

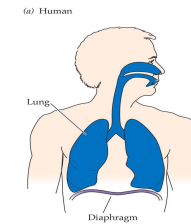
# Respiration

## Properties and Transport of gases

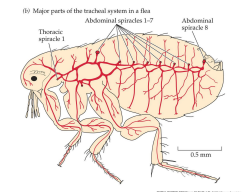
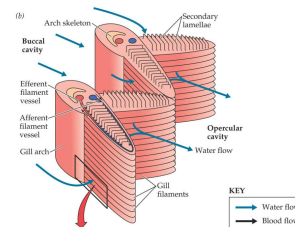


← 1 atm		1 atm
	Percent of all gas	Partial pressure in atmospheres
	Oxygen 20.95	0.2095
	Nitrogen 78.09	0.7809
	Argon 0.93	0.0093
	Carbon dioxide 0.03	0.0003
		$\Sigma = 1 \text{ atm}$
		1 atm

## External respiration and Ventilation

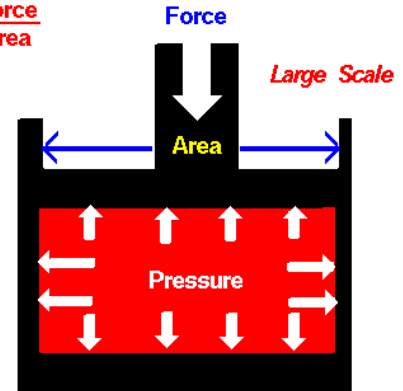


## Vertebrate and Invertebrate breathing

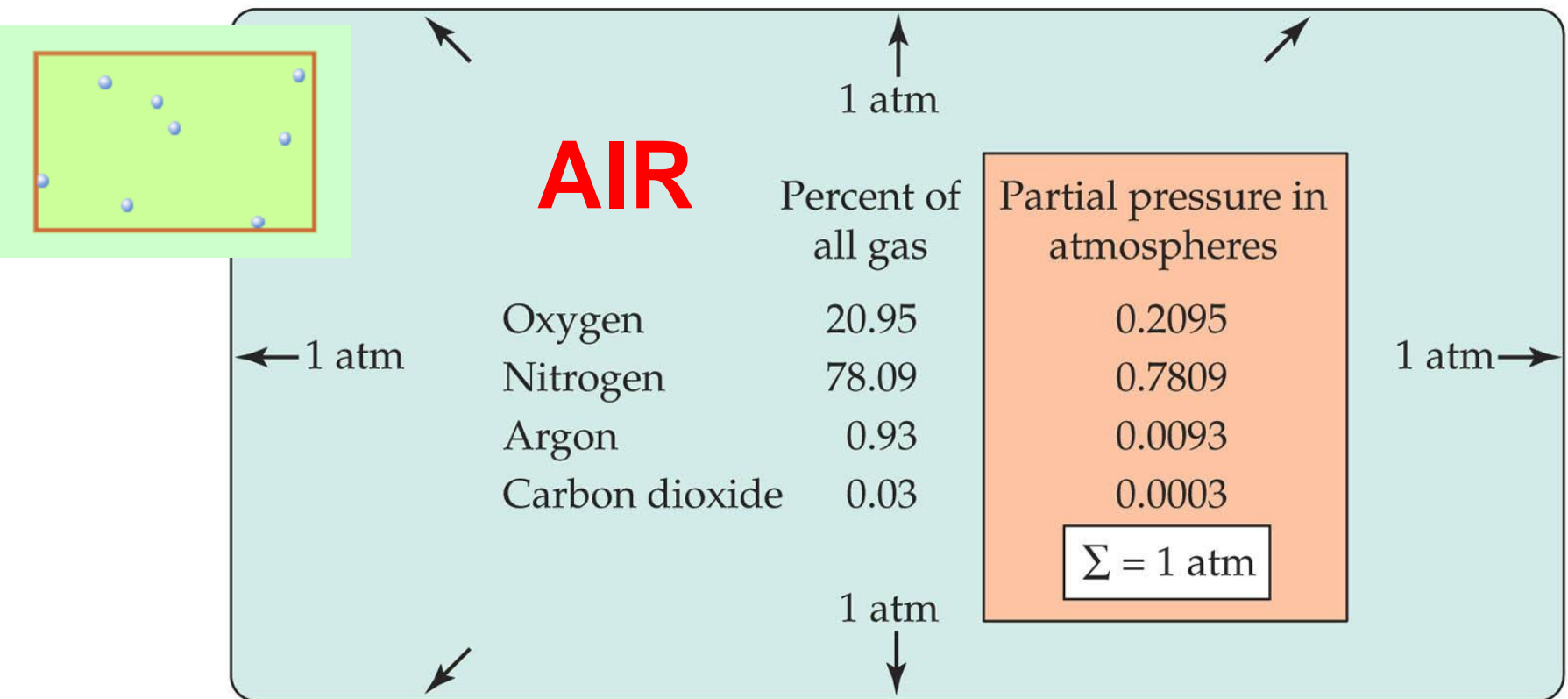


# Properties of gases: the total pressure exerted by a mixture of gases

$$P = \frac{\text{Force}}{\text{Area}}$$



- The **total pressure** of a gas mixture is the sum of the partial pressures of individual gases (Dalton law).
- Each **partial pressure** is independent of the other gases.
- Gases **diffuse** from regions of high partial pressure to low, at a rate proportional to the difference

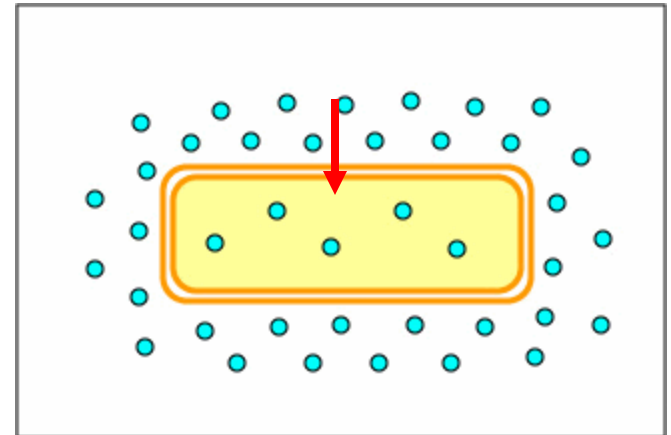
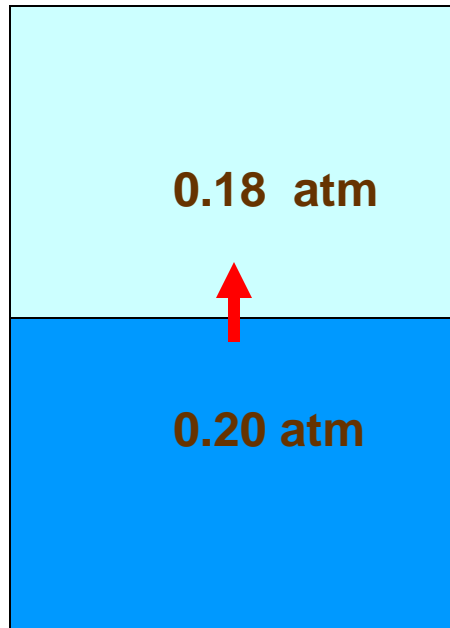


# Temperature and salinity decrease gas solubility in solutions

- The concentration of a gas is proportional to the partial pressure
- Henry's LAW:  $C = AP$  (concentration = abs coeff x partial pressure)
- **A**: absorption coefficient (solubility of gas in a solution)
- $\text{CO}_2$  much higher solubility than  $\text{O}_2$

# Transport of Gases

## 1. Simple diffusion : high partial press --- low part press (random molecule movement)



- Gases diffuse more easily in gases than liquids (200.000 for O<sub>2</sub>) (**liquid in lungs**)
- **Diffusion can supply O<sub>2</sub> for distances of 1 mm in tissues**
- Only free gas contribute to the gas partial pressure (**Hemoglobin**)

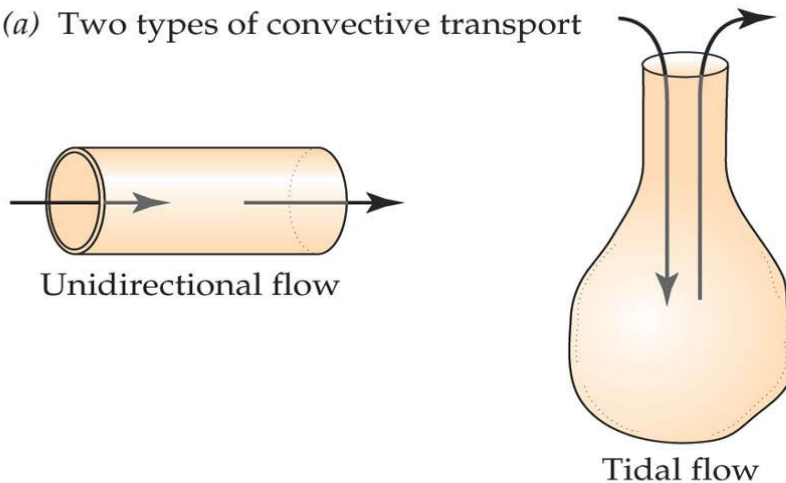
Transport of gases: Gases move also by **convective gas transport**

**2. convective gas transport**: a fluid moving from place to place carries along the gas transported in the fluid

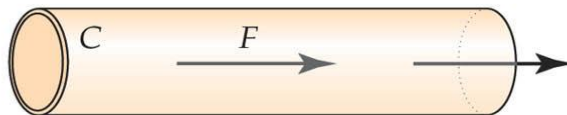
**Much more effective than simple diffusion**: breathing and pumping of blood.

**Movement of fluids**: natural or muscle driven.

(a) Two types of convective transport



(b) Calculation of the rate of convective gas transport



$C$  = Total concentration of gas in flowing fluid (mol/L)

$F$  = Flow rate of fluid (L/second)

Rate of convective gas transport =  $C \cdot F$

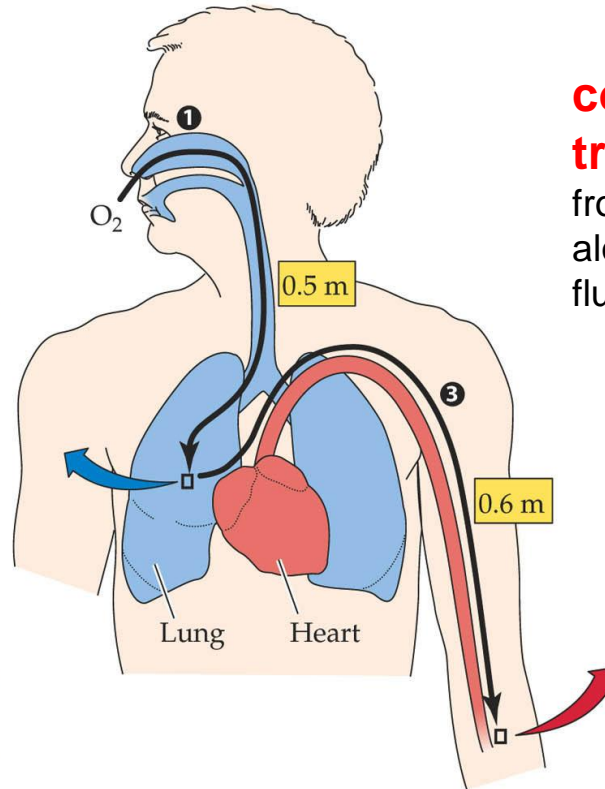
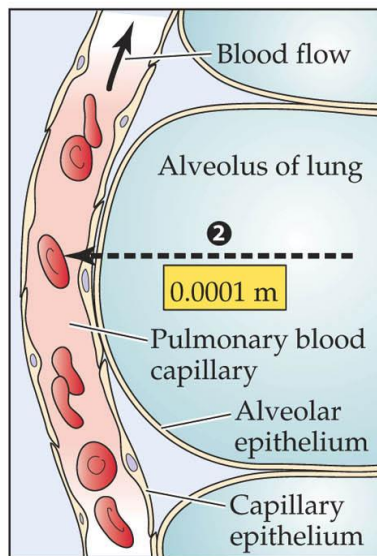
**Hemoglobin: 50X Transport**  
**Heart: 5 liters/min**

# Gas transport occurs by alternating convection and diffusion

## Mechanisms of oxygen transport in the delivery of $O_2$ to the mitochondria

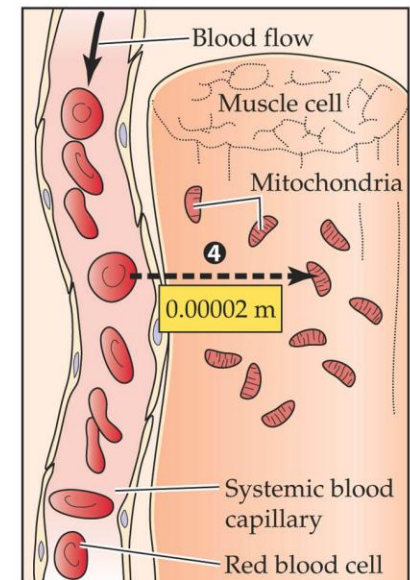
KEY

—→ Convection  
- - -→ Diffusion



### convective gas

**transport** : a fluid moving from place to place carries along the gas transported in the fluid



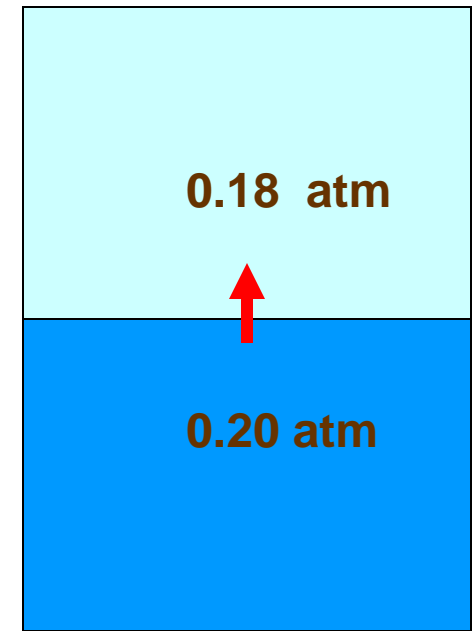
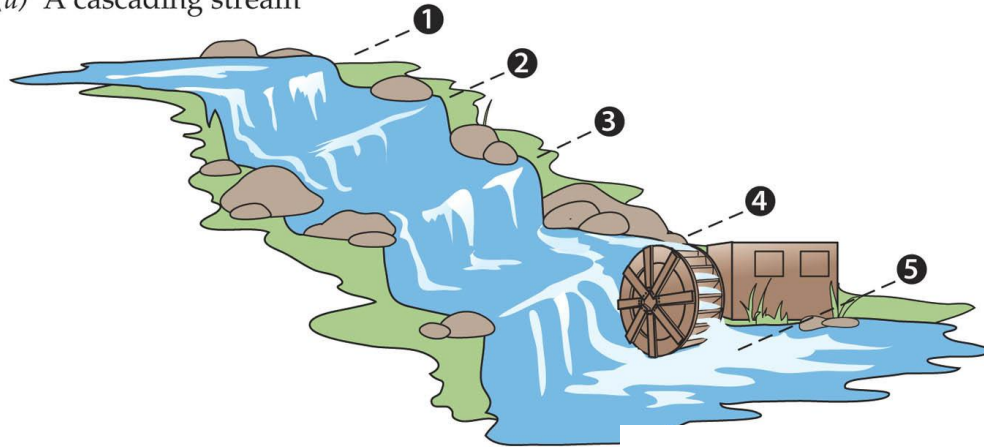
KEY

