CHAPTER 3: RESPIRATION

Respiration is the set of processes that allows animals to obtain oxygen from their environment and eliminate carbon dioxide. Oxygen supports cellular energy production, while carbon dioxide must be removed as a waste product of metabolism. Different animals accomplish this through skin, gills, tracheal systems, or lungs.

2. Respiration is more than breathing

In an animal with lungs and a blood-based transport system, respiration involves several connected processes:

Process	Meaning
Ventilation	Movement of air into and out of the lungs.
External gas exchange	Movement of oxygen and carbon dioxide between the lungs and blood.
Gas transport	Delivery of oxygen to tissues and return of carbon dioxide to the lungs through the blood.
Internal gas exchange	Exchange of gases between blood and body tissues.
Cellular respiration	Cellular reactions that use oxygen in aerobic energy production and generate carbon dioxide.

Breathing supplies the lungs with air, but oxygen must still cross the respiratory membrane, travel to tissues, and reach the cells that use it. These are distinct steps, not interchangeable terms.

For mammals, the overall pathway is:

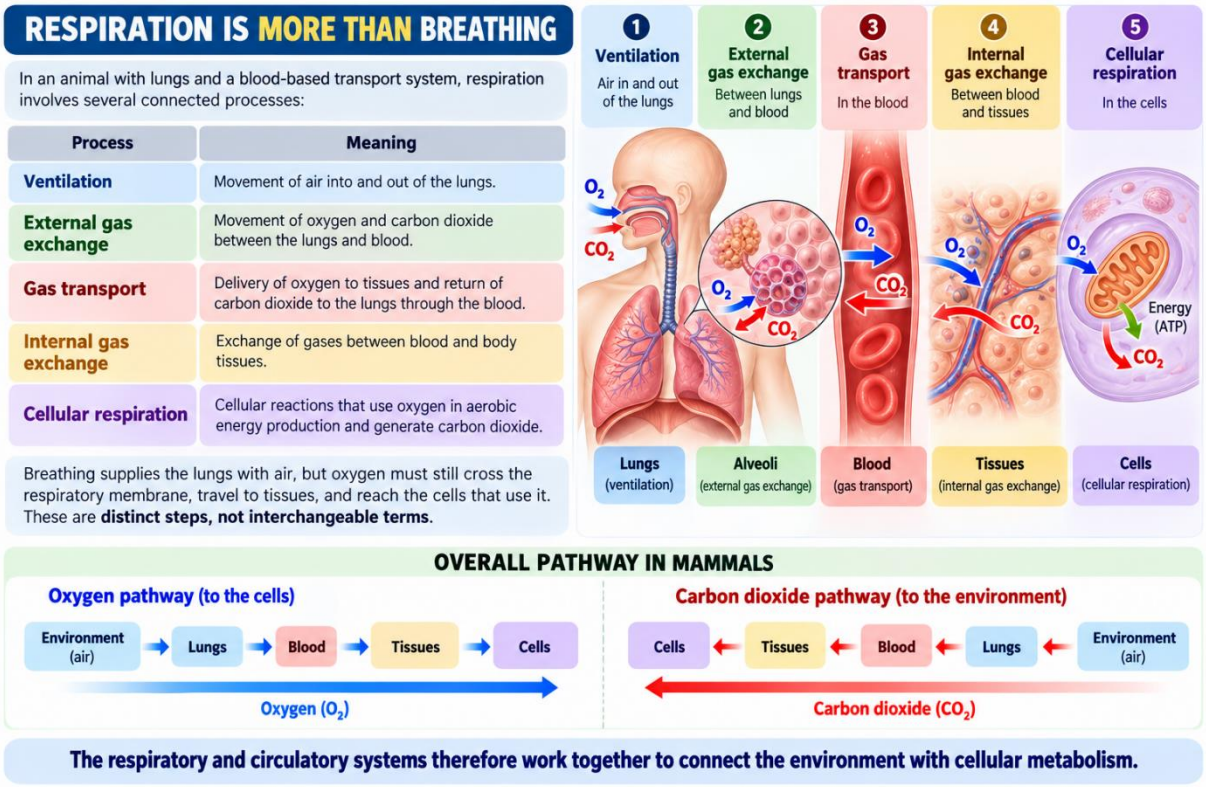
Oxygen:

Environment → lungs → blood → tissues → cells

Carbon dioxide:

Cells → tissues → blood → lungs → environment

The respiratory and circulatory systems therefore work together to connect the environment with cellular metabolism.



