Meccanismi funzionali di adattamento all’ambiente

UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA
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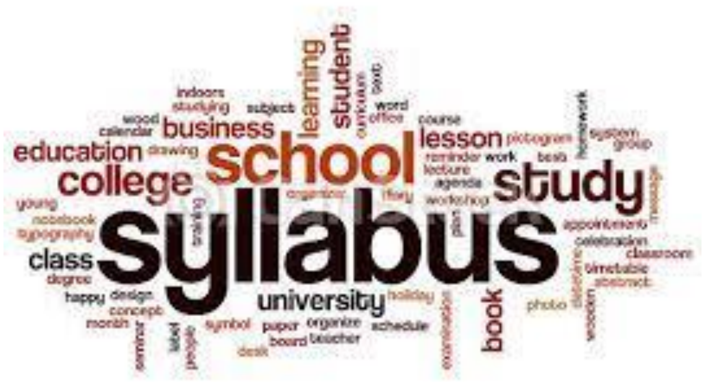
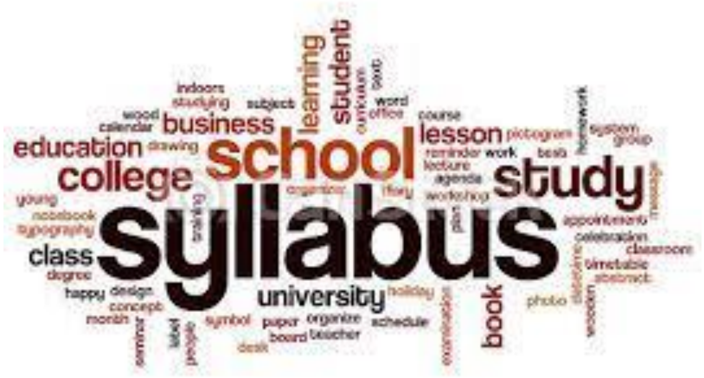
Course outline