—→ Convection  
- - -→ Diffusion

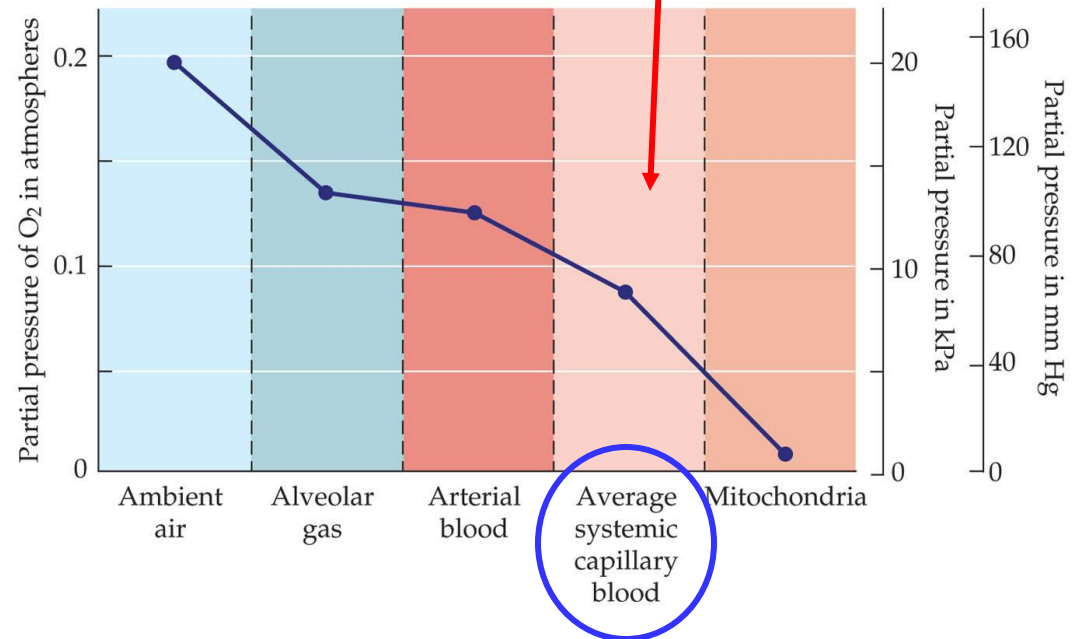
**Simple diffusion** : high partial press --- low part press

# The oxygen cascade

(a) A cascading stream



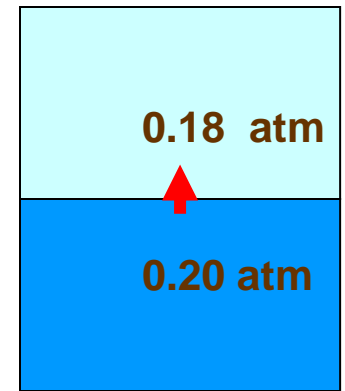
(b) The oxygen cascade in people



# The physical properties of air and water affect respiration

**Solubility of O<sub>2</sub> in cold water  
Higher than warm water**

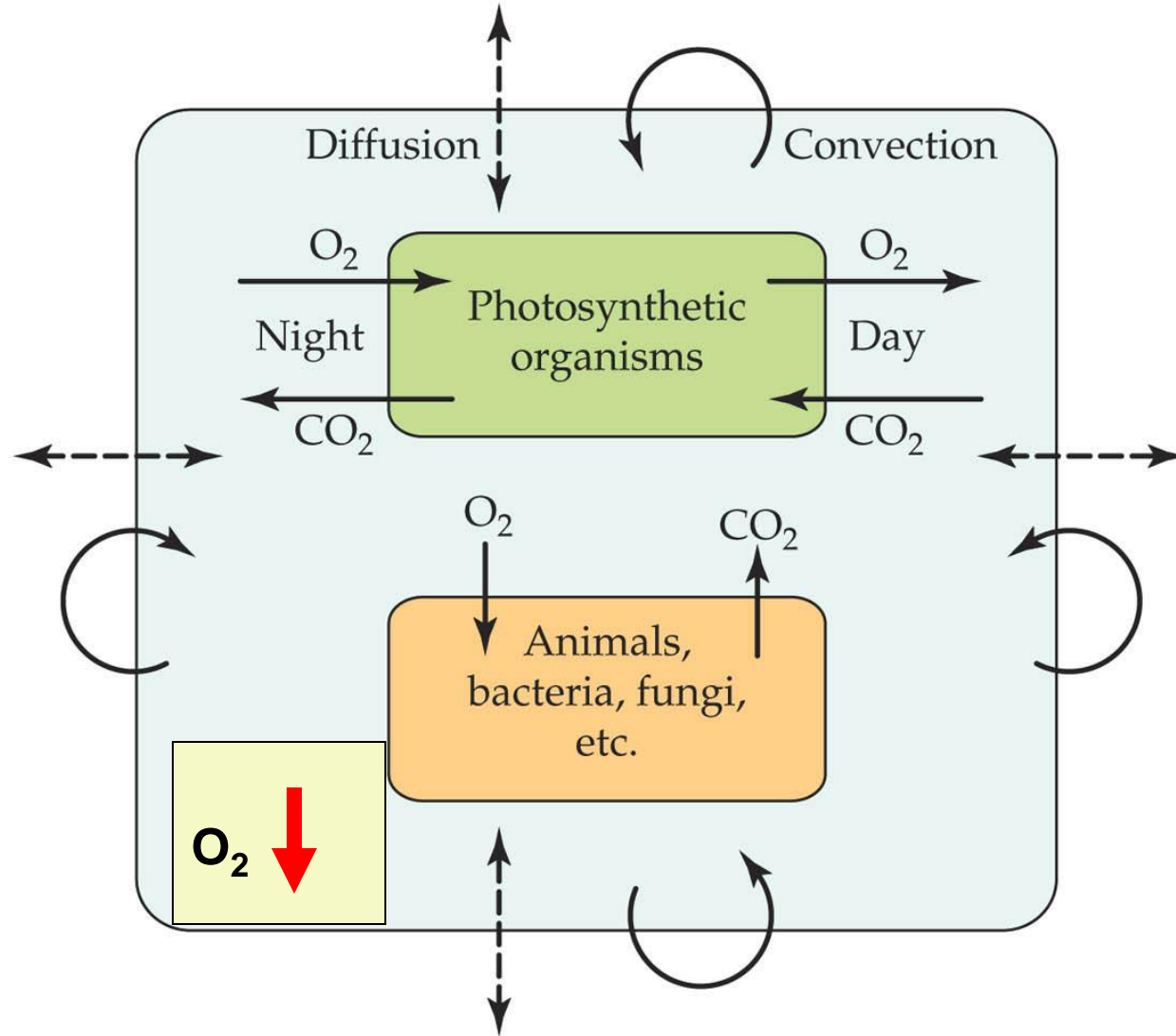
	Concentration of O <sub>2</sub> (mL O <sub>2</sub> at STP/L) at specified temperature		
	0°C	12°C	24°C
Air	210	200	192
Freshwater	10.2	7.7	6.2
Seawater <sup>a</sup>	8.0	6.1	4.9



**Water more dense: more energy to move it!**

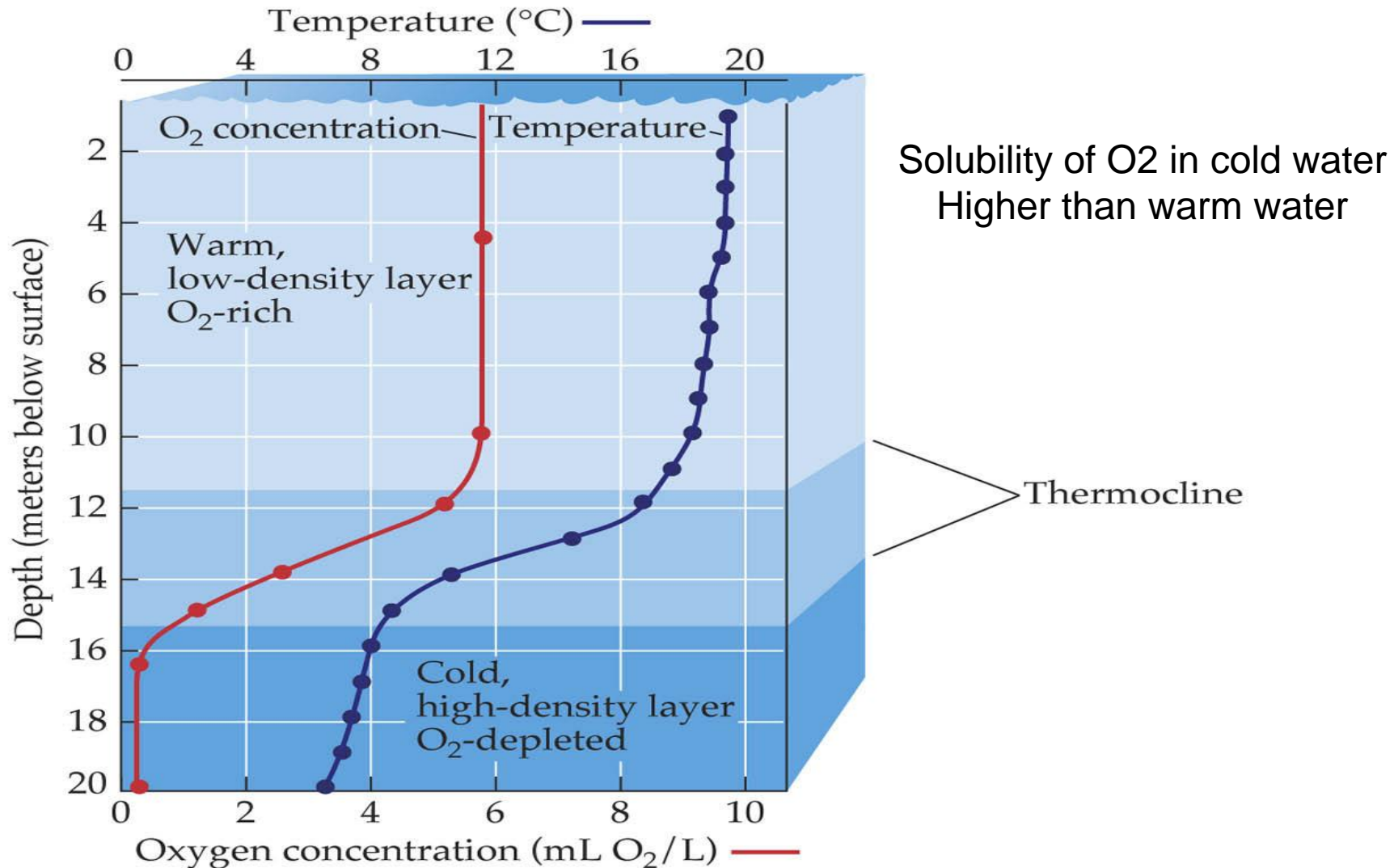
**A water-breathing animals must work much harder to obtain oxygen!**

## Processes that affect partial pressures of $O_2$ and $CO_2$ within an environment



# Oxygen supply to the deep waters of a lake

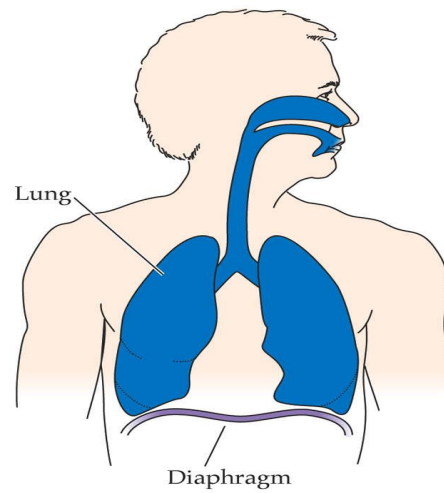
Solubility of O<sub>2</sub> in water is only 3-5 %. Changes with Temperature and other factors.



