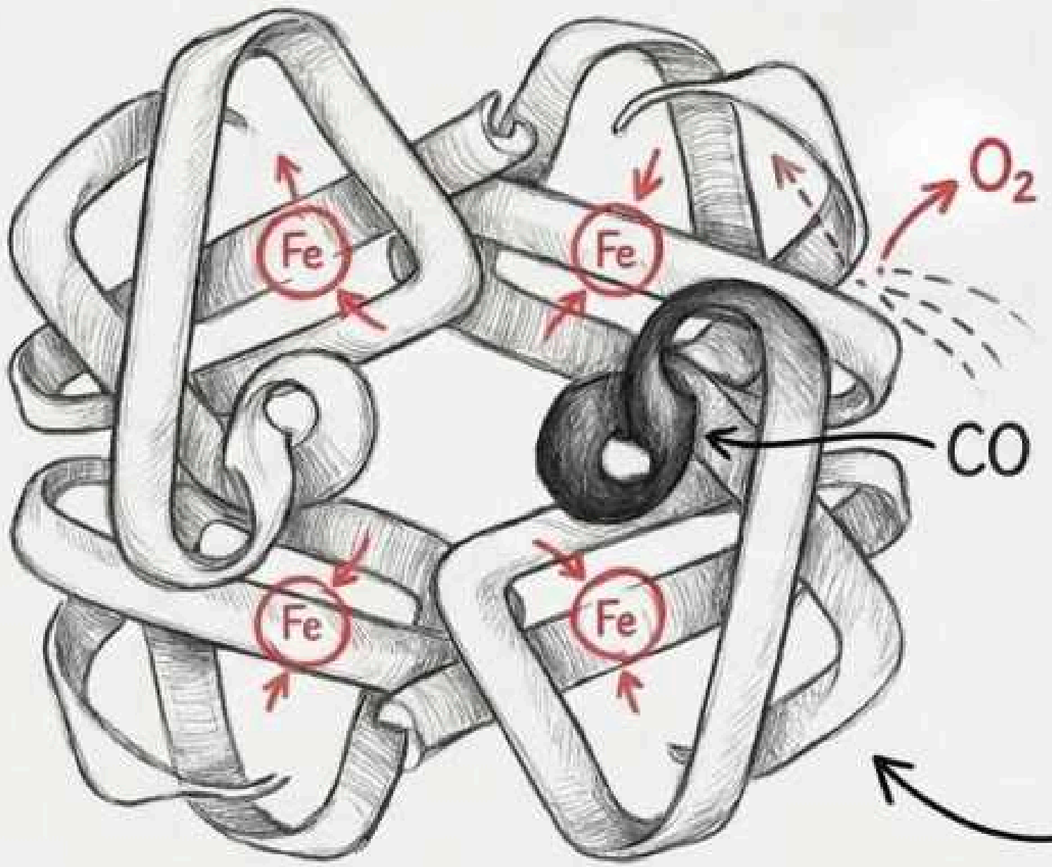
Total bound oxygen = 200 mL per Liter.

Dissolved oxygen = only 3 mL per Liter.

Carbon Monoxide exploits hemoglobin's binding sites

The Danger of CO:

- Binds to Hemoglobin more than 200 times as tightly as Oxygen.
- Even small amounts amounts block hemoglobin from carrying oxygen. Colorless and odorless—home detectors are critical life-saving tools.