3. The basic principle: diffusion

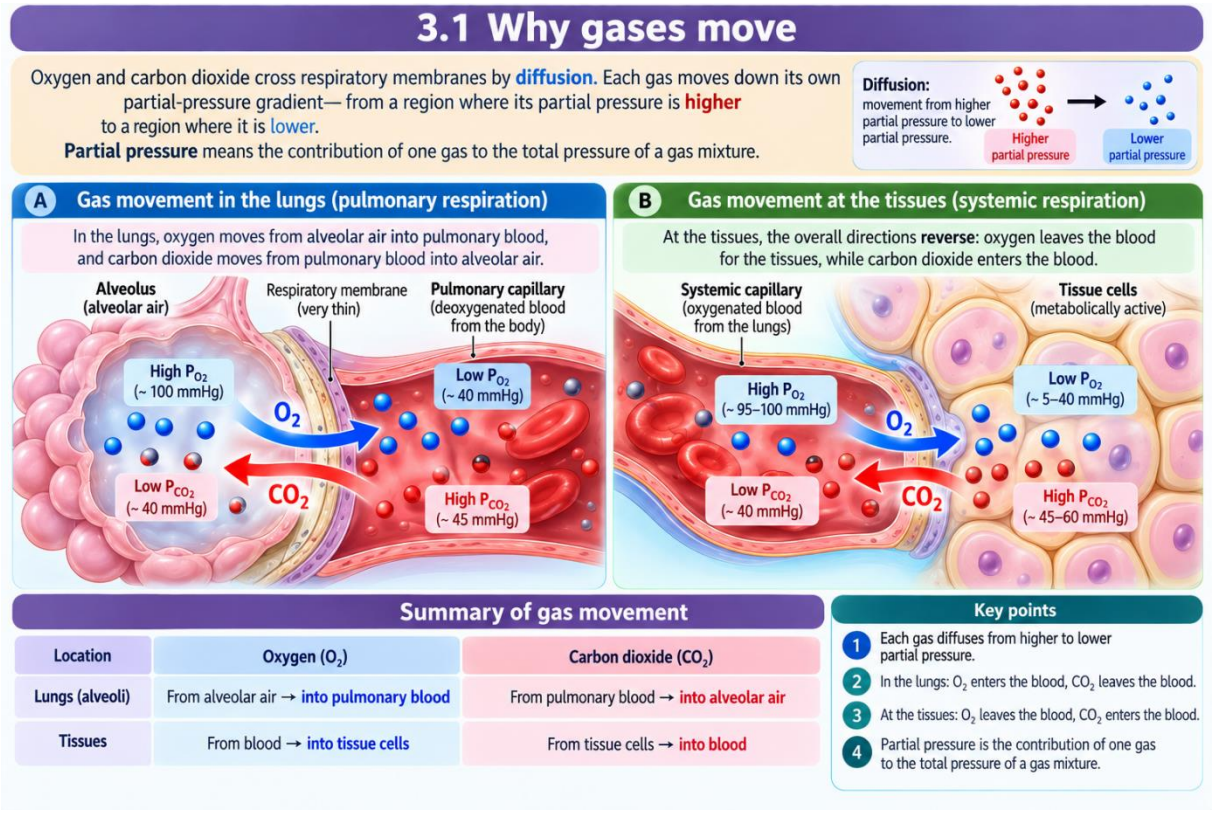
3.1 Why gases move

Oxygen and carbon dioxide cross respiratory membranes by diffusion. Each gas moves down its own partial-pressure gradient—from a region where its partial pressure is higher to a region where it is lower. Partial pressure means the contribution of one gas to the total pressure of a gas mixture.

In mammalian lungs:

- Oxygen moves from alveolar air into pulmonary blood.
- Carbon dioxide moves from pulmonary blood into alveolar air.

At the tissues, the overall directions reverse: oxygen leaves the blood for the tissues, while carbon dioxide enters the blood for transport back to the lungs.