# Respiration

## External respiration and Ventilation

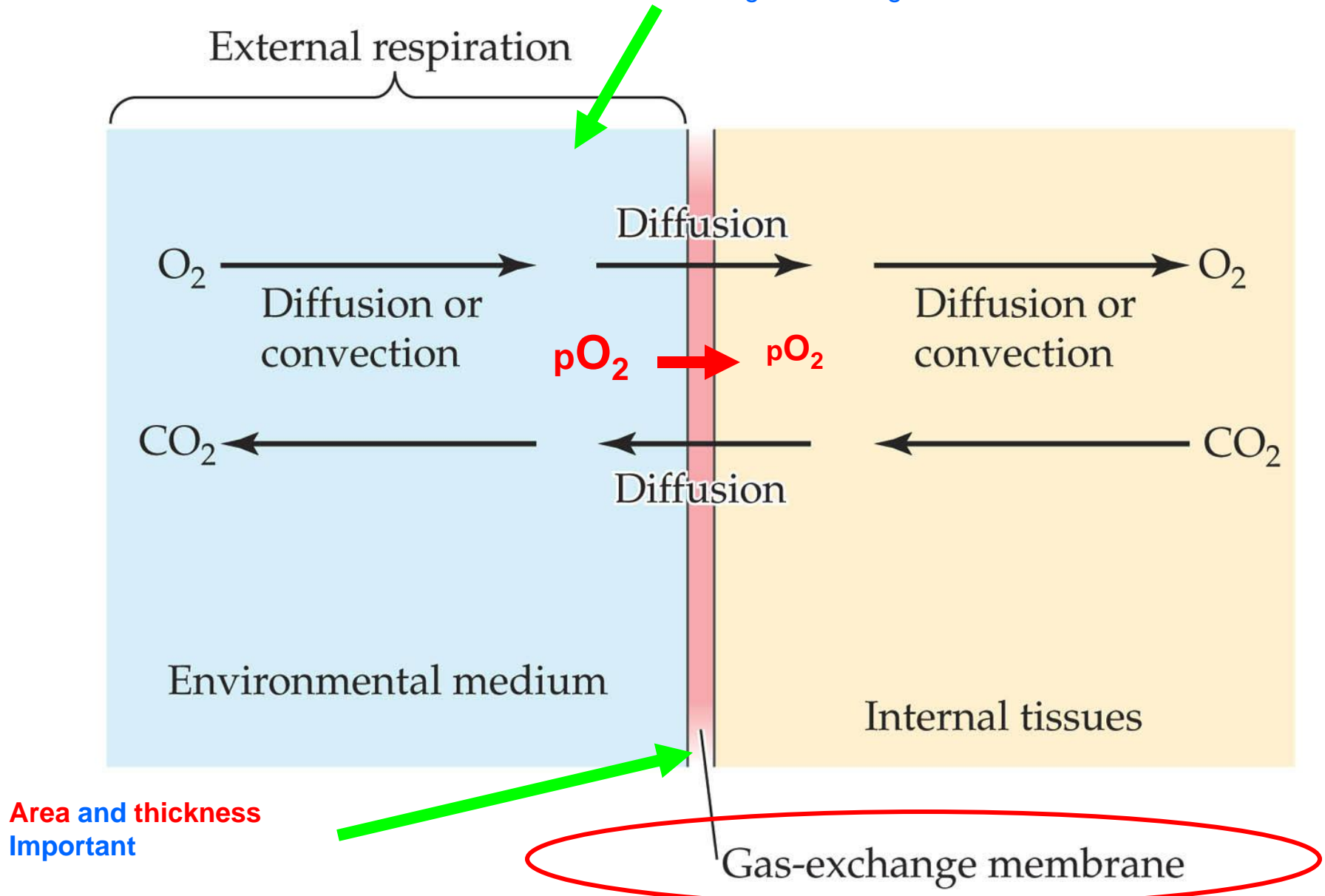
(a) Human



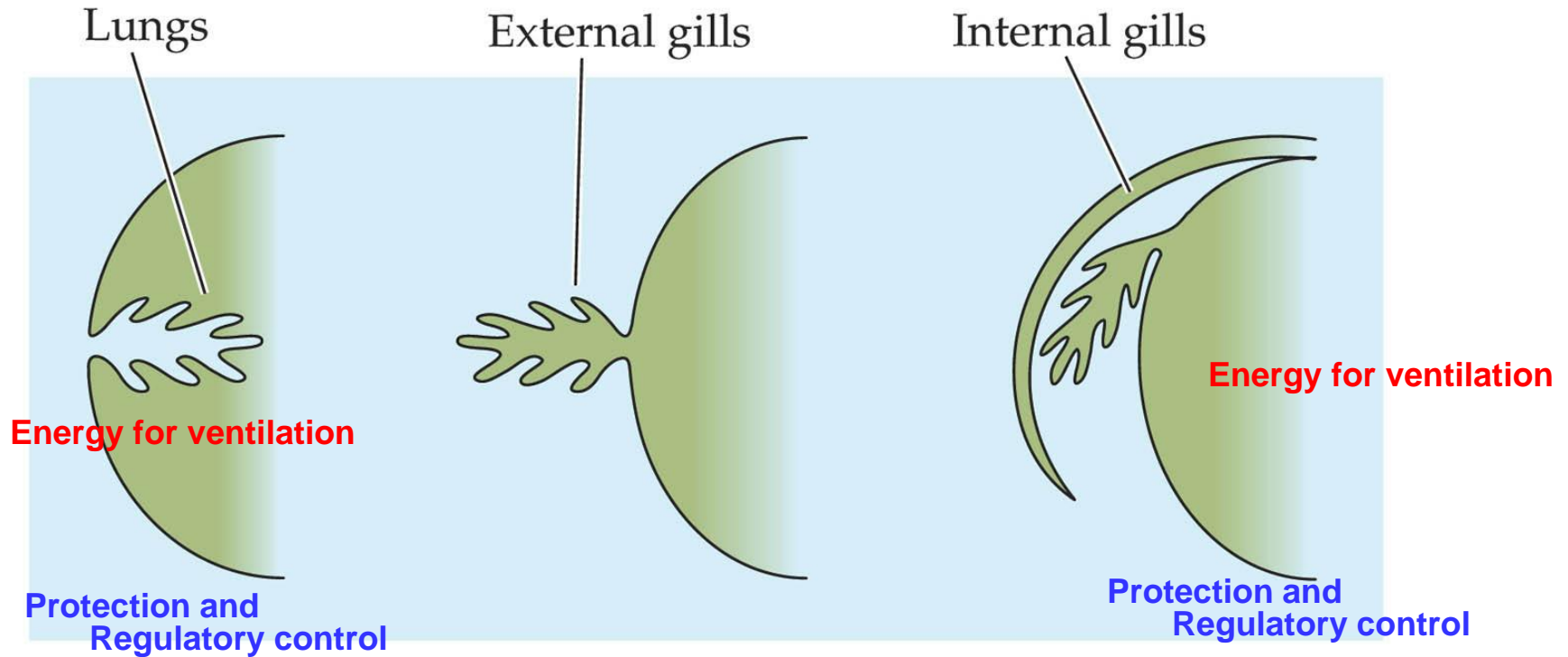
# EXTERNAL RESPIRATION: Generalized features of animal gas exchange

**External respiration (breathing):** transport of gases **from** and **to** the environment

**Ventilation:** **convecting** movement of air or water to and from the gas-exchange membrane

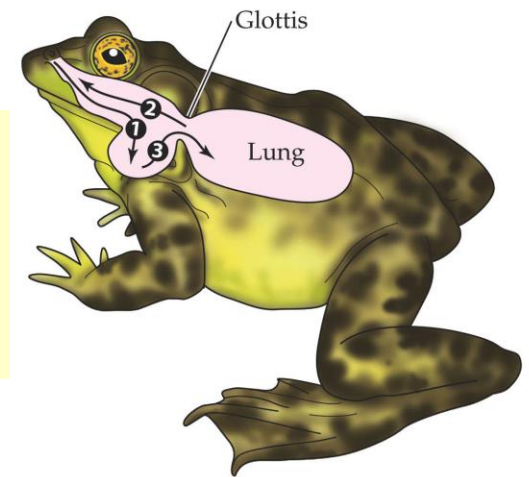


# Three types of respiratory structures



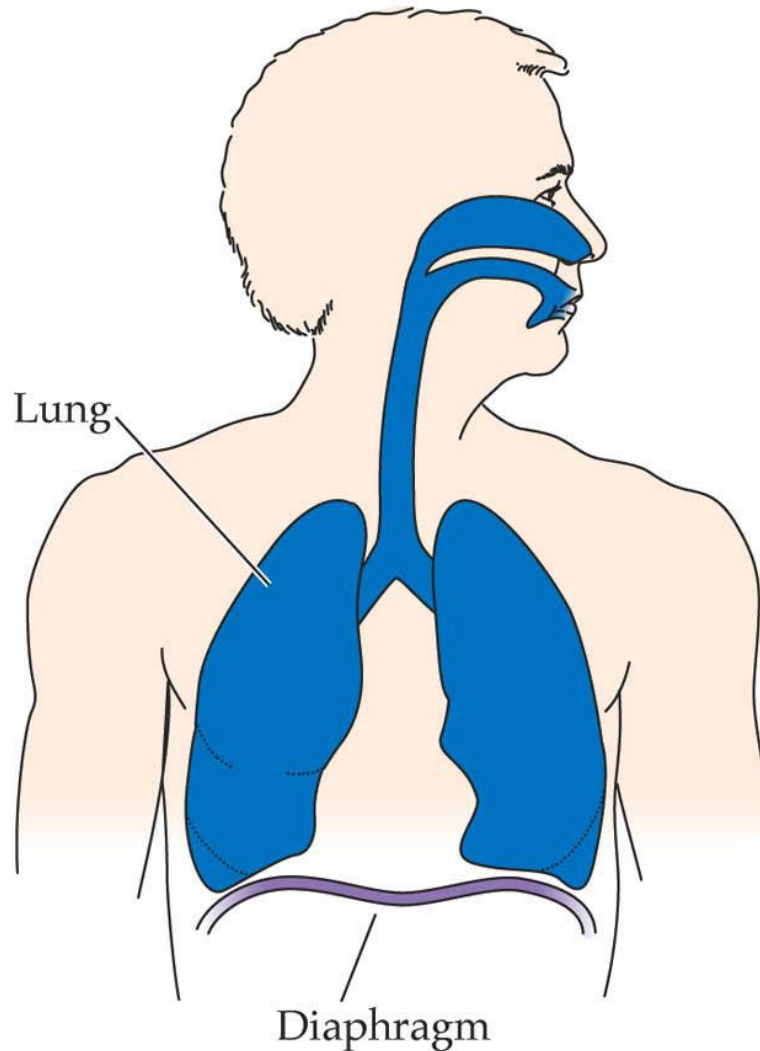
**Pulmonary:** lungs----- **invaginated**, contain the environment

**Branchial:** gills ----- **evaginated** into the environment

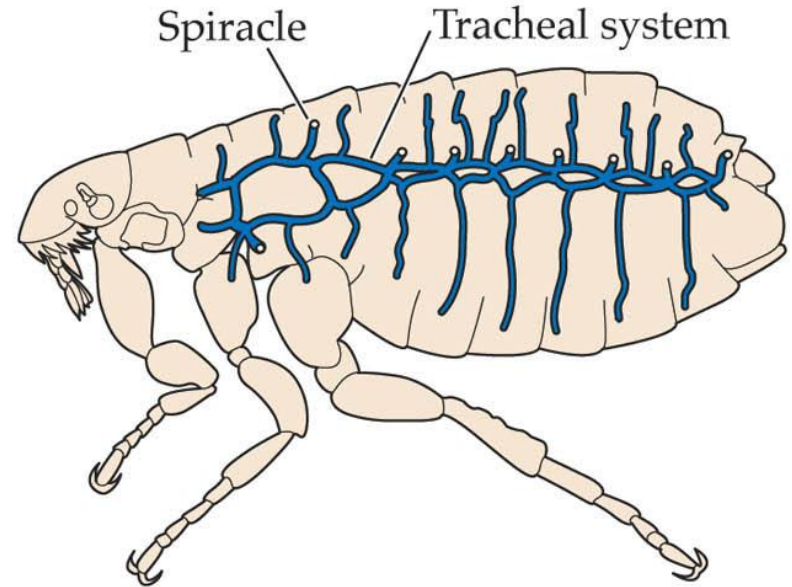


**Lungs are adaptive for terrestrial breathing because of the structural support  
(water gives structural support to gills)**

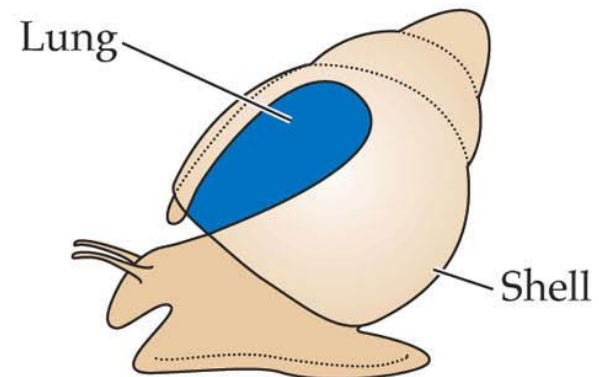
(a) Human



(b) Insect



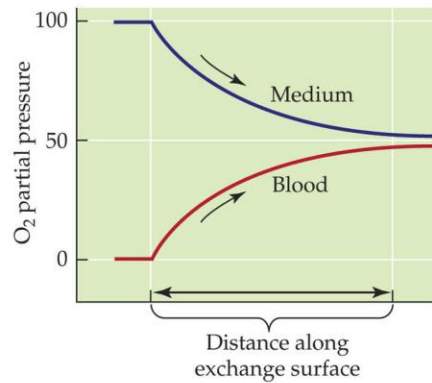
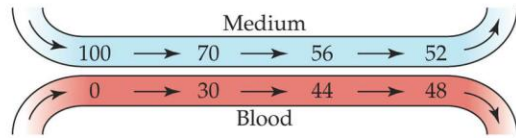
(c) Land snail



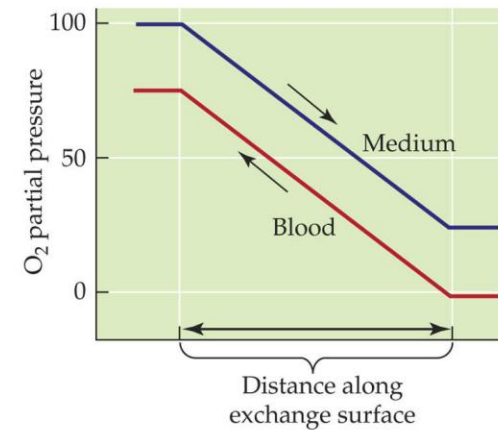
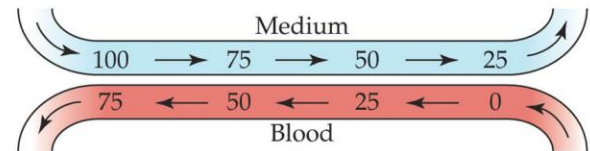
# Oxygen transfer from the environmental medium to the blood

The  $O_2$  partial pressure in blood leaving the breathing organ depends on the relation between the **flow of the blood** and the **flow of the air or water**.