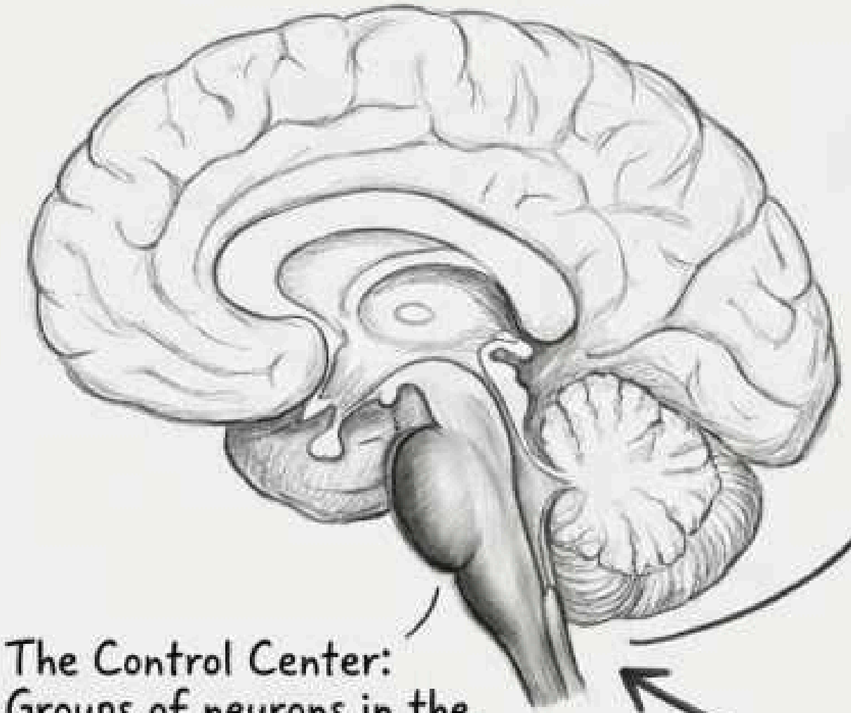


Meanwhile, CO_2 Transport:

- Unlike oxygen, most carbon dioxide does not rely heavily on hemoglobin.
- It travels through the blood primarily as bicarbonate.

¶ 4.18

The brainstem monitors carbon dioxide to set the breathing rhythm



The Control Center: Groups of neurons in the medulla (brainstem) automatically set the breathing rhythm.

The Primary Sensor Feedback Loop:

1. CO_2 levels rise in the blood.
2. Blood becomes more acidic.
3. Sensors detect acidity and trigger the medulla to breathe faster.

(Note: Low oxygen is a secondary trigger, usually only mattering if it has fallen drastically).

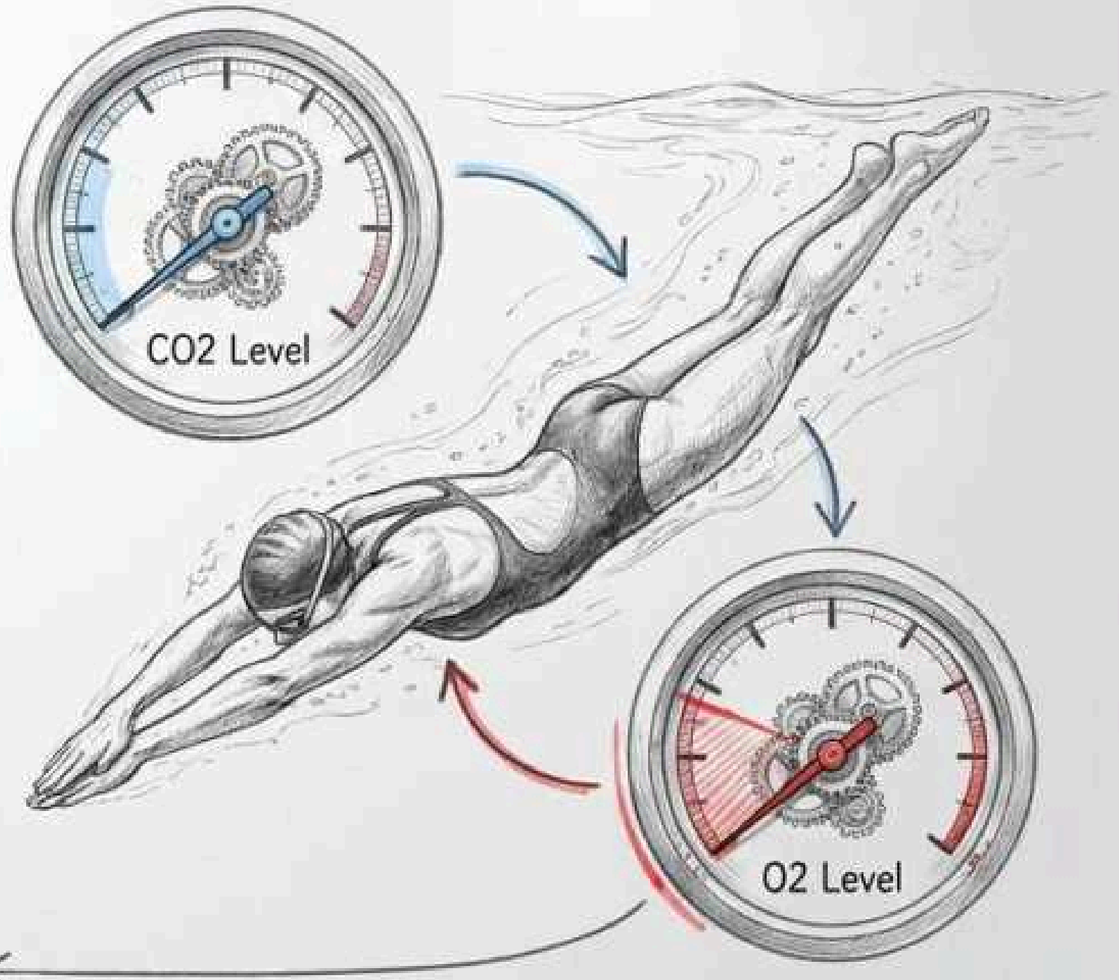
Why hyperventilating before swimming is uniquely dangerous