- ✓Circulatory system
- ✓Respiratory system
- ✓Osmoregulation and excretion

Course outline



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- ✓Respiratory system
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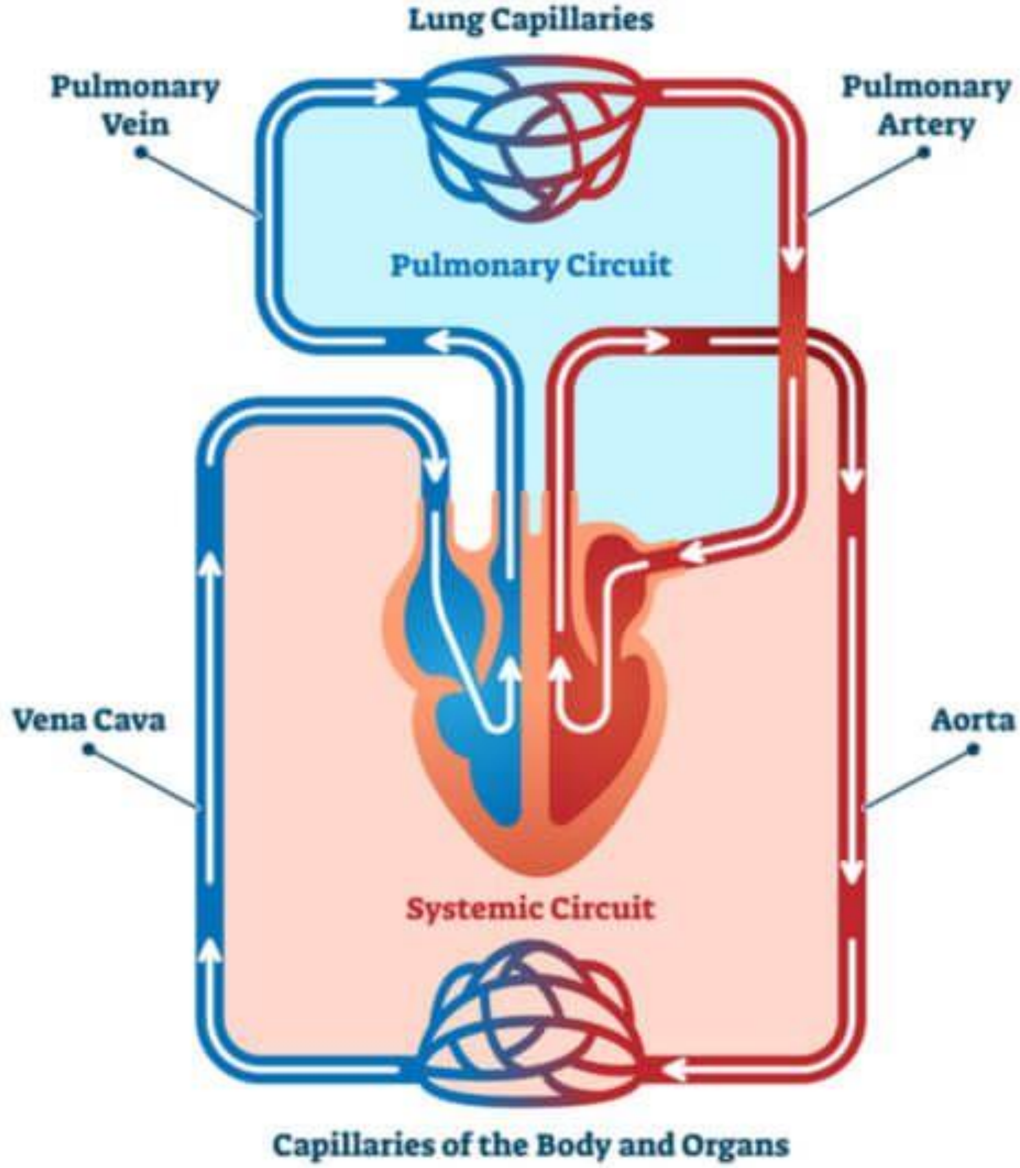
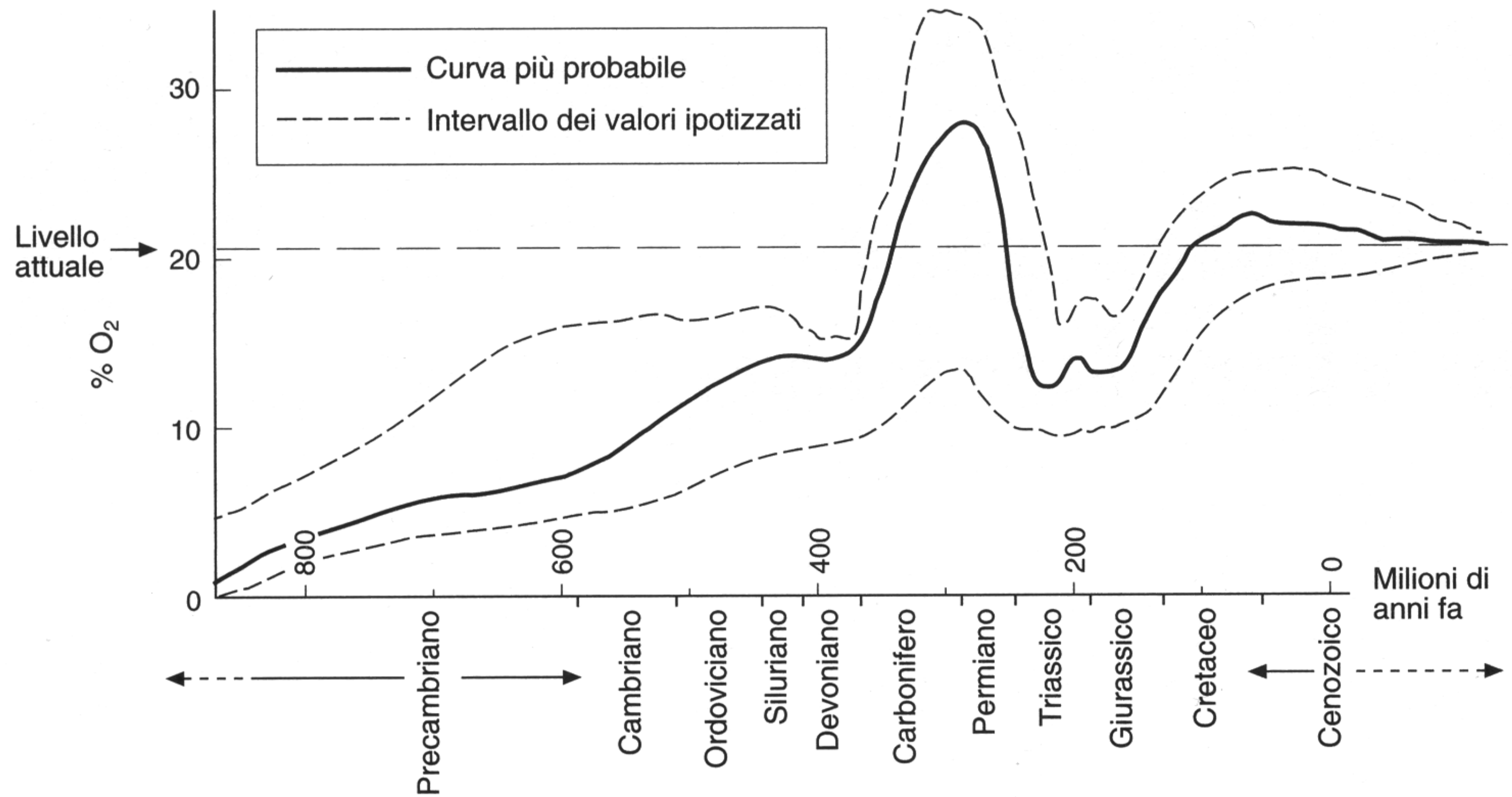