(a) Concurrent gas exchange

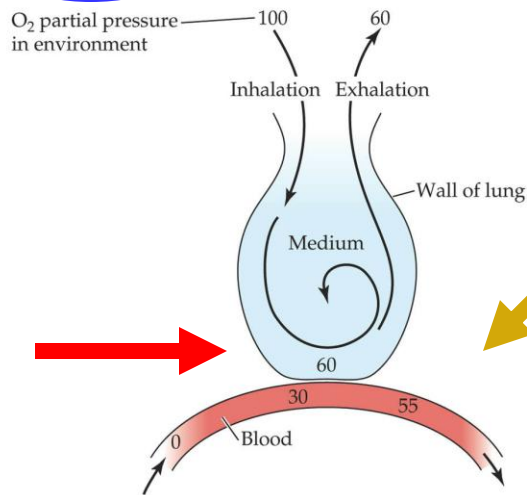


(b) Countercurrent gas exchange



**Unidirectional flow**

Tidal gas exchange



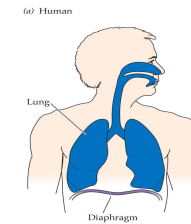
# Respiration

## Properties and Transport of gases

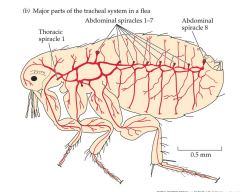
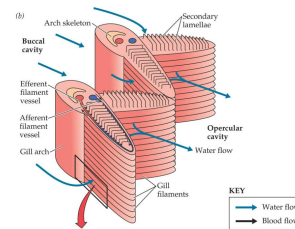


← 1 atm		1 atm
	Percent of all gas	Partial pressure in atmospheres
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	Nitrogen 78.09	0.7809
	Argon 0.93	0.0093
	Carbon dioxide 0.03	0.0003
		$\Sigma = 1 \text{ atm}$
		1 atm

## External respiration and Ventilation



## Vertebrate and Invertebrate breathing



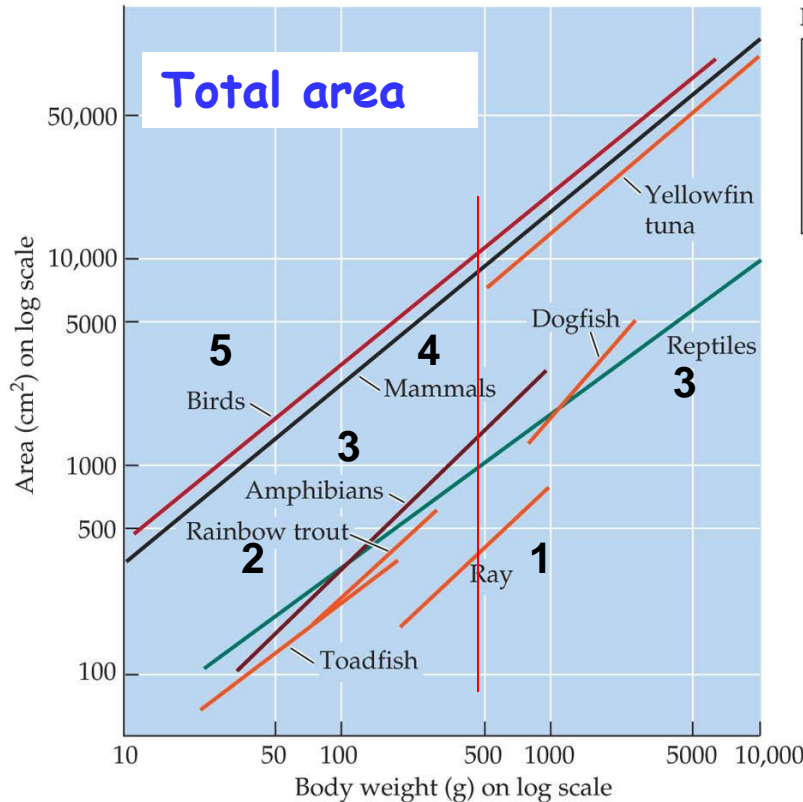
# Vertebrate Breathing

1. Total area and thickness of the gas-exchange membrane in the gills or lungs
2. The percentage of  $O_2$  and  $CO_2$  exchange that occurs across the skin

# Vertebrate Breathing

## Total area and thickness of the gas-exchange membrane in the gills or lungs

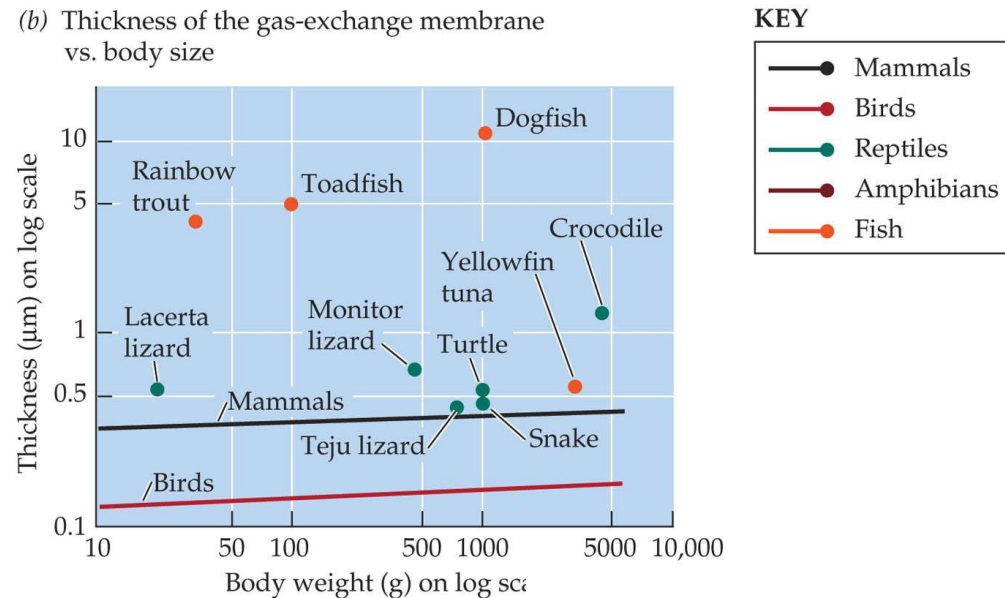
(a) Area of the gas-exchange membrane vs. body size



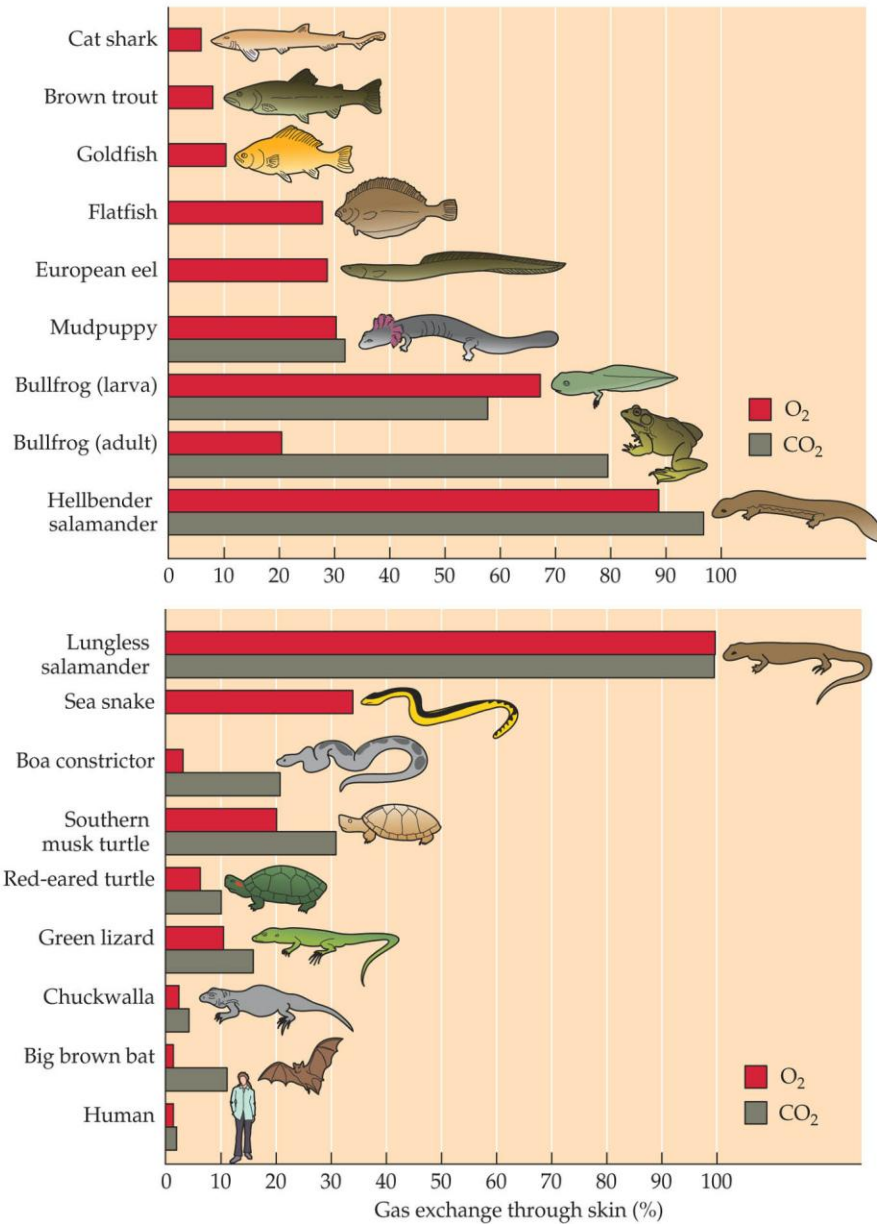
**HOMEOTHERMY**  
**Metabolic rate**

## Thickness of the gas-exchange membrane

(b) Thickness of the gas-exchange membrane vs. body size



# The percentage of O<sub>2</sub> and CO<sub>2</sub> exchange that occurs across the skin



**Skin's desiccation resistance**

# The control of active ventilation

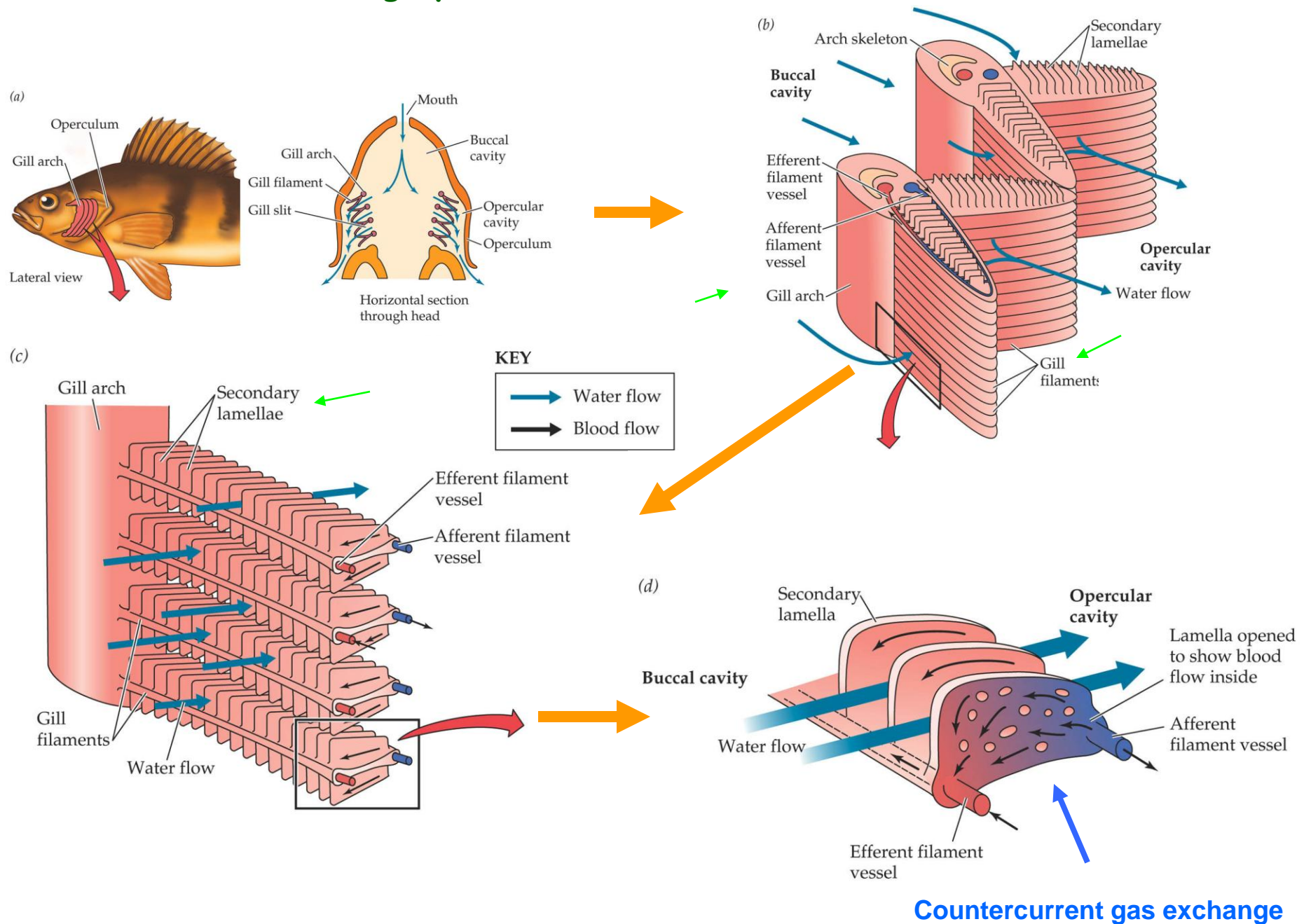
## 1. Continuous breathing : Mammals, birds, fish



## 2. Intermittent breathing (apnea): reptiles, amphibians, air-breathing fish.



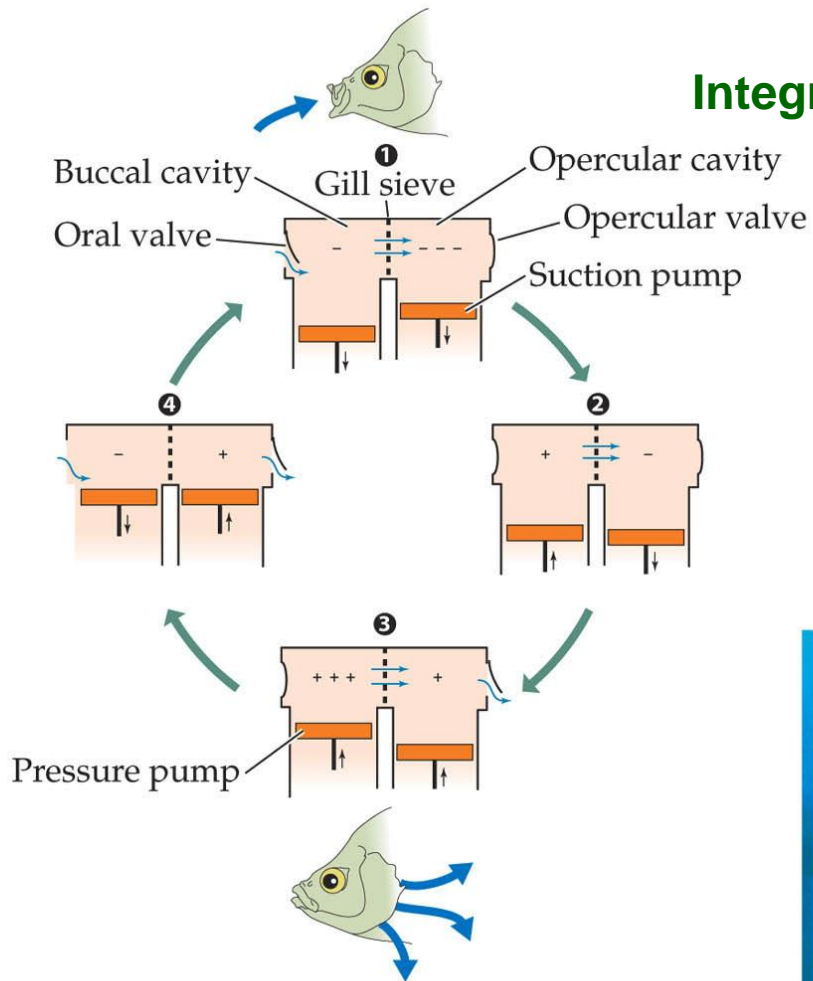
# The branchial breathing system in teleost fish