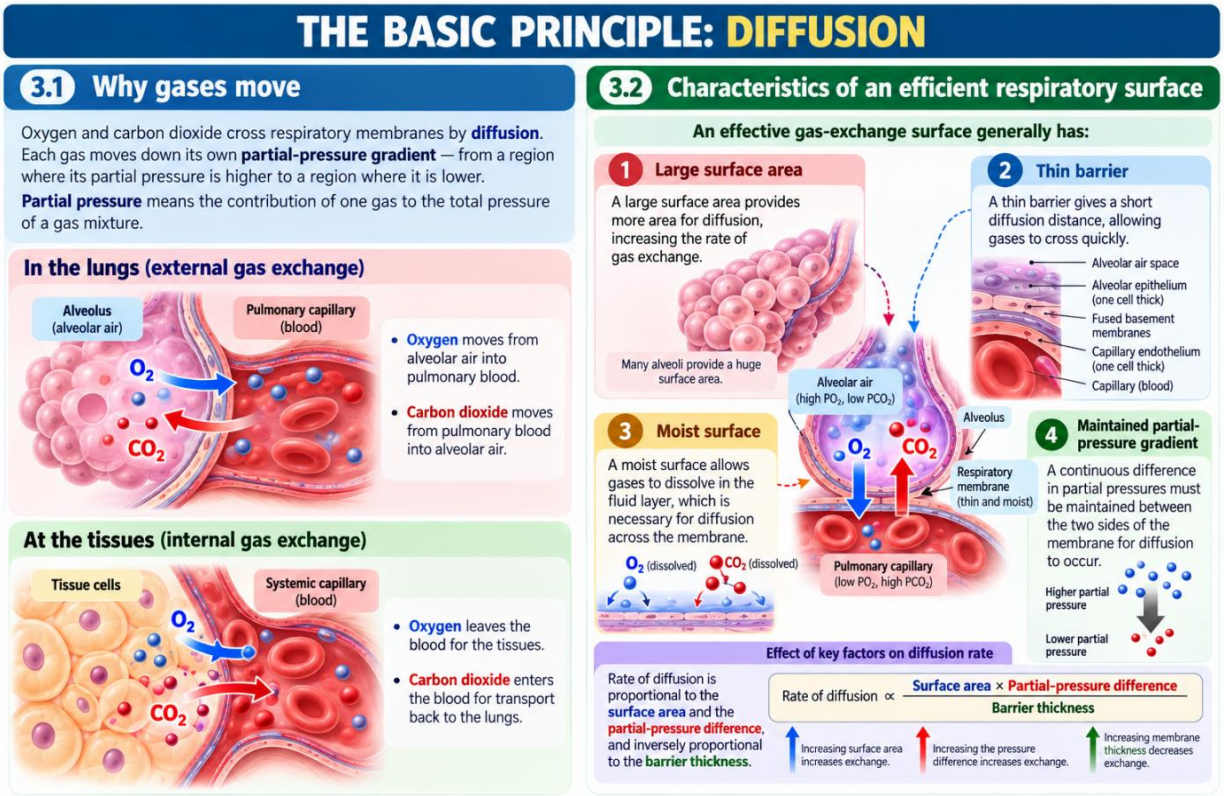


3.2 Characteristics of an efficient respiratory surface

An effective gas-exchange surface generally has:

1. A large surface area.
2. A thin barrier, giving a short diffusion distance.
3. A moist surface, allowing gases to dissolve.
4. A maintained partial-pressure gradient.

Thus, increasing surface area or the pressure difference improves exchange, while increasing membrane thickness slows it.

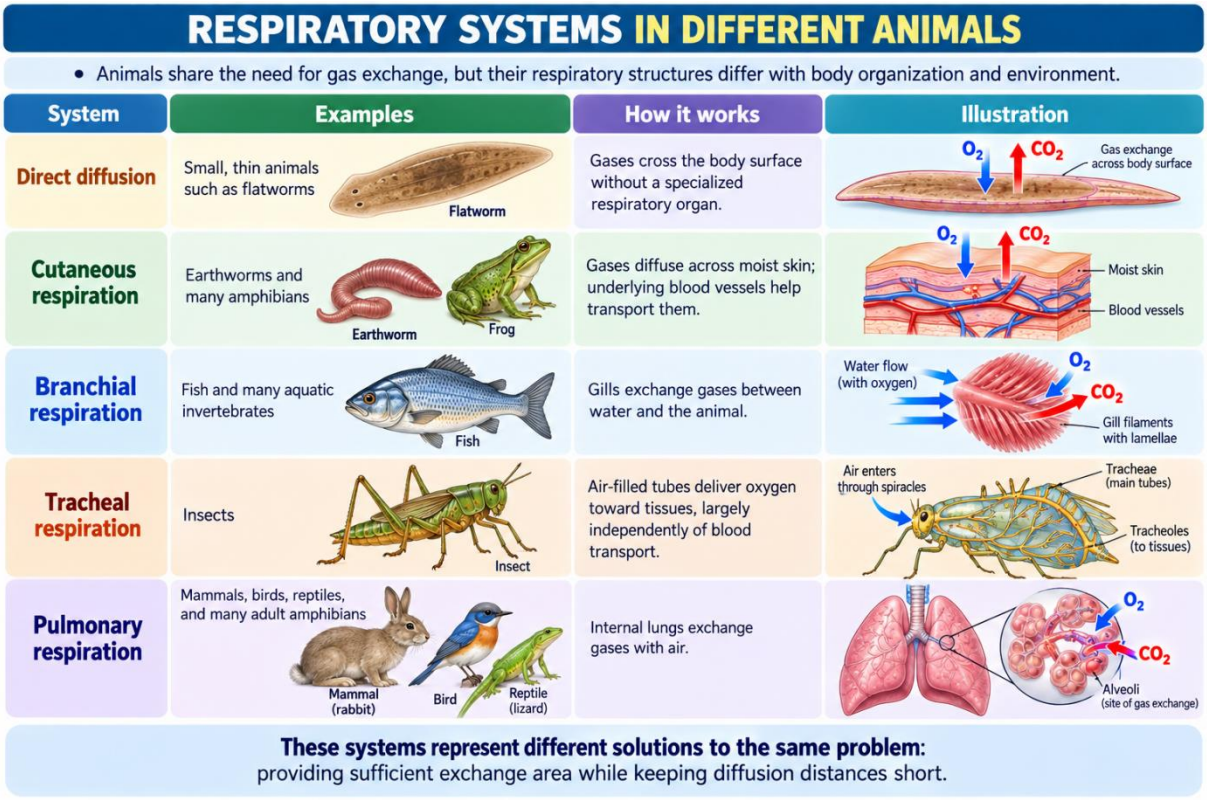


4. Respiratory systems in different animals

- Animals share the need for gas exchange, but their respiratory structures differ with body organization and environment.