Lung Capillaries
Pulmonary Vein
Pulmonary Artery
Pulmonary Circuit
Vena Cava
Aorta
Systemic Circuit
Capillaries of the Body and Organs

Gas Demands

- Energy is essential for sustaining all life supporting cellular activities. For most animals to survive for extended periods of time, aerobic (oxygen-using) metabolism is necessary
- Gas exchange supplies O_2 for cellular respiration and disposes of CO_2
- In addition to obtaining O_2, animals must eliminate the CO_2 produced as a byproduct of aerobic metabolism at the same rate it is produced to prevent dangerous fluctuations in pH (that is, to maintain the acid–base balance), because CO_2 generates carbonic acid



Curva più probabile
Intervallo dei valori ipotizzati
30
20
10
0
Livello attuale
% O2
800
600
400
200
0
Milioni di anni fa
Precambriano
Cambriano
Ordoviciano
Siluriano
Devoniano
Carbonifero
Permiano
Triassico
Giurassico
Cretaceo
Cenozoico

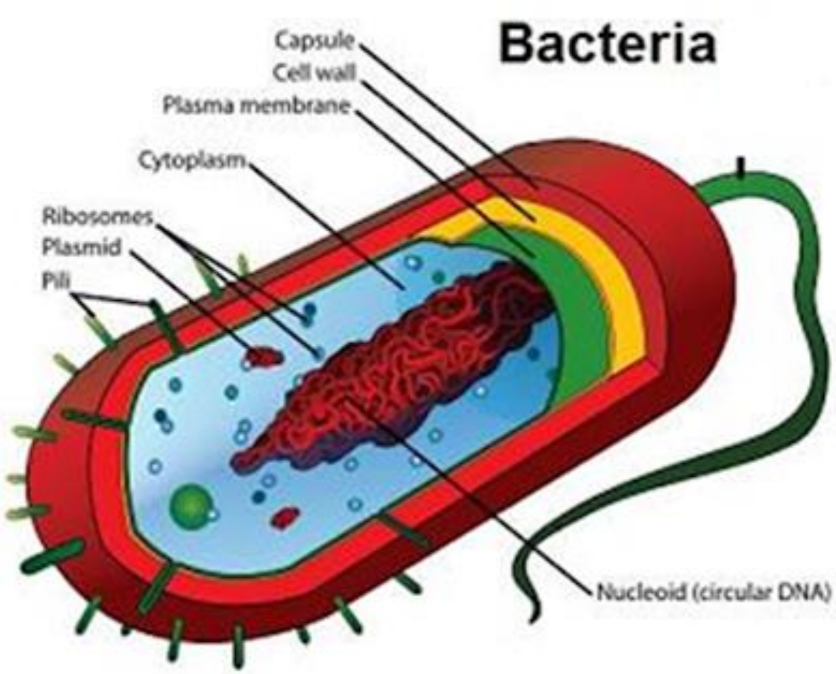
Geological History of Oxygen

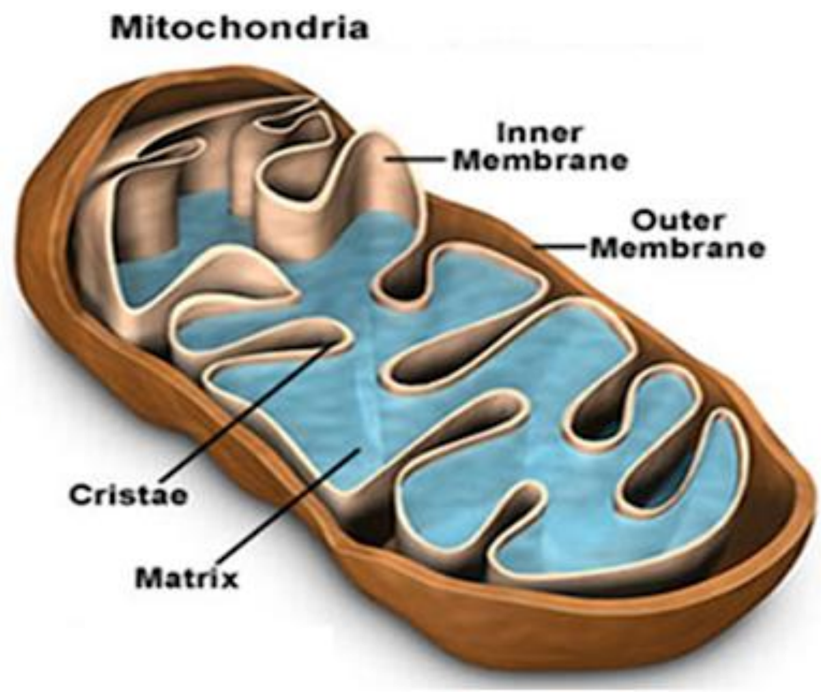
SCAN ME

In this Click & Learn, students explore an interactive graph of atmospheric oxygen levels over the last 3.8 billion years, which covers three geologic eons: the Archean, the Proterozoic, and the Phanerozoic.

The graph includes descriptions of the biological and geological factors that influenced oxygen levels in different time periods, and how life on Earth was affected.

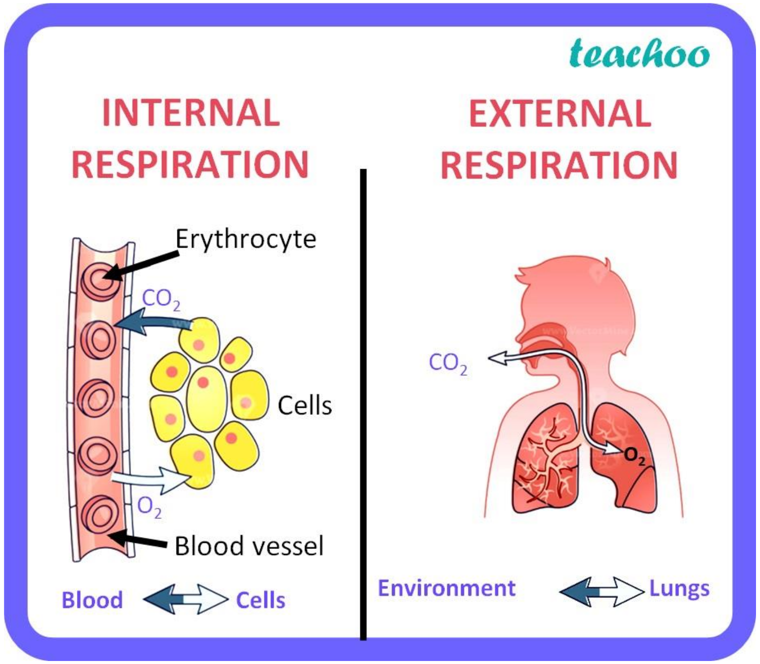
Cellular Respiration: use of oxygen by cells to produce ATP





Respiration

The term **respiration** refers to all of the processes of gas movement and metabolism, with two distinct components:



1. External Respiration: exchange of gases between air in the lungs and in the blood

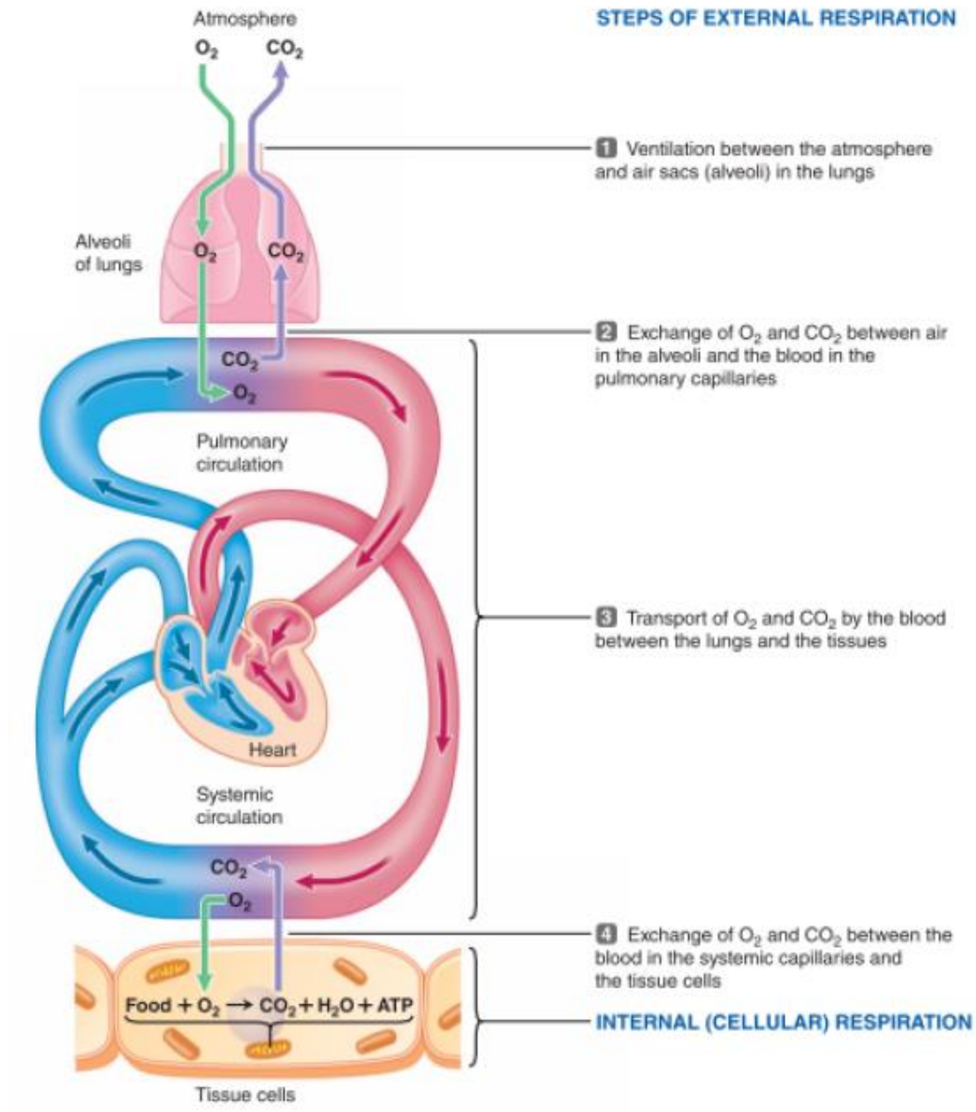
2. Internal Respiration: exchange of gases between the blood and the cells of the body