The Urge to Breathe:

- Driven by rising CO2 (acidity), not by falling O2. This causes the burning lungs feeling when holding your breath.

The Hyperventilation Trap:

- Overbreathing beforehand 'blows off' CO2, starting the swimmer with artificially low levels.
- The normal urge to breathe is removed or delayed.
- Oxygen can drop too far before the brain sounds the alarm, causing the swimmer to faint underwater without warning.



Lecture 4 Problem Set: Calculate the ventilation

Scenario 1:

A person takes 15 breaths/min, each 400 mL (Tidal Volume).
Dead space is 150 mL.

Minute ventilation = 6000 mL/min ?

Alveolar ventilation = 3750 mL/min ?

Scenario 2:

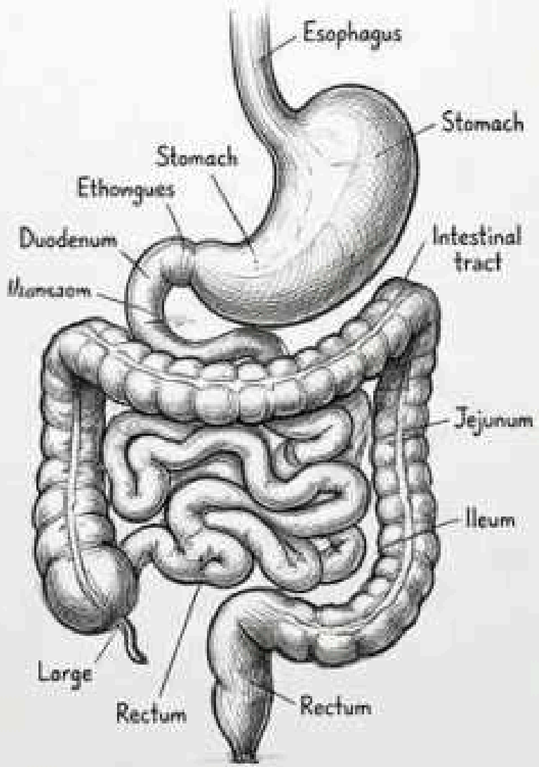
The person starts breathing 30 shallower breaths of 200 mL each.

New alveolar ventilation = 1500 mL/min ?

Coming up: Turning from oxygen to the fuel itself

✓ Lecture 4: Oxygen

Lecture 5 Preview: With the oxygen delivery system mapped, we now explore how the body processes the fuel it burns.



Lecture 5
Next Topics: Digestion, Metabolism, and the Balance of Energy.