# Breathing in teleost fish

## Gill ventilation

Integration of buccal and opercular pumps



## Ram ventilation



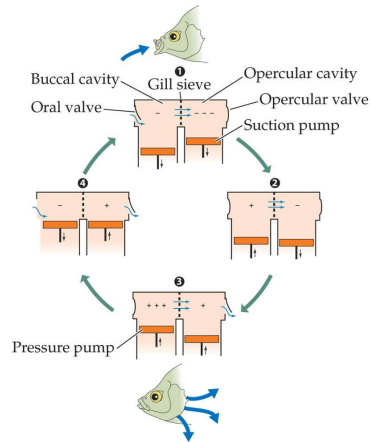
- > More gill surface
- > Very thin membranes

# Regulation of Breathing in fish

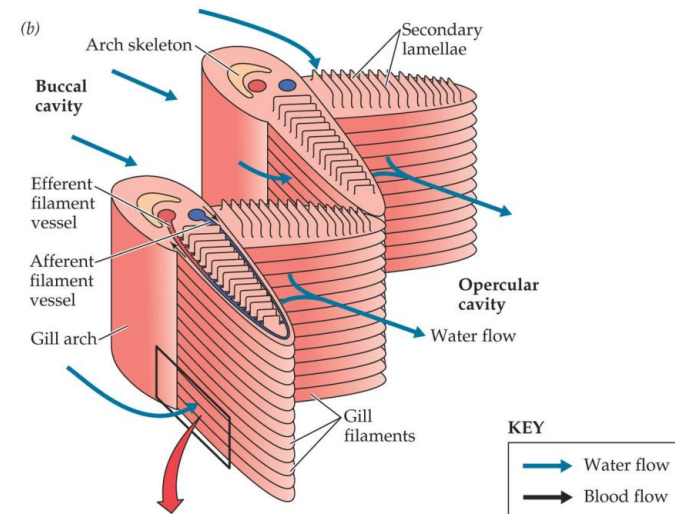
Exercise

Decrease of oxygen

**Increase Gill ventilation**



**Increase Lamellar recruitment**



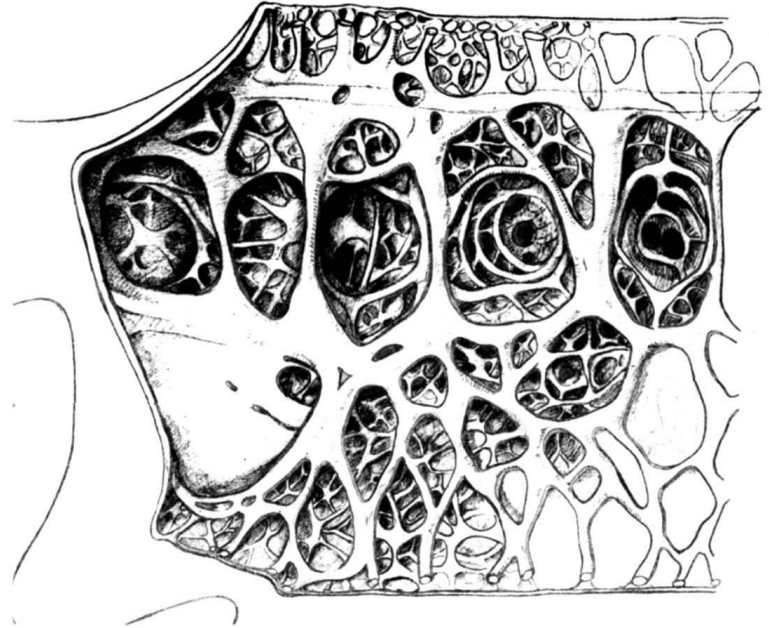
# Lungfish and their lungs

## Alimentary canal adaptations

(b) An African lungfish in the genus *Protopterus*



(a) The inner wall of a lungfish lung



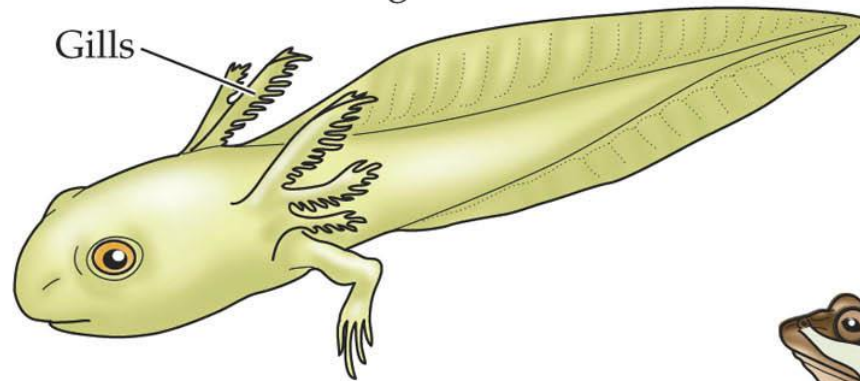
## Florida Gar (*Lepisosteus platyrhincus*)

## Highly vascularized swim bladder

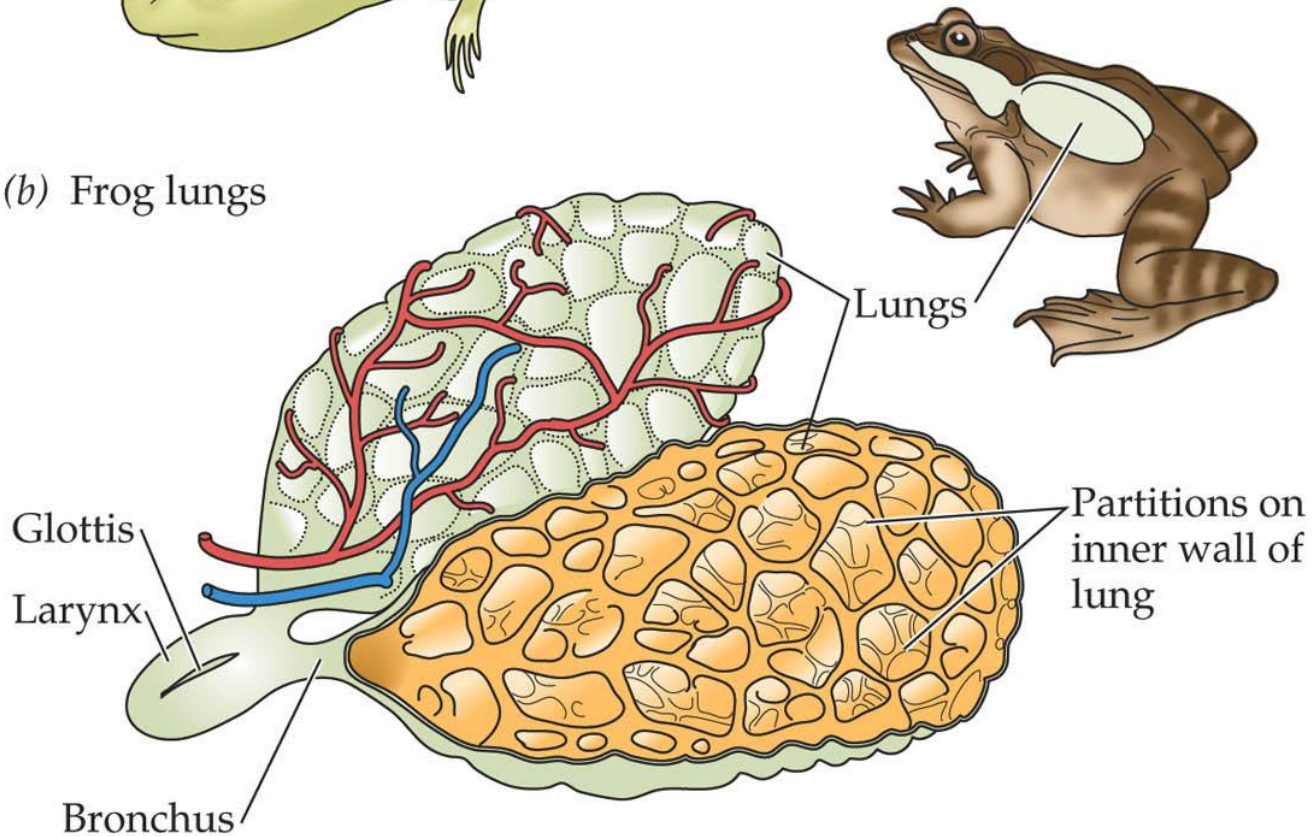


# Breathing organs of amphibians

(a) Salamander larva with gills

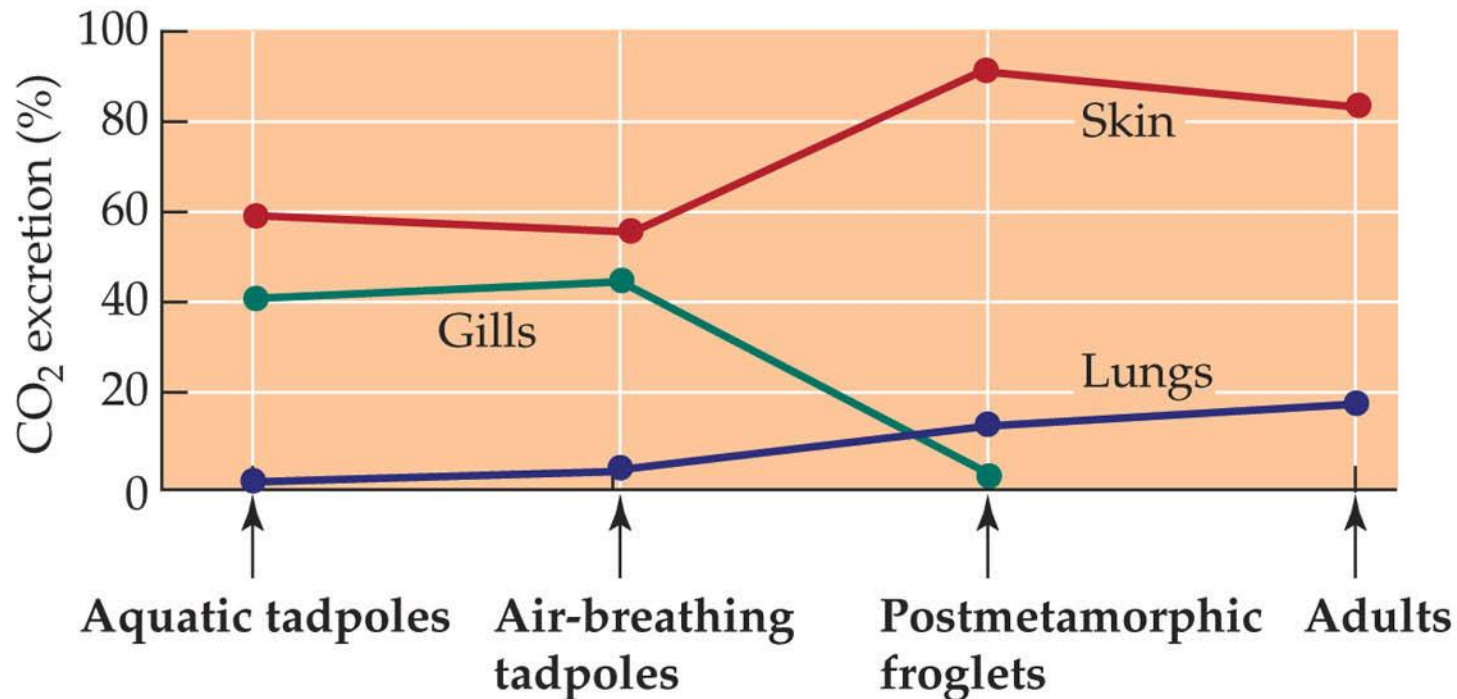
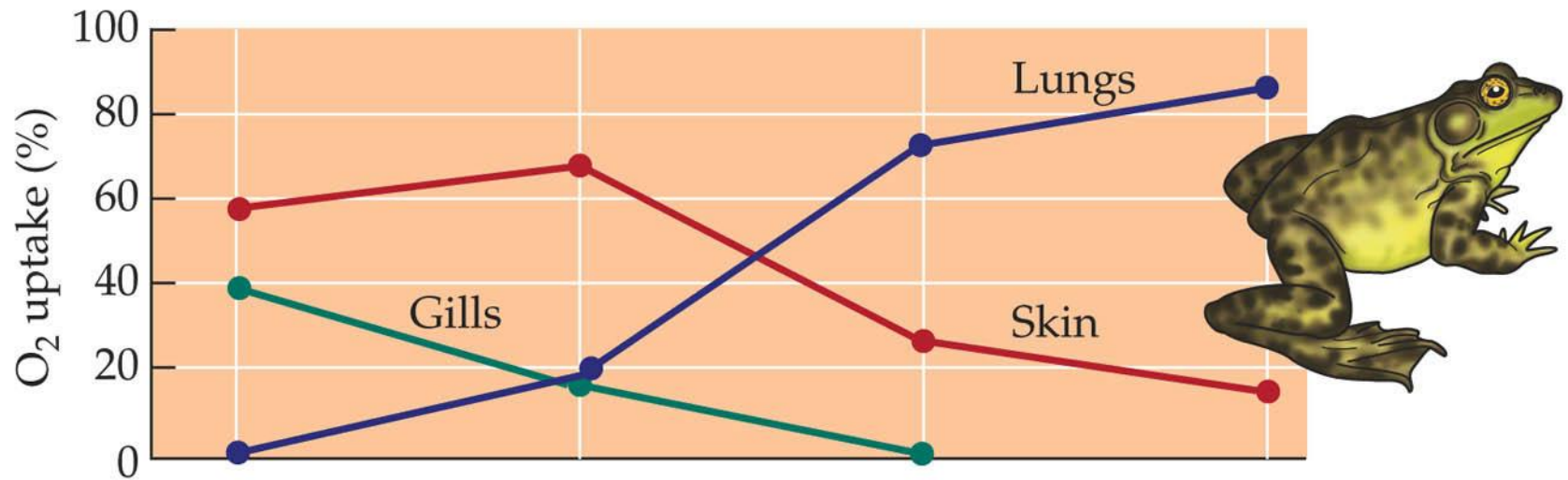