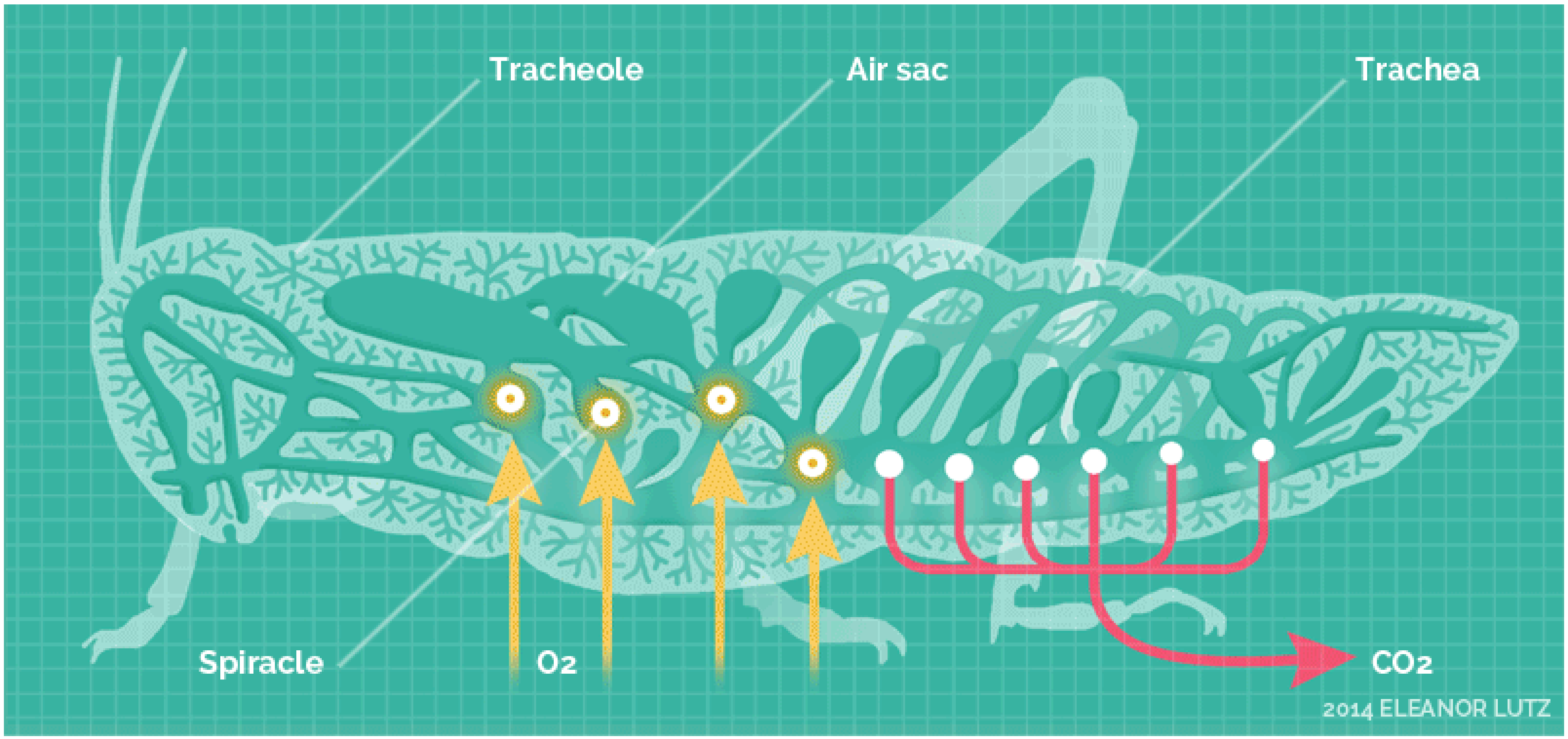
External respiration

External respiration, also known as breathing, involves both bringing air into the lungs (inhalation) and releasing air to the atmosphere (exhalation).

During internal respiration, oxygen and carbon dioxide are exchanged between the cells and blood vessels.

- ✓ *Exchange* (i.e., O2 and CO2 moving oppositely) across membranes by the relatively slow process of *diffusion,* and
- ✓ *Bulk transport*—the movement of the medium that contains the O2 and CO2
    a. bypasses diffusion altogether to move gases much more quickly than diffusion
    b. enhances diffusion gradients

