Respiration and Gas Exchange

Matthew Williams • Biology • May 9, 2026

Respiration and Gas Exchange

Every living cell needs energy to carry out its processes. Respiration is the set of chemical reactions that releases this energy from food molecules. It should not be confused with breathing — breathing is the physical movement of air in and out of the lungs, while respiration is the biochemical process that happens inside cells.

Aerobic Respiration

Aerobic respiration uses oxygen to break down glucose completely, releasing a large amount of energy. It takes place mainly in the mitochondria.

Word equation:

glucose + oxygen ’carbon dioxide + water (+ energy released as ATP)

Balanced chemical equation:

C₆H₁₂O₆ + 6O₂ ’ 6CO₂ + 6H₂O

ATP

ATP (adenosine triphosphate) is the molecule that transfers energy within cells. When a cell needs energy, ATP is broken down to ADP, releasing usable energy at the site where it is needed. Cells use ATP for:

- muscle contraction
- active transport across membranes
- protein synthesis
- cell division
- nerve impulse transmission
- maintaining body temperature

Aerobic respiration produces far more ATP per glucose molecule than anaerobic respiration.

Anaerobic Respiration

Anaerobic respiration releases energy from glucose without oxygen. The yield of ATP is much lower than aerobic respiration, and waste products accumulate.

	In animal muscle cells	In yeast
Equation	glucose ’lactic acid	glucose ’ethanol + carbon dioxide
ATP yield	small	small
Waste product	lactic acid	ethanol + CO,
Application	sprinting, heavy exercise	bread-making, brewing

During intense exercise, muscles may not receive oxygen quickly enough. Anaerobic respiration provides ATP temporarily, but lactic acid builds up. This causes muscle fatigue and pain. After exercise, extra oxygen is consumed to break down lactic acid — this extra oxygen consumption is called the **oxygen debt**.

Yeast fermentation is used industrially: carbon dioxide from fermentation makes bread rise, and ethanol produced during fermentation is the basis of alcoholic beverages.

Aerobic vs Anaerobic Comparison

Feature	Aerobic	Anaerobic
Oxygen required	yes	no
Glucose fully broken down	yes	no
ATP produced	large amount	small amount
Waste products	CO,and water	lactic acid (animals) or ethanol + CO,(yeast)
Location	mitochondria	cytoplasm
Duration	sustained	short-term only

Gas Exchange Surfaces

Gas exchange is the movement of respiratory gases (oxygen and carbon dioxide) between an organism and its environment. For efficient diffusion, gas exchange surfaces share common features:

Feature	Why it matters
Large surface area	allows more gas to diffuse simultaneously
Thin walls	short diffusion distance
Moist surface	gases dissolve before diffusing through the membrane
Good blood supply (in animals)	maintains steep concentration gradient; carries gases away quickly
Ventilation	replaces stale air to maintain gradient (in air-breathing organisms)