System	Examples	How it works
Direct diffusion	Small, thin animals such as flatworms	Gases cross the body surface without a specialized respiratory organ.
Cutaneous respiration	Earthworms and many amphibians	Gases diffuse across moist skin; underlying blood vessels help transport them.
Branchial respiration	Fish and many aquatic invertebrates	Gills exchange gases between water and the animal.
Tracheal respiration	Insects	Air-filled tubes deliver oxygen toward tissues, largely independently of blood transport.
Pulmonary respiration	Mammals, birds, reptiles, and many adult amphibians	Internal lungs exchange gases with air.

These systems represent different solutions to the same problem: providing sufficient exchange area while keeping diffusion distances short.



4.1 Gills: obtaining oxygen from water

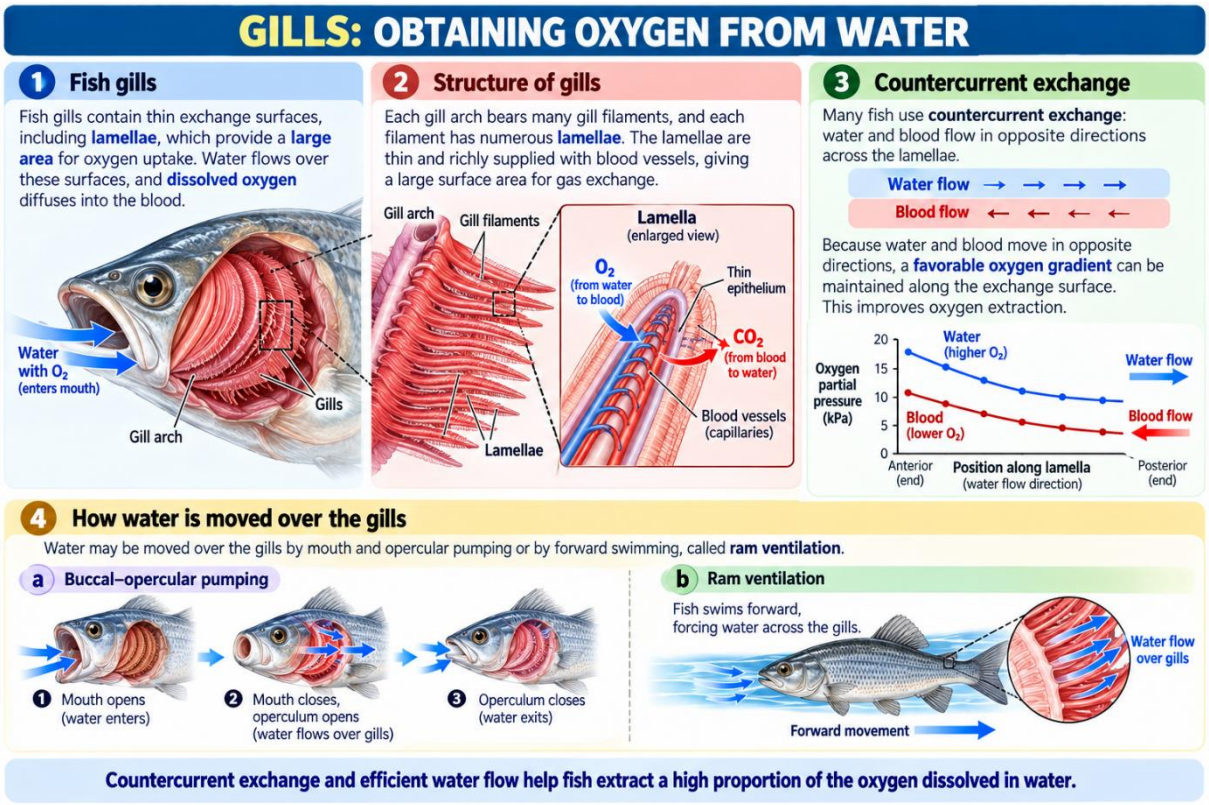
Fish gills contain thin exchange surfaces, including lamellae, which provide a large area for oxygen uptake. Water flows over these surfaces, and dissolved oxygen diffuses into the blood.

Many fish use countercurrent exchange:

Water flow → → → →

Blood flow ← ← ← ←

Because water and blood move in opposite directions, a favorable oxygen gradient can be maintained along the exchange surface. This improves oxygen extraction. Water may be moved over the gills by mouth and opercular pumping or by forward swimming, called ram ventilation.