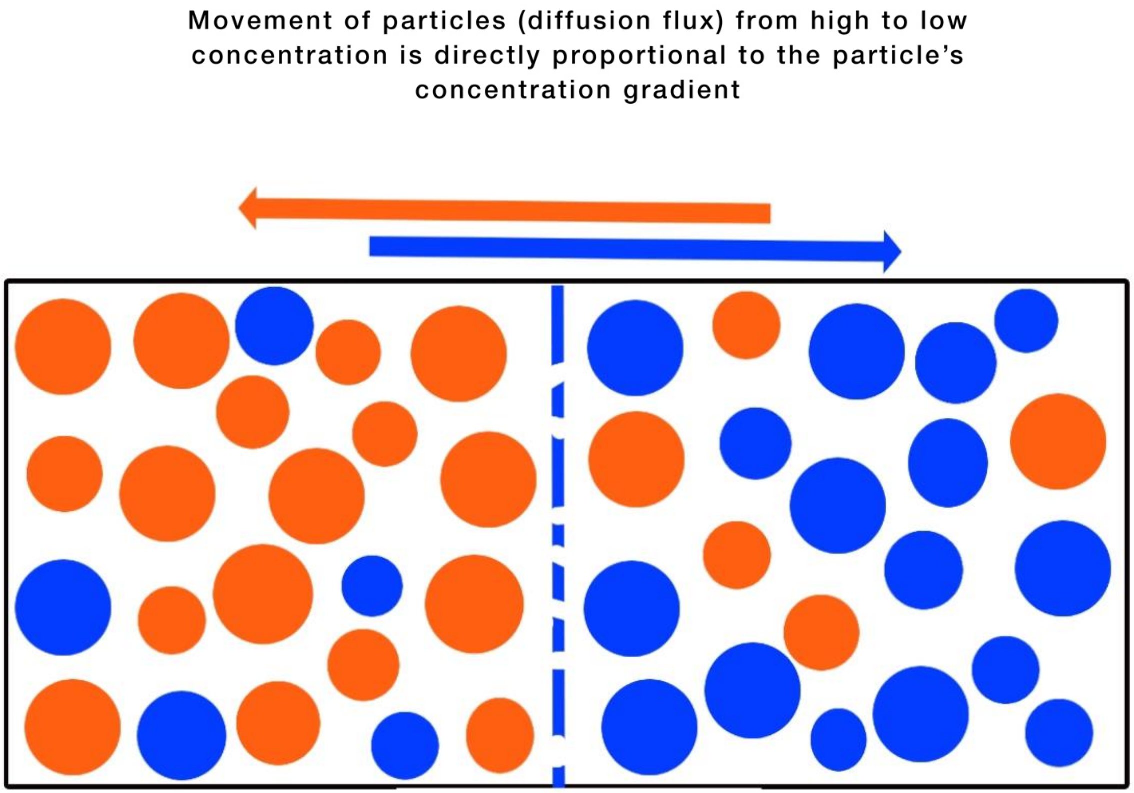

STEPS OF EXTERNAL RESPIRATION
Atmosphere
O_2
CO_2
Alveoli of lungs
O_2
CO_2
1 Ventilation between the atmosphere and air sacs (alveoli) in the lungs
CO_2
O_2
2 Exchange of O_2 and CO_2 between air in the alveoli and the blood in the pulmonary capillaries
Pulmonary circulation
3 Transport of O_2 and CO_2 by the blood between the lungs and the tissues
Heart
Systemic circulation
CO_2
O_2
4 Exchange of O_2 and CO_2 between the blood in the systemic capillaries and the tissue cells
Food + O_2 → CO_2 + H_2O + ATP
INTERNAL (CELLULAR) RESPIRATION
Tissue cells



Tracheole
Air sac
Trachea
Spiracle
O2
CO2
2014 ELEANOR LUTZ

Gas diffusion

Gas diffusion follows Fick's law for partial pressure gradients



Gas diffusion

For gases, the term C (concentration) is replaced with the partial pressure P as follows:

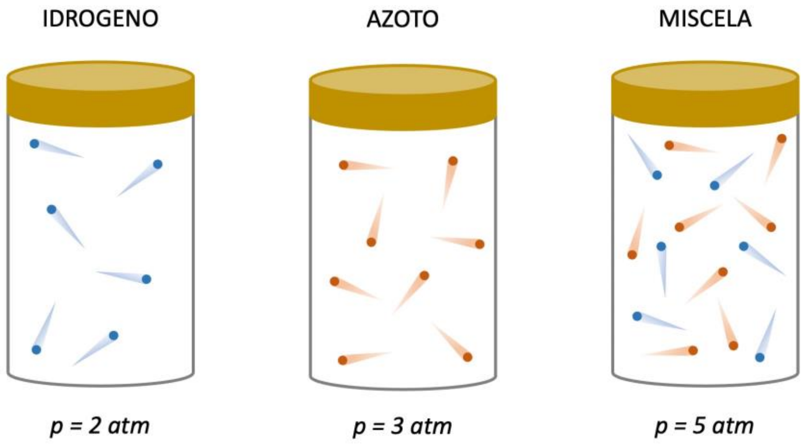
$$\text{Rate of diffusion } (Q) = \frac{\Delta P \cdot A \cdot D}{\Delta X}$$