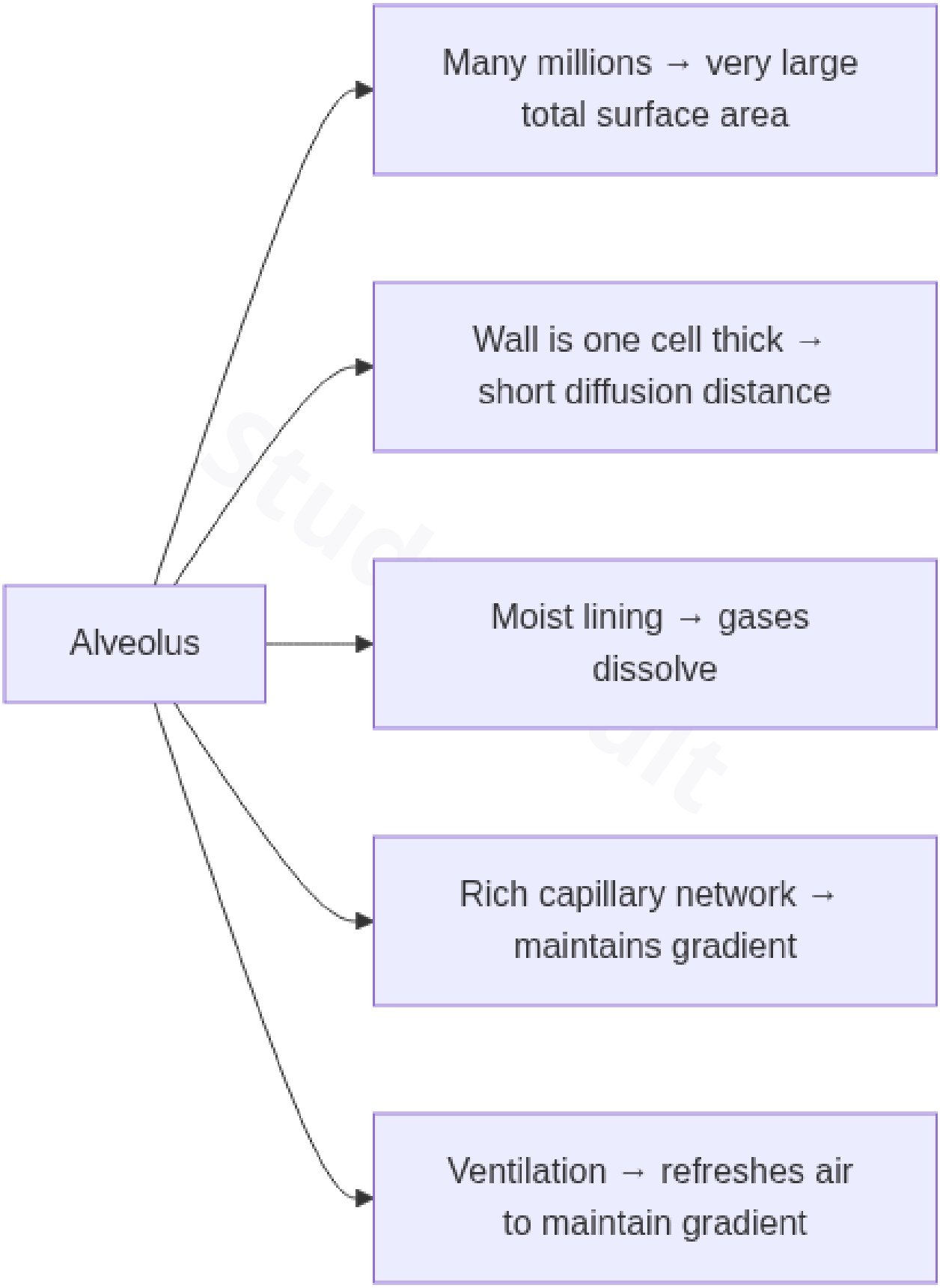
Human Gas Exchange

The Respiratory System

Air passes through: nasal cavity ’pharynx ’larynx ’trachea ’bronchi ’bronchioles ’alveoli.

The **trachea** has C-shaped rings of cartilage that keep it open. It is lined with ciliated epithelium and mucus-producing goblet cells — cilia sweep mucus and trapped particles upward toward the throat.

The **alveoli** are the site of gas exchange in the lungs. Each alveolus is a tiny air sac surrounded by capillaries.



Alveolus adaptations for gas exchange

Breathing Mechanism

Breathing is the physical process of moving air into and out of the lungs, controlled by the diaphragm and intercostal muscles.

Stage	Diaphragm	Intercostal muscles	Chest volume	Pressure	Air movement
Inhalation	contracts (flattens)	contract (ribs move up and out)	increases	decreases	air flows in
Exhalation	relaxes (domes up)	relax (ribs move down and in)	decreases	increases	air flows out

Air moves from high pressure to low pressure — the same principle as diffusion, but at the level of the whole lung.

Composition of Air

Gas	Inhaled	Exhaled
Oxygen	~21%	~16%
Carbon dioxide	~0.04%	~4%
Nitrogen	~78%	~78%
Water vapour	low (variable)	high (saturated)

The differences reflect gas exchange at the alveoli: oxygen is absorbed and carbon dioxide is added. Nitrogen is not used.

Gas Exchange in Plants

Plants exchange gases through **stomata** — pores mainly on the lower surface of leaves, controlled by **guard cells**. Guard cells change shape when they gain or lose water, opening or closing the stomatal pore.

During the day (when photosynthesis is active):

- CO,diffuses in through stomata for photosynthesis
- O,produced by photosynthesis diffuses out
- Water vapour also diffuses out (transpiration)

At night (no photosynthesis, only respiration):

- O,diffuses in for respiration
- CO,produced by respiration diffuses out

The spongy mesophyll layer has large air spaces that allow gas to circulate between cells before reaching the stomata.

> 📝 **Exam Tip**
> A common exam question asks whether a plant photosynthesises or respires at night. Plants respire continuously — day and night. During bright daylight, photosynthesis is much faster than respiration, so the net effect is CO,uptake. At night there is no photosynthesis, so only respiration occurs.

Effects of Smoking

Tobacco smoke contains hundreds of harmful substances. The three most important for CSEC are nicotine, tar, and carbon monoxide.

Substance	Effects
Nicotine	addictive; raises heart rate and blood pressure; constricts blood vessels
Tar	settles in airways; contains carcinogens (cancer-causing chemicals); paralyses cilia so mucus accumulates
Carbon monoxide	binds to haemoglobin irreversibly, reducing oxygen-carrying capacity of blood

Smoking-related diseases

Disease	Description
Chronic bronchitis	inflammation of the airways; excess mucus production; persistent cough; cilia damaged by tar cannot clear mucus
Emphysema	alveoli walls break down; fewer, larger air spaces; greatly reduced surface area; shortness of breath
Lung cancer	carcinogens in tar cause uncontrolled cell division in lung tissue
Cardiovascular disease	nicotine and carbon monoxide damage blood vessels and reduce oxygen delivery; increases risk of heart attack and stroke

Remember

Tar damages cilia ’mucus builds up ’bacteria are not cleared ’risk of infection increases. This cycle explains smoker's cough and increased susceptibility to chest infections.

PRACTICE — RESPIRATION AND GAS EXCHANGE

Aerobic respiration

The breakdown of glucose using oxygen to produce CO, water, and a large yield of ATP.

Anaerobic respiration

The breakdown of glucose without oxygen; produces lactic acid in animals or ethanol and CO,in yeast.

ATP

Adenosine triphosphate; the molecule that transfers energy within cells.

Oxygen debt

The extra oxygen consumed after exercise to break down accumulated lactic acid.

Alveoli

Tiny air sacs in the lungs adapted for efficient gas exchange: thin walls, large surface area, moist, well-supplied with capillaries.

Inhalation

Active process; diaphragm contracts and flattens; intercostal muscles contract; thoracic volume increases; pressure falls; air enters.

Exhalation

Passive process at rest; diaphragm and intercostal muscles relax; thoracic volume decreases; pressure rises; air leaves.

Stomata

Pores in the leaf epidermis through which gases and water vapour are exchanged.

Guard cells

Cells that surround a stoma and control its opening and closing.

Nicotine

Addictive substance in tobacco that raises heart rate and blood pressure.

Tar
Substance in tobacco smoke that contains carcinogens and paralyses cilia, allowing mucus and pathogens to accumulate.

Emphysema
A smoking-related disease in which alveoli walls break down, reducing gas exchange surface area.