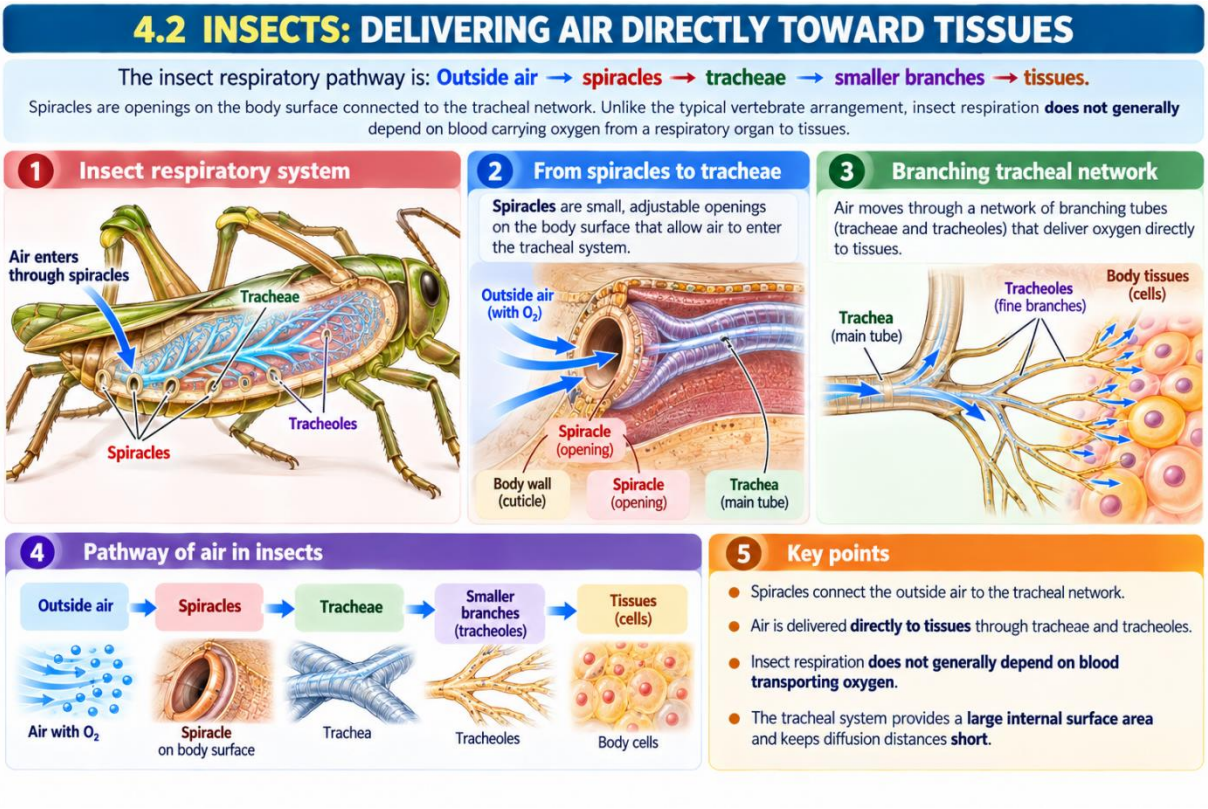


4.2 Insects: delivering air directly toward tissues

The insect respiratory pathway is:

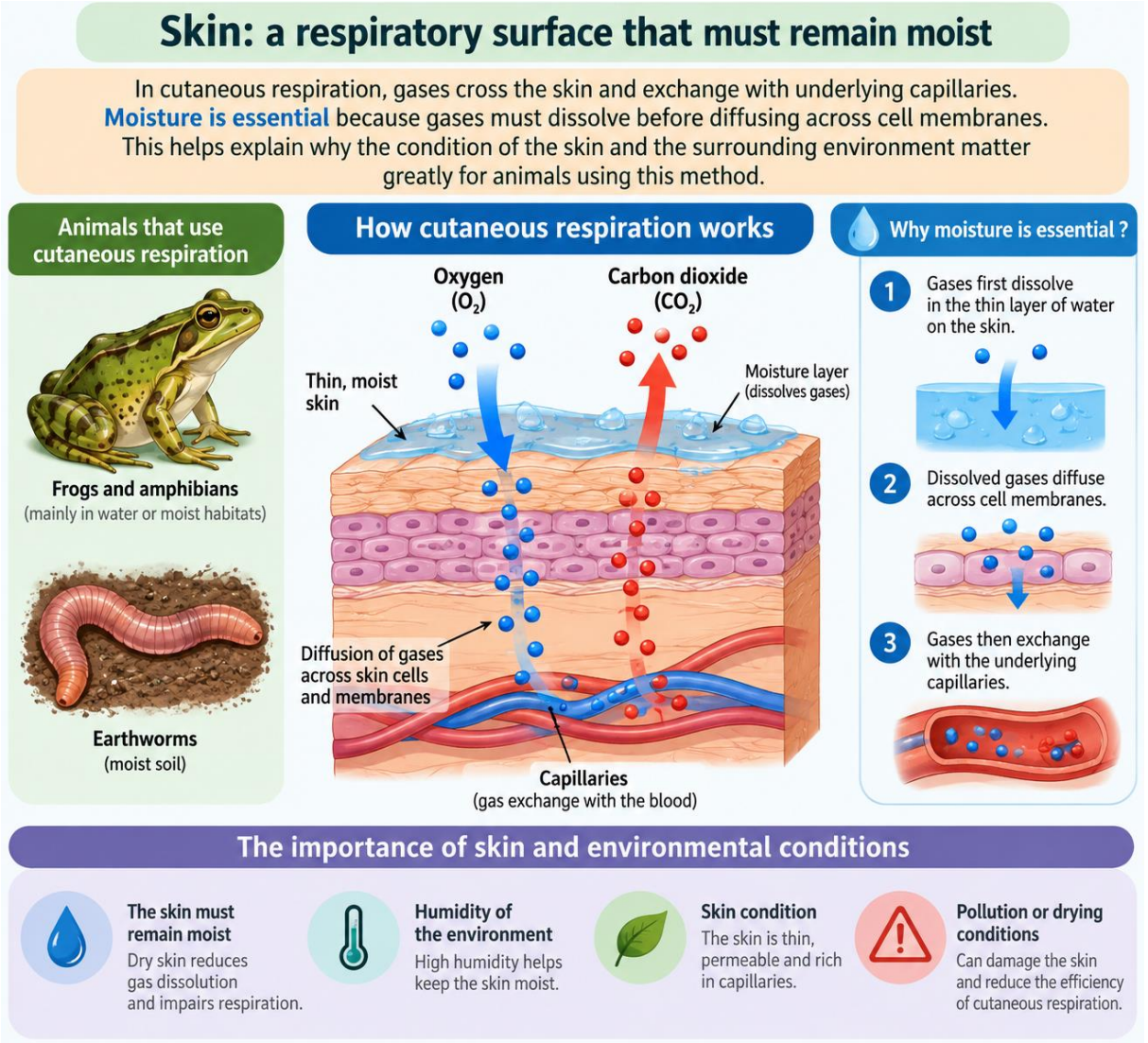
Outside air → spiracles → tracheae → smaller branches → tissues