(b) Frog lungs



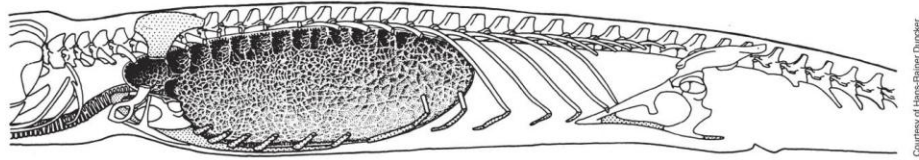
**Simply well vascularized sacs**

# The development of external respiration in the bullfrog (*Rana catesbeiana*)



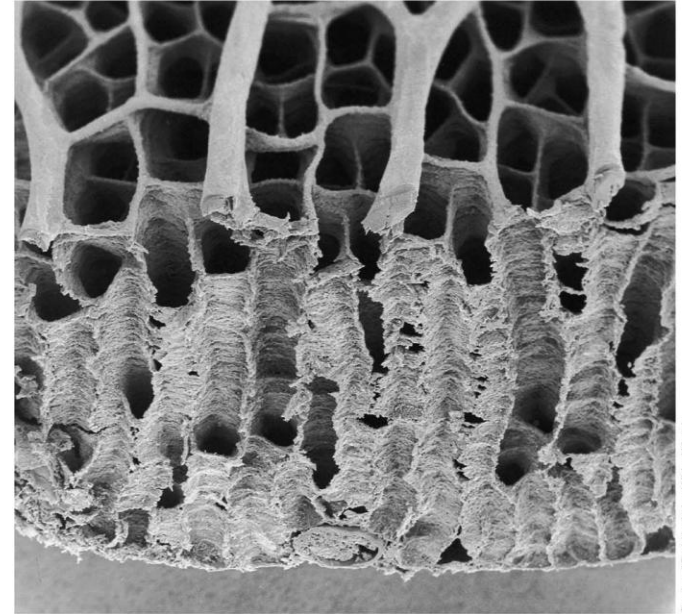
# Lizard lungs

(a) A unicameral lung in a lacertid lizard

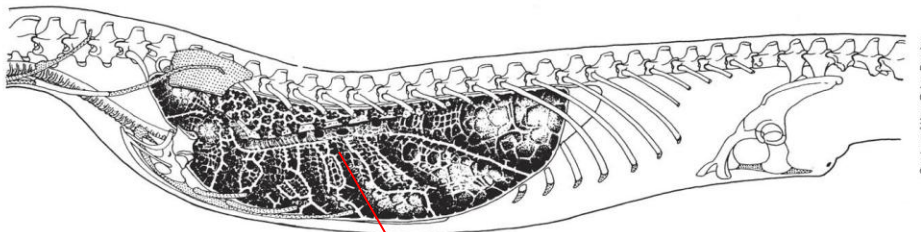


**All respiration by lungs**

(b) Scanning electron micrograph of the wall of a tegu lizard lung



(c) A multicameral lung in a monitor lizard

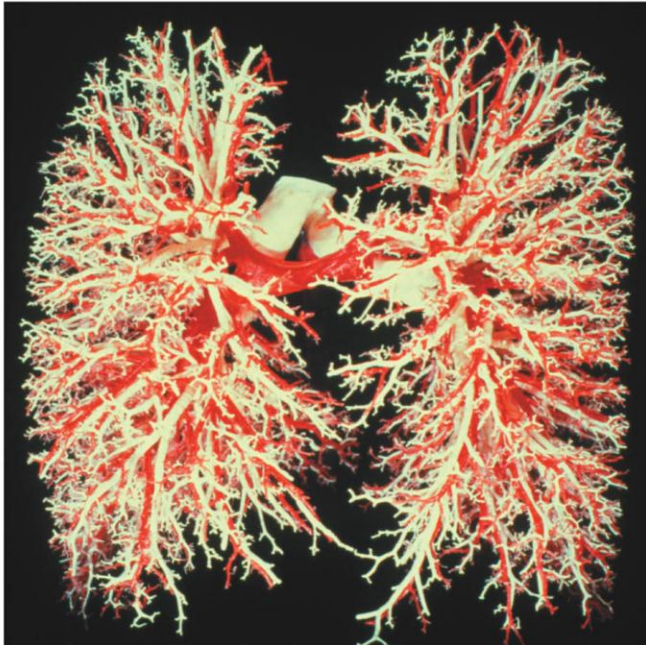


Bronchus: cartilage-reinforced tube

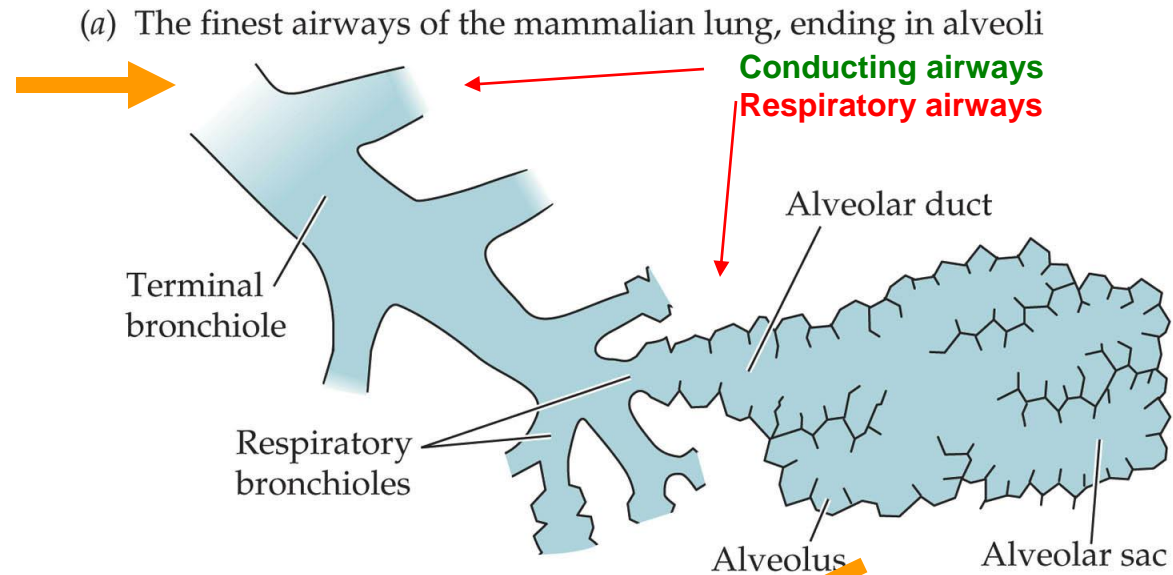
**Lungs filled by suction.**

**Action thoracic and abdominal muscles**

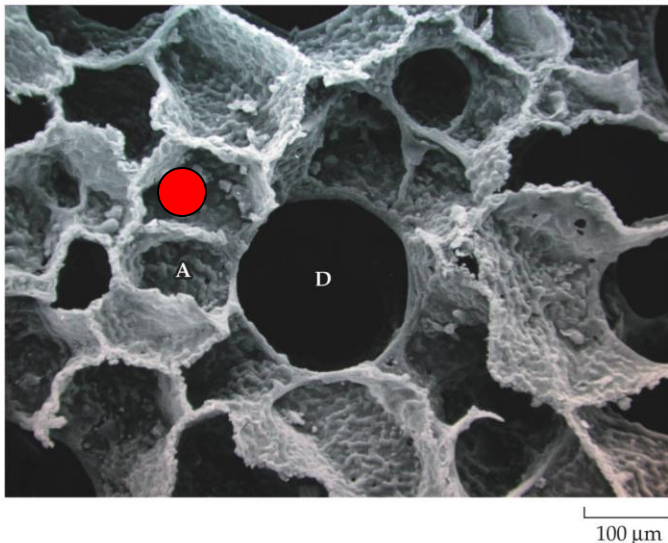
# The airways in human lungs



Airways and arteries injected with plastic



(b) Scanning electron micrograph of a human lung



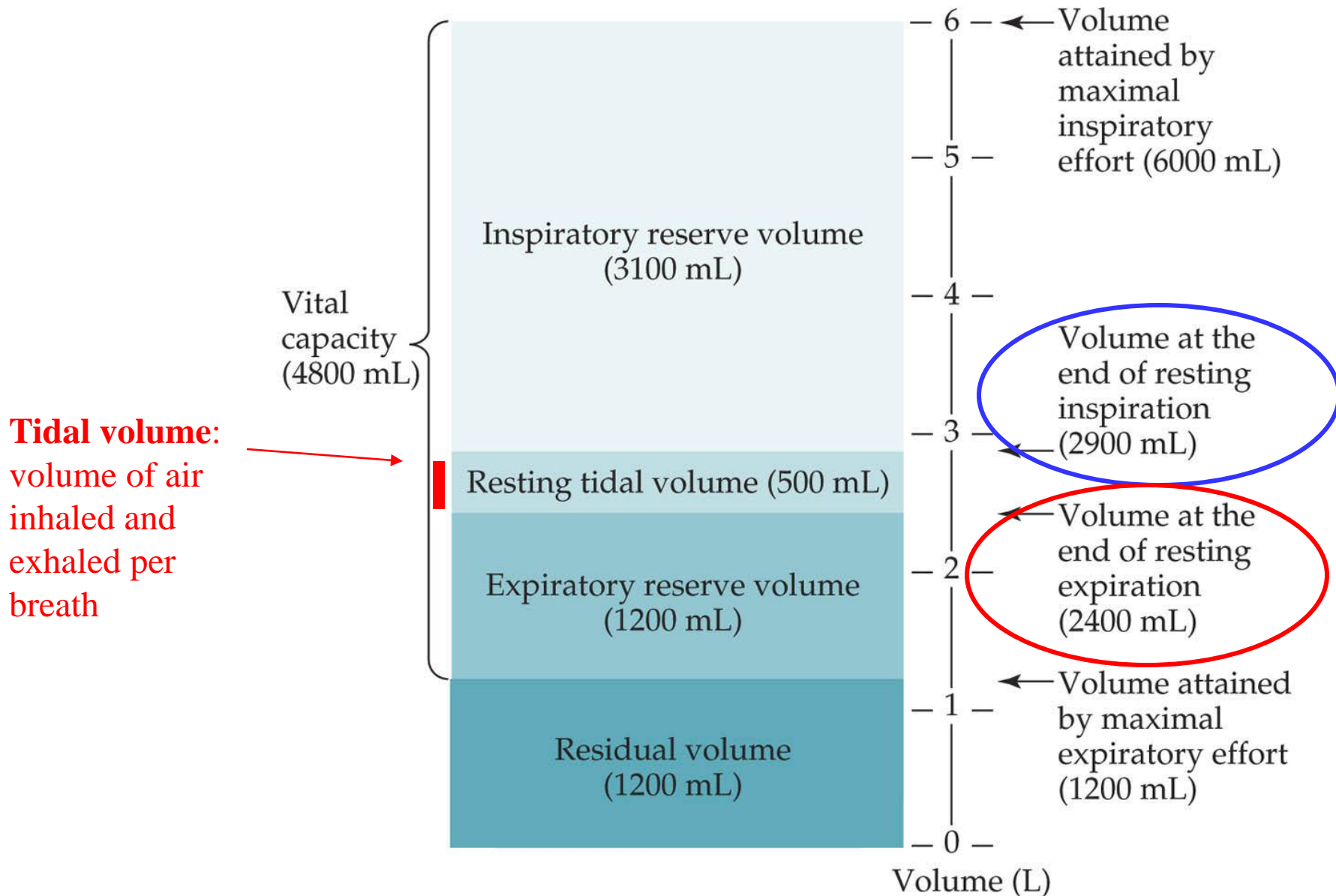
300 million alveoli in the lungs of a human

140 m<sup>2</sup> surface

Trachea  
primary bronchus,  
secondary bronchus  
higher-order bronchi

Bronchioles  
Alveolar ducts  
Alveolar sacs  
alveoli

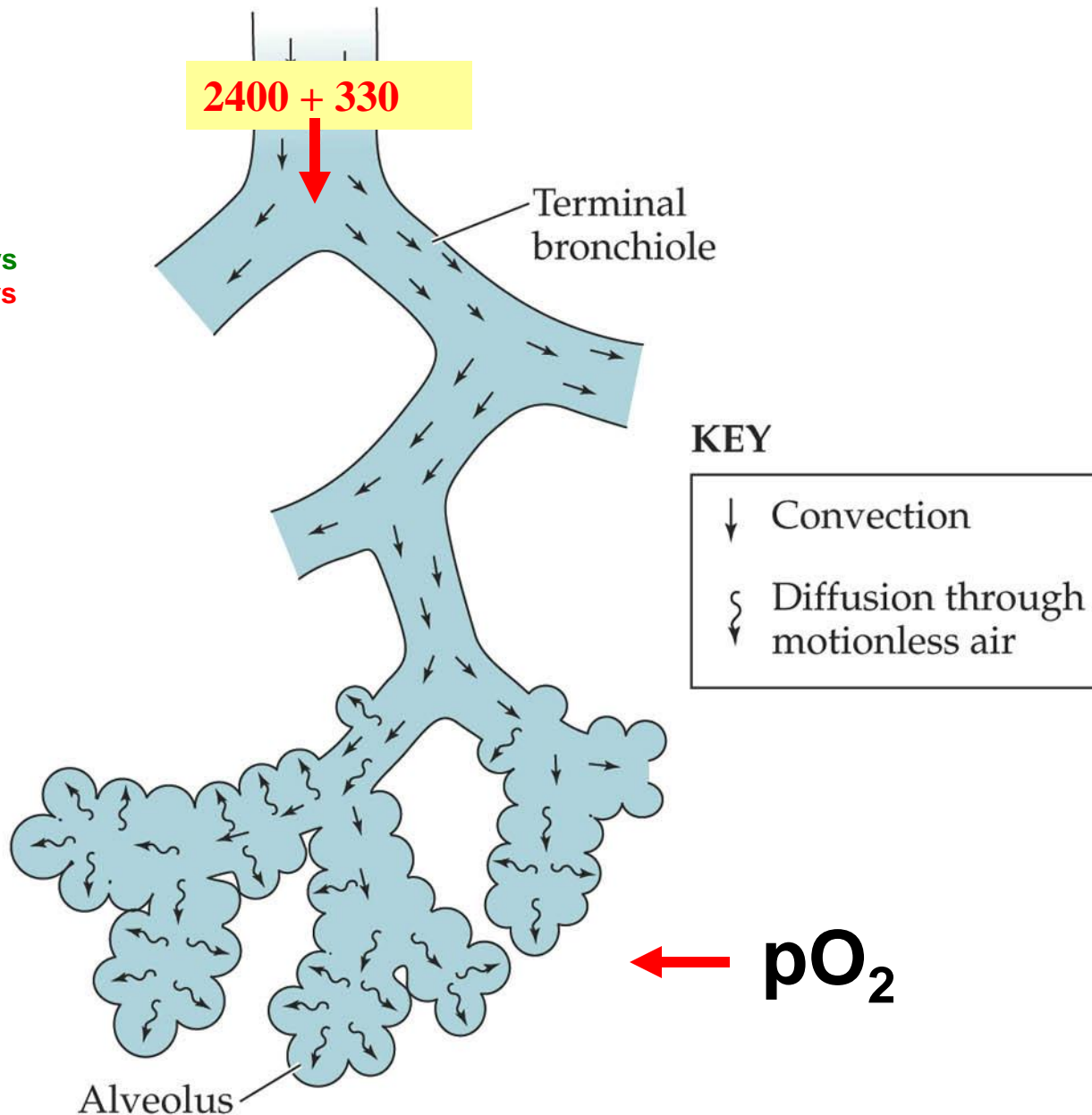
# Dynamic lung volumes in healthy young adult men