Spiracles are openings on the body surface connected to the tracheal network. Unlike the typical vertebrate arrangement, insect respiration does not generally depend on blood carrying oxygen from a respiratory organ to tissues.



4.3. Skin: a respiratory surface that must remain moist

In cutaneous respiration, gases cross the skin and exchange with underlying capillaries. Moisture is essential because gases must dissolve before diffusing across cell membranes. This helps explain why the condition of the skin and the surrounding environment matter greatly for animals using this method.



5. Mammalian respiratory anatomy

The mammalian respiratory system has two functional regions:

- Conducting region: carries air toward and away from the exchange surfaces.
- Respiratory region: contains the surfaces where gases exchange with blood.

A simplified air pathway is:

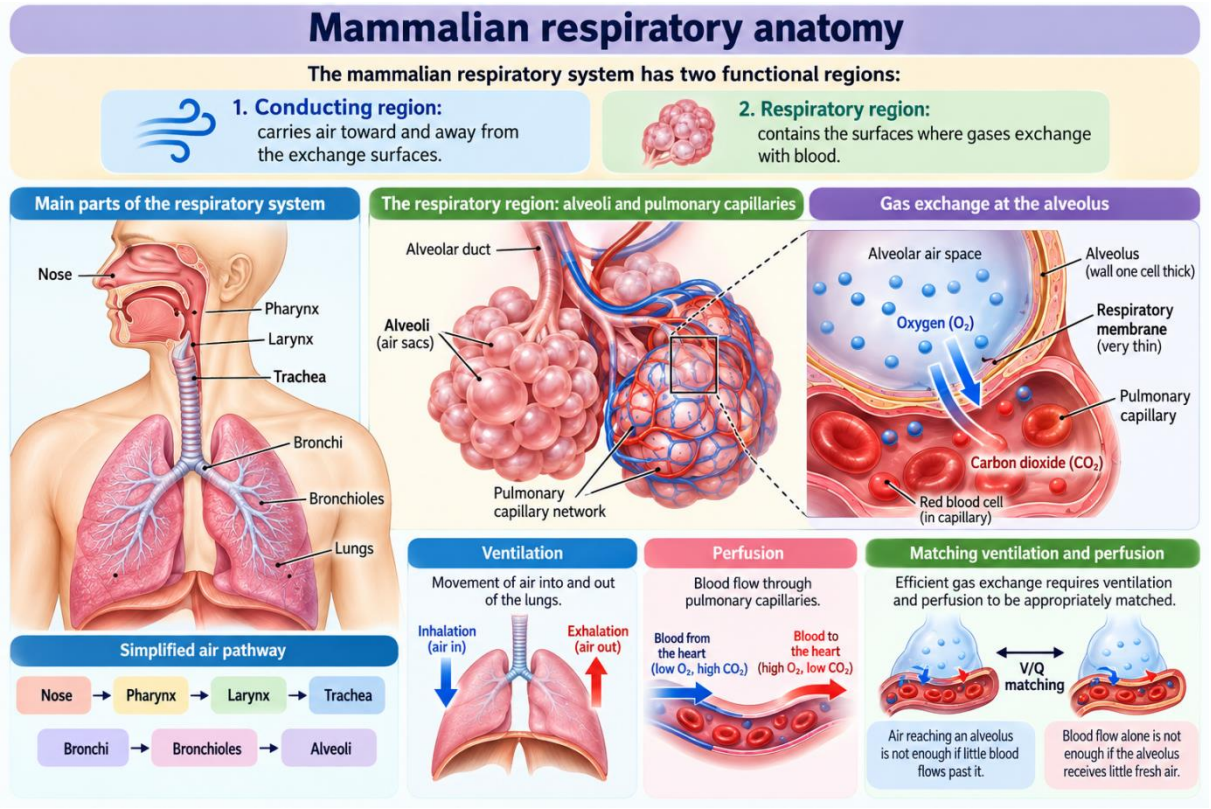
Nose → pharynx → larynx → trachea→ bronchi → bronchioles → alveoli

Alveoli are small air spaces closely associated with pulmonary capillaries. Oxygen and carbon dioxide cross the thin alveolar–capillary respiratory membrane. Their close association links ventilation with blood flow.

Two terms are especially important:

- Ventilation: movement of air into and out of the lungs.
- Perfusion: blood flow through pulmonary capillaries.

Efficient gas exchange requires these processes to be appropriately matched. Air reaching an alveolus is not enough if little blood flows past it; blood flow alone is not enough if the alveolus receives little fresh air.



6. Mechanics of breathing in mammals

Air moves because of a pressure difference between the atmosphere and the lungs. Respiratory muscles change thoracic and lung volume, producing the pressure changes that drive airflow.

6.1 Inspiration

During normal inspiration:

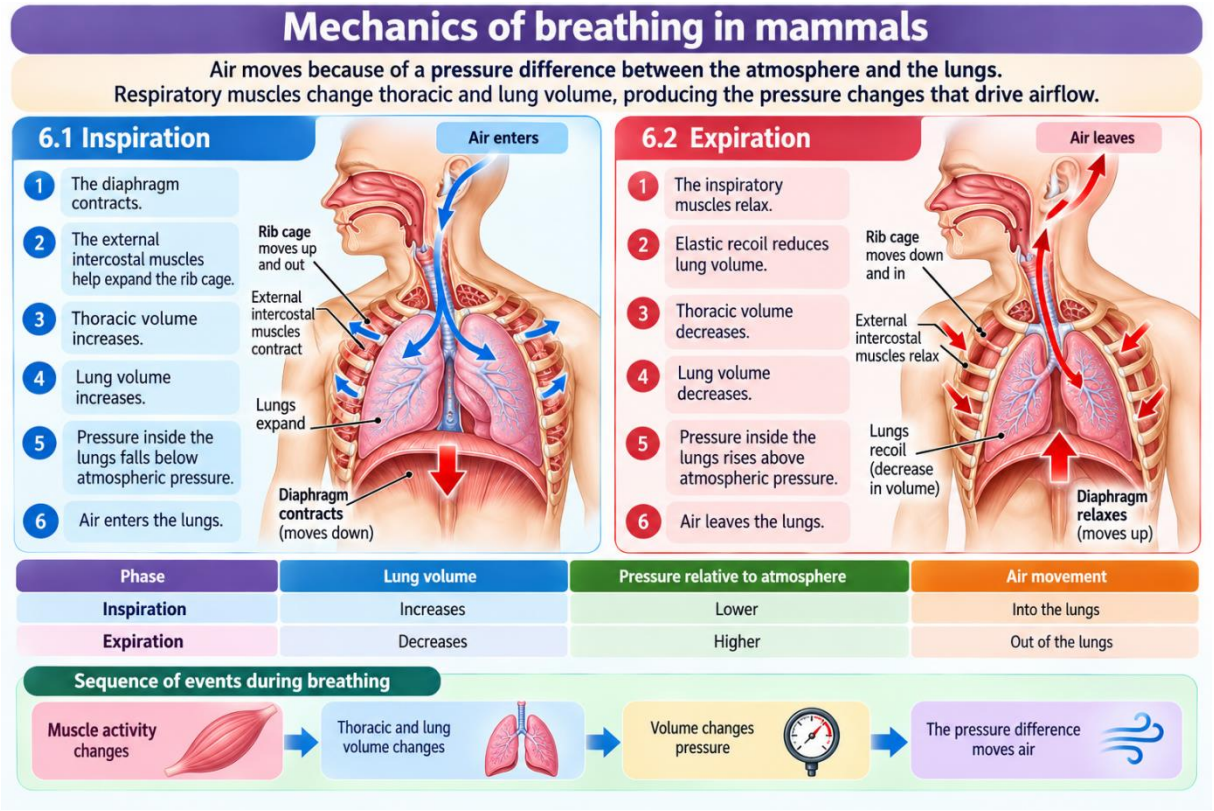
1. The diaphragm contracts.
2. The external intercostal muscles help expand the rib cage.
3. Thoracic volume increases.
4. Lung volume increases.
5. Pressure inside the lungs falls below atmospheric pressure.
6. Air enters the lungs.

6.2 Expiration

During quiet expiration, the inspiratory muscles relax and elastic recoil reduces lung volume. Pressure inside the lungs rises above atmospheric pressure, so air leaves. Quiet expiration is normally largely passive, whereas forceful expiration requires additional muscular activity.

Phase	Lung volume	Pressure relative to atmosphere	Air movement
Inspiration	Increases	Lower	Into the lungs
Expiration	Decreases	Higher	Out of the lungs

The important sequence is: muscle activity changes volume, volume changes pressure, and the pressure difference moves air.



7. Transport of respiratory gases

7.1 Oxygen transport

Oxygen is not very soluble in blood plasma. Most oxygen is therefore transported bound to hemoglobin inside red blood cells, while a smaller amount remains dissolved.