# Mechanisms of gas transport in final branches of mammalian lungs during inhalation

2400 Vol Exp  
500 (170-330)

↑  
Conducting airways  
Respiratory airways



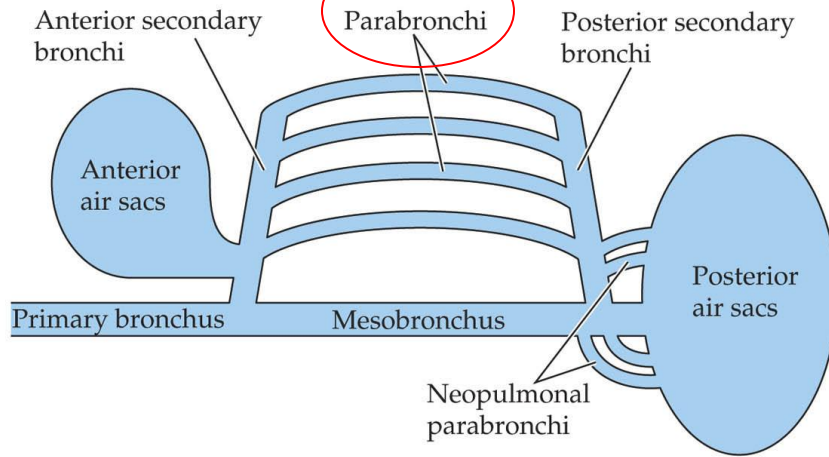
# Airflow in the lungs and air sacs of birds

bellows



**GAS EXCHANGE**

(a) Anatomy

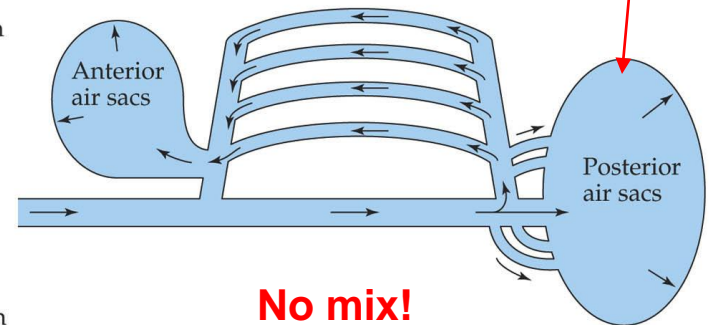


**Fly (high metabolism)!**  
**High elevation (less oxygen)**

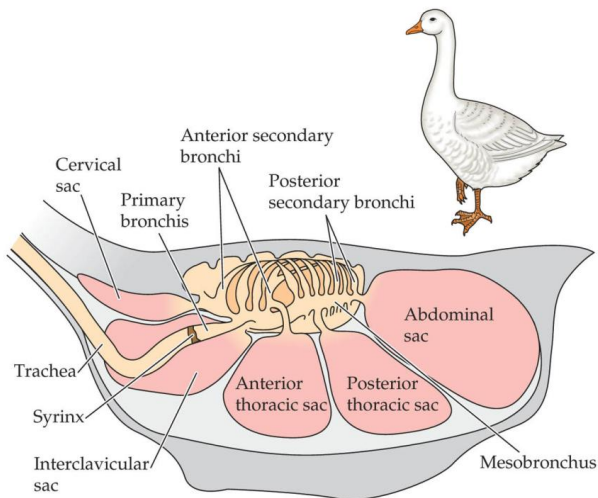
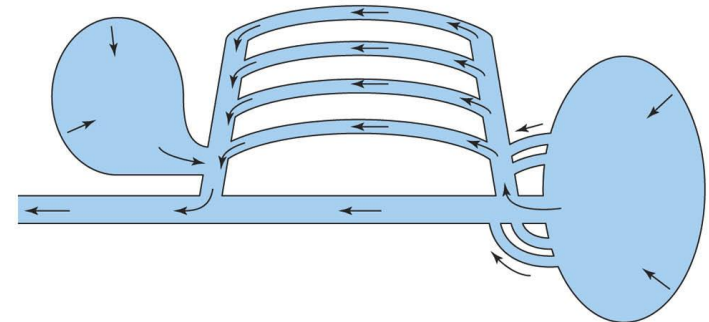
**UNIDIRECTIONAL FLOW!**

**Fresh air**

(b) Inhalation



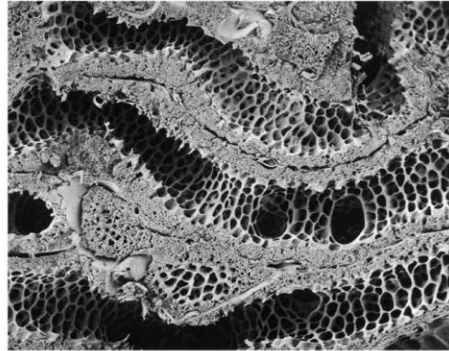
(c) Exhalation



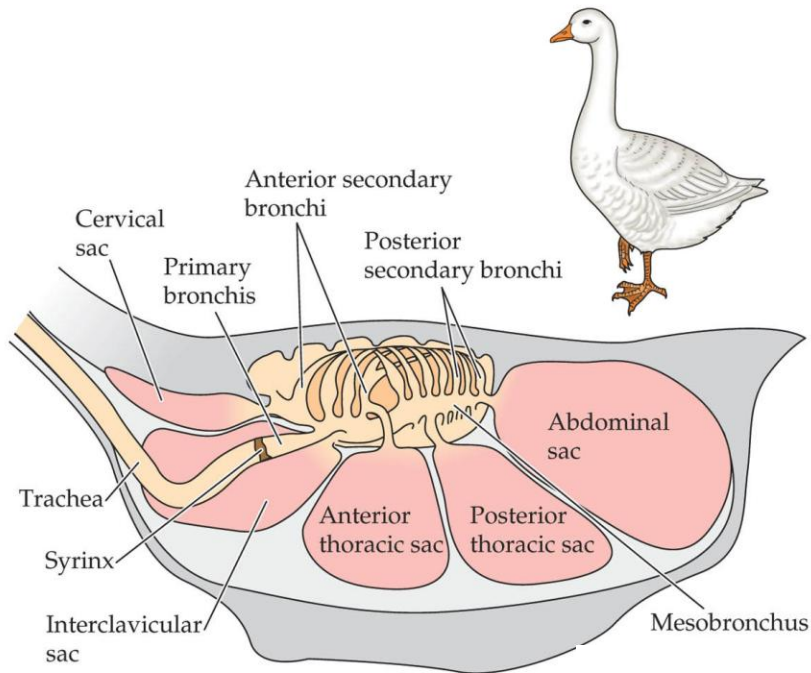
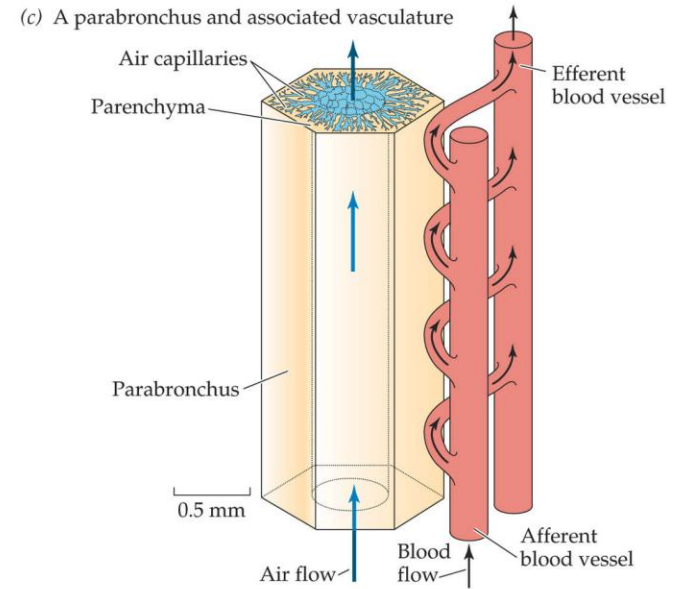
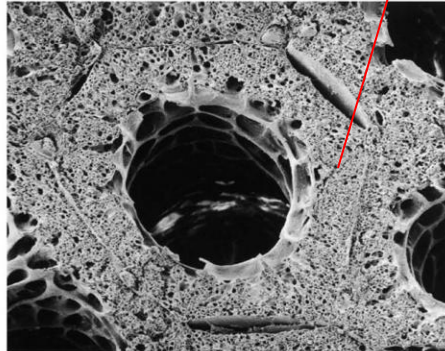
# Parabronchi and air capillaries: The gas-exchange sites in avian lungs