Hemoglobin loads oxygen at the lungs and releases it at tissues. Its oxygen-binding properties help regulate how much oxygen reaches different tissues. The oxygen–hemoglobin dissociation curve describes the relationship between oxygen partial pressure and hemoglobin saturation.

The key distinction is:

- Oxygen partial pressure describes the dissolved oxygen that drives diffusion.
- Hemoglobin provides most of the blood's oxygen-carrying capacity.

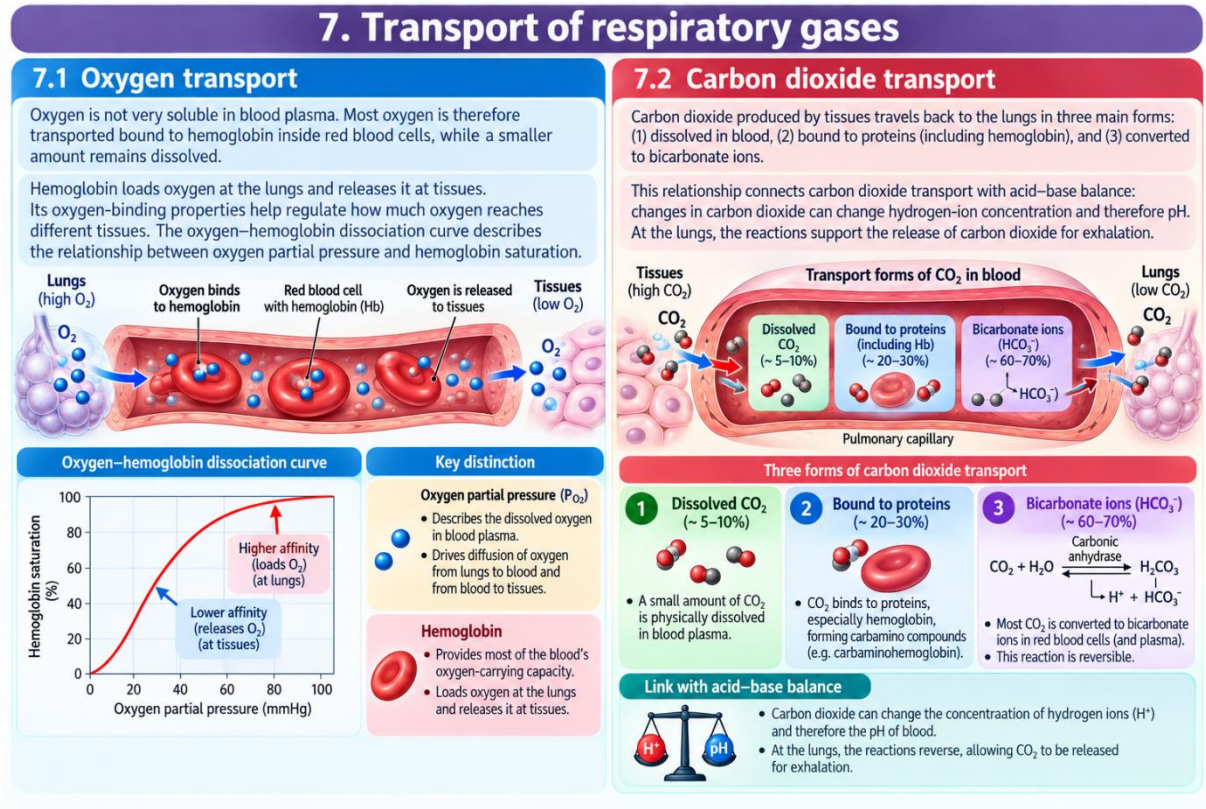
7.2 Carbon dioxide transport

Carbon dioxide produced by tissues travels back to the lungs in three main forms:

- Dissolved in blood.

- Bound to proteins, including hemoglobin.
- Converted to bicarbonate ions.

This relationship connects carbon dioxide transport with acid–base balance: changes in carbon dioxide can change hydrogen-ion concentration and therefore pH. At the lungs, the reactions support the release of carbon dioxide for exhalation.



8. Regulation of breathing

Breathing is rhythmic but adjustable. Neural networks in the medulla and pons coordinate respiratory activity, while sensory feedback helps adjust its rate and depth.

8.1 Chemical control

Chemoreceptors provide information about:

- Carbon dioxide.
- Oxygen.
- pH.

Under normal resting conditions in healthy mammals, carbon dioxide-related chemical feedback is a major driver of ventilation. Increasing carbon dioxide stimulates breathing, helping remove the excess gas.

A simplified feedback loop is:

CO_2 increases

↓

Chemical feedback stimulates respiratory control networks

↓

Ventilation increases

↓

More CO_2 is removed

This is negative feedback: the response opposes the original disturbance.

8.2 Why regulation differs between animal groups

The same chemical signal is not equally important in every animal. In many water-breathing animals, environmental oxygen availability strongly influences ventilation. When water oxygen falls, breathing movements may increase to improve oxygen uptake.

Therefore, avoid applying the mammalian rule “carbon dioxide strongly drives breathing” to all animals without considering their respiratory system and environment.