## Air capillaries and blood capillaries

(a) Scanning electron micrograph of parabronchi in longitudinal section



(b) Scanning electron micrograph of a parabronchus in cross section



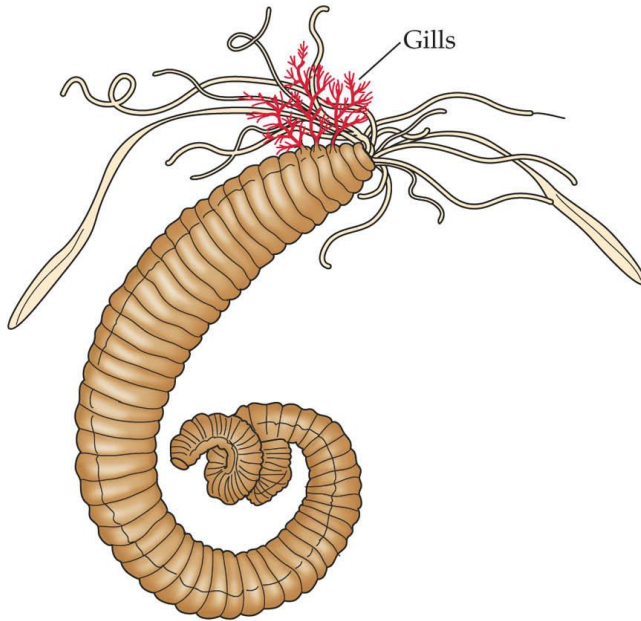
**Greater tidal volumes**

**High gas exchange surface**

**Thin gas exchange membrane**

# A diversity of gills in aquatic invertebrates

(a) Polychaete annelid with gill tufts

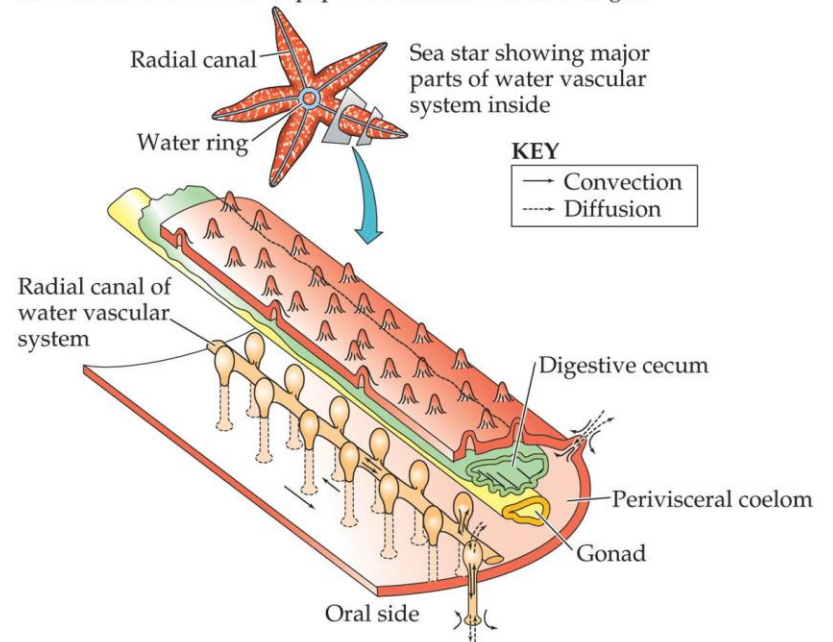


(b) Polychaete annelid with tentacular fan



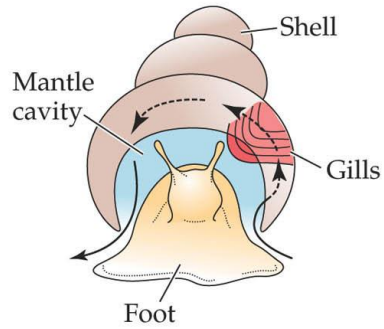
## External gills

(c) Sea star with branchial papulae and tube feet used as gills

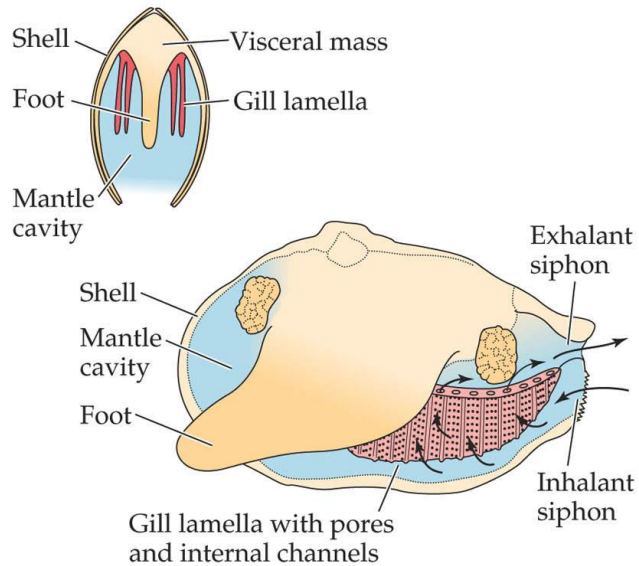


# The diversification of the breathing system in molluscs

(a) Aquatic snail



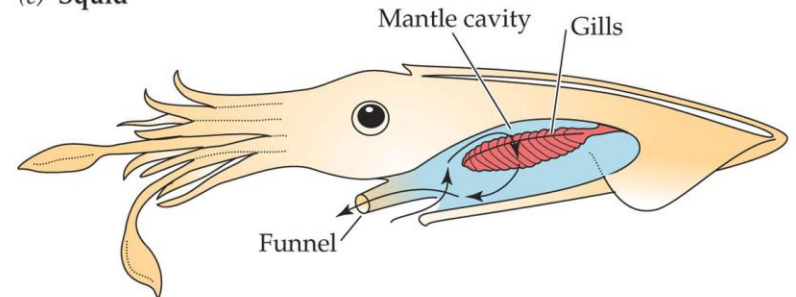
(b) Clam



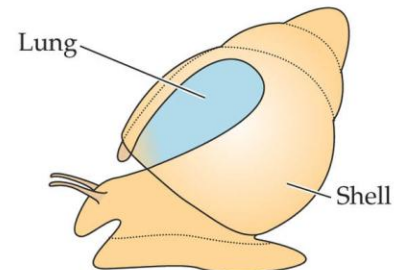
## Internal gills

Sheet-gilled = lamellibranchs

(c) Squid

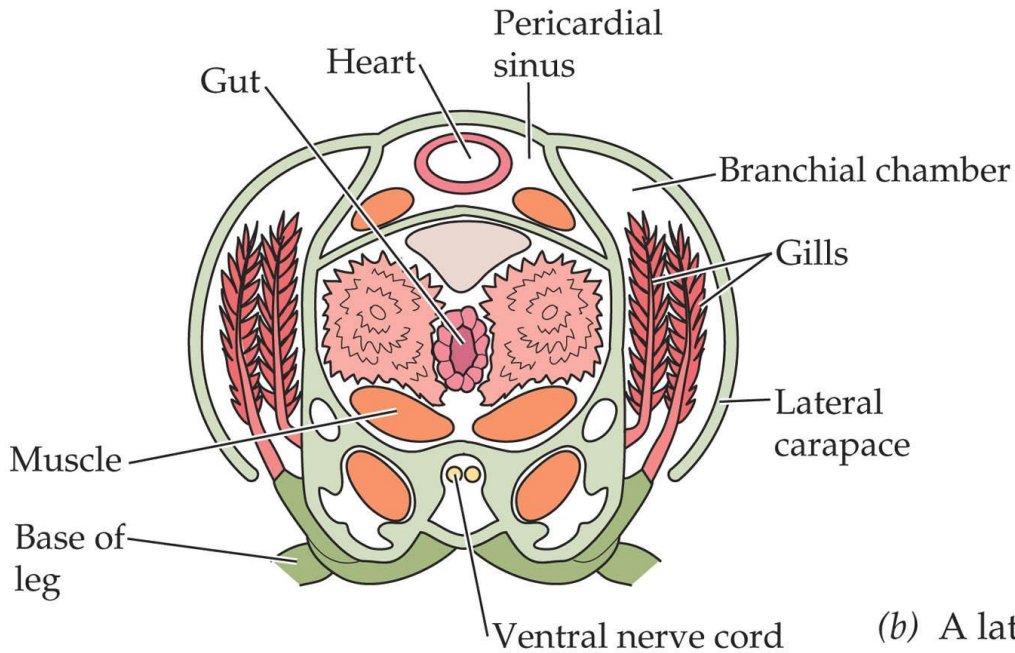


(d) Pulmonate land snail

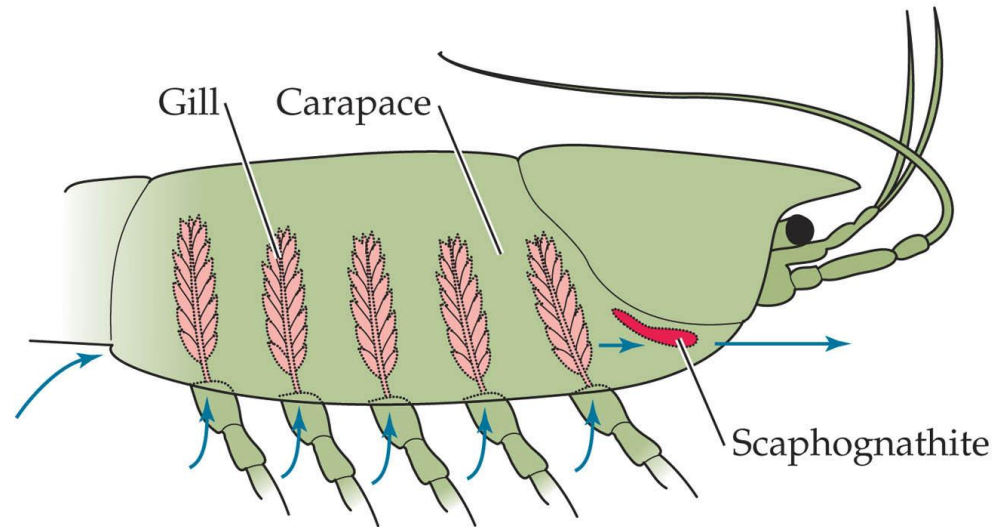


# The gills and ventilation in a crayfish (Decapod crustacean)

(a) A transverse section through the thorax of a crayfish

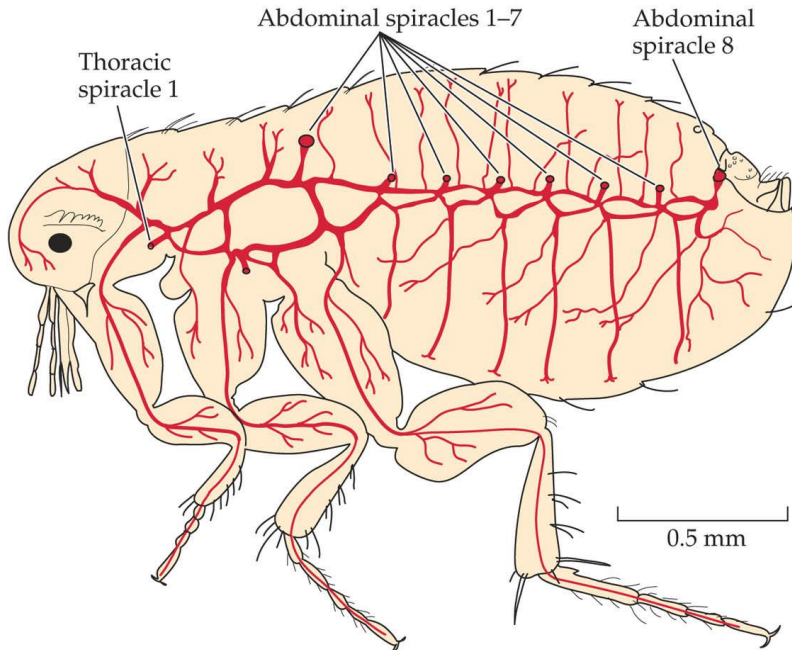


(b) A lateral view showing the gills under the carapace

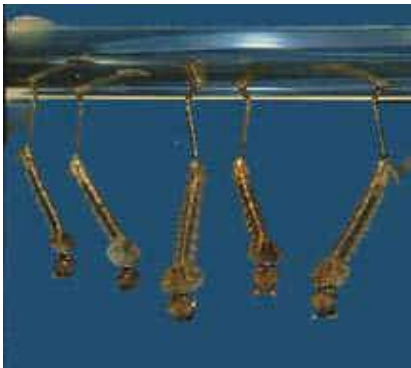


# All insects breathe using a tracheal system of gas-filled tubes

(b) Major parts of the tracheal system in a flea

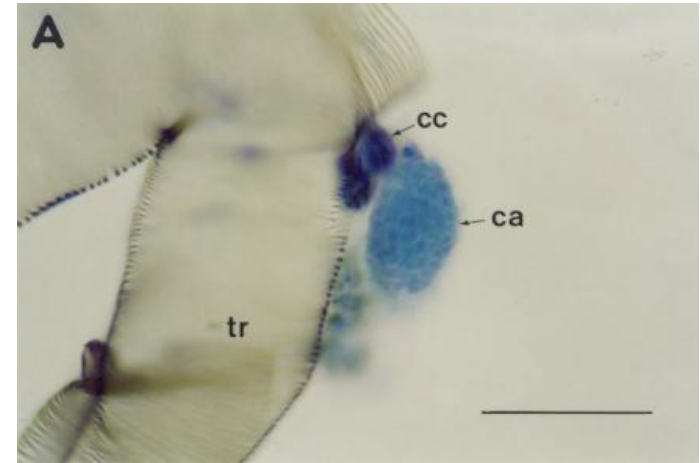


**Spiracle control (desiccation)**  
**Active Ventilation**

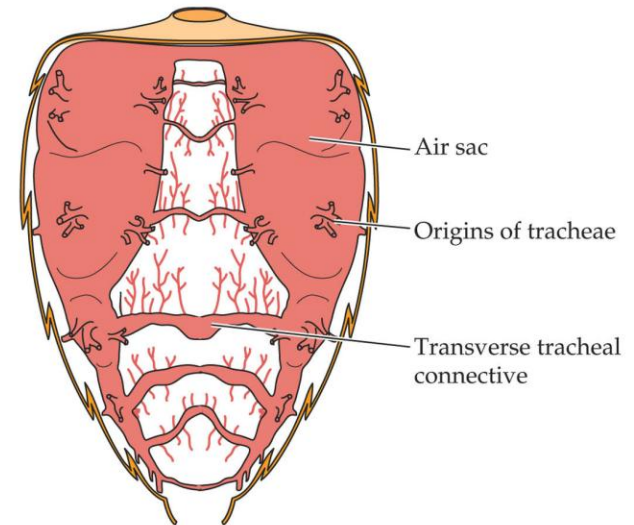


**Spiracles in the surface**  
**Tracheal Gills**

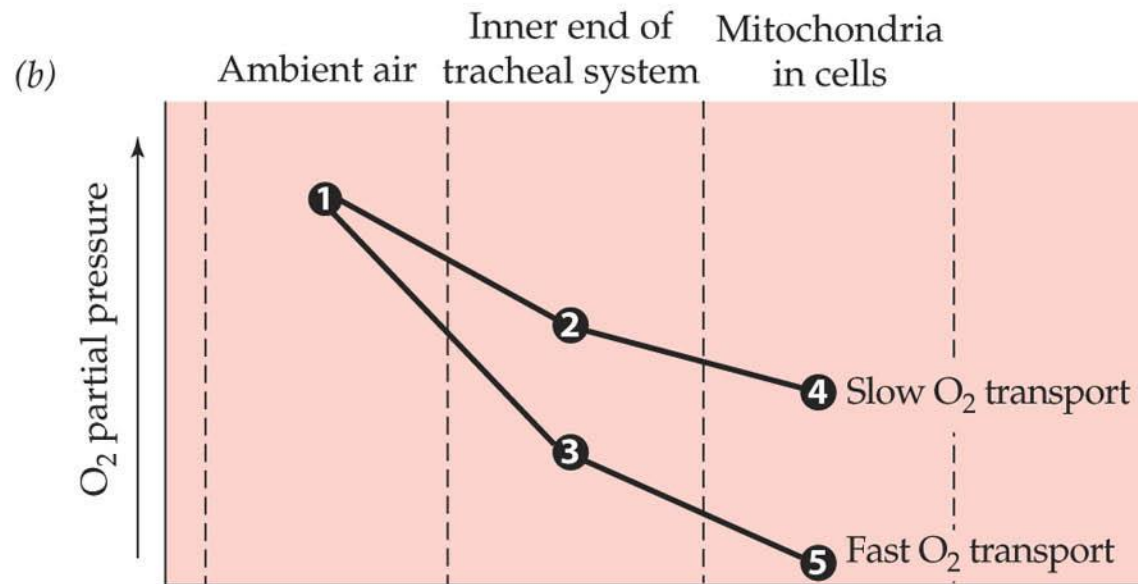
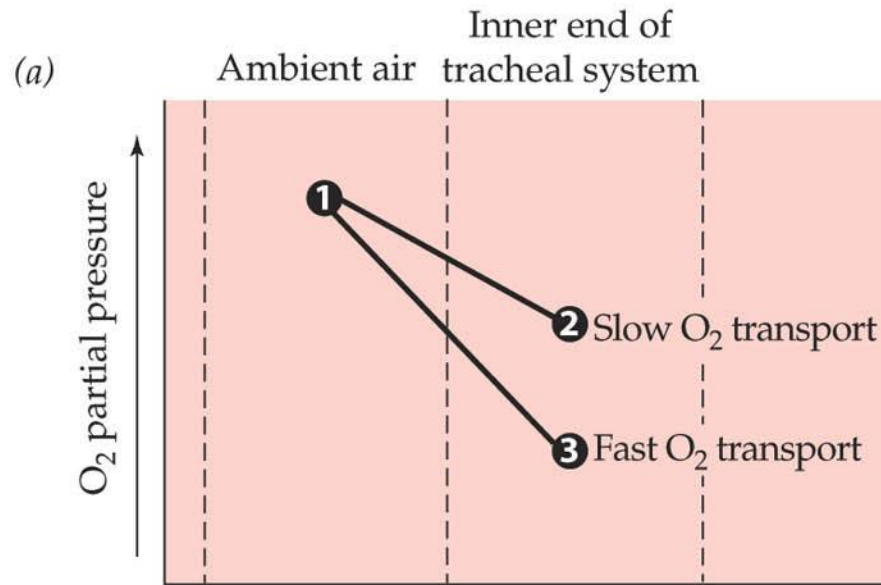
**The gas-exchange surface is close to each cell**



(c) Air sacs in the abdomen of a worker honeybee



# Insect oxygen cascades assuming oxygen transport by diffusion



# A book lung