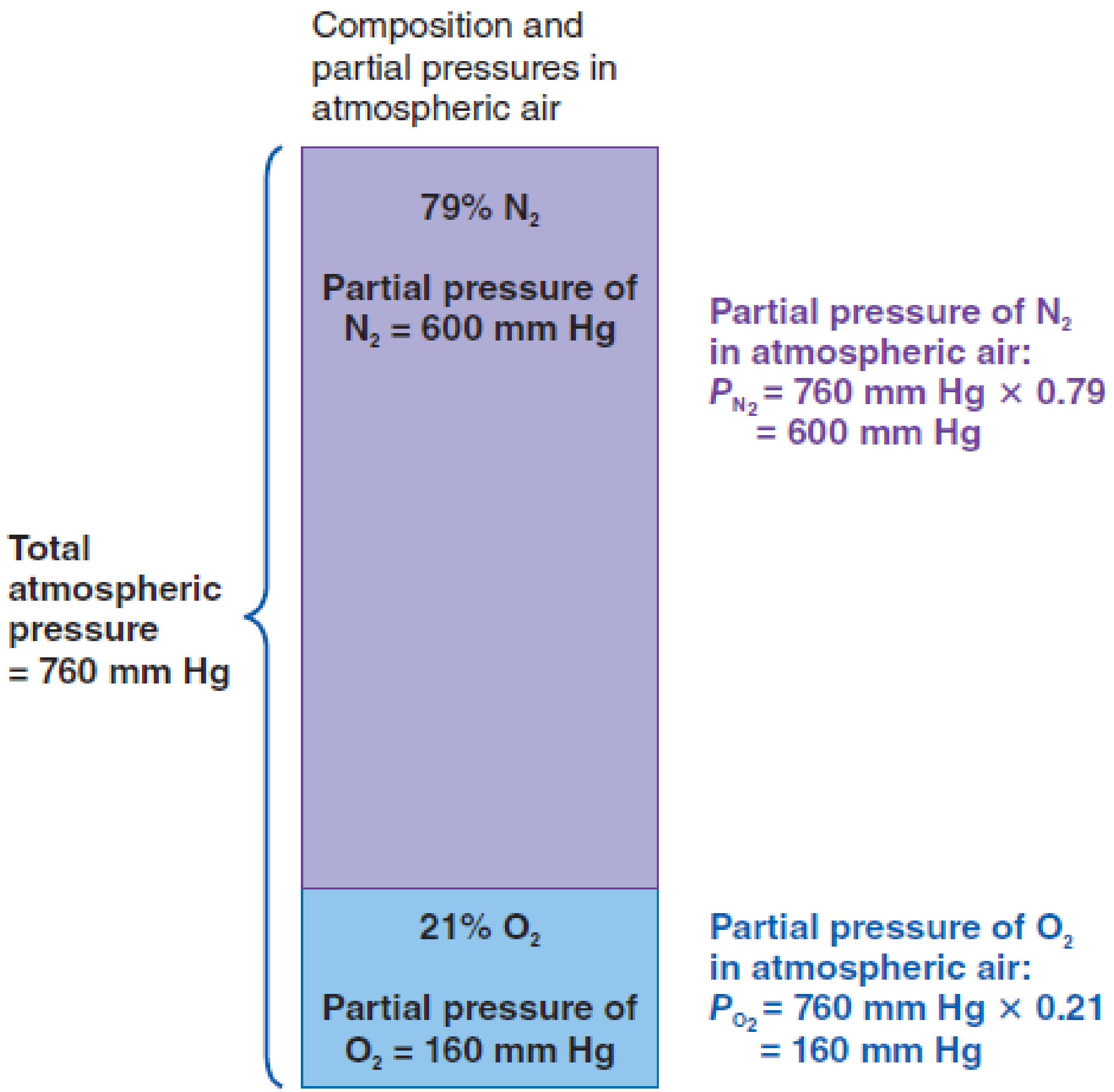
D *= the diffusion coefficient (which depends on, among other things, molecular weight, temperature, and the permeability of any barrier between two points)*
A *= the surface area for gas exchange*
ΔP *= the gas gradient (in partial pressure) = P1 − P2, where P1 is the partial pressure in one compartment and P2 is the pressure in the other*
ΔX *= the distance the gas must cover*

Partial pressure

- ✓ The total pressure is equal to the sum of the pressures that each gas in the mixture partially contributes.

- ✓ The pressure exerted by a particular gas is directly proportional to the percentage of that gas in the total air mixture.




Composition and partial pressures in atmospheric air
79% N_2
Partial pressure of N_2 = 600 mm Hg
21% O_2
Partial pressure of O_2 = 160 mm Hg
Total atmospheric pressure = 760 mm Hg
Partial pressure of N_2 in atmospheric air:
P_{N_2} = 760 mm Hg × 0.79 = 600 mm Hg
Partial pressure of O_2 in atmospheric air:
P_{O_2} = 760 mm Hg × 0.21 = 160 mm Hg

Gas Exchange During Breathing

TABLE 8.7 Partial Pressures of Gases During Breathing

Gas	Partial Pressure (mmHg) Inspired Air	Alveolar Air	Expired Air
Nitrogen, N_2	594	573	569
Oxygen, O_2	160.	100.	116
Carbon dioxide, CO_2	0.3	40.	28
Water vapor, H_2O	5.7	47	47
Total	760.	760.	760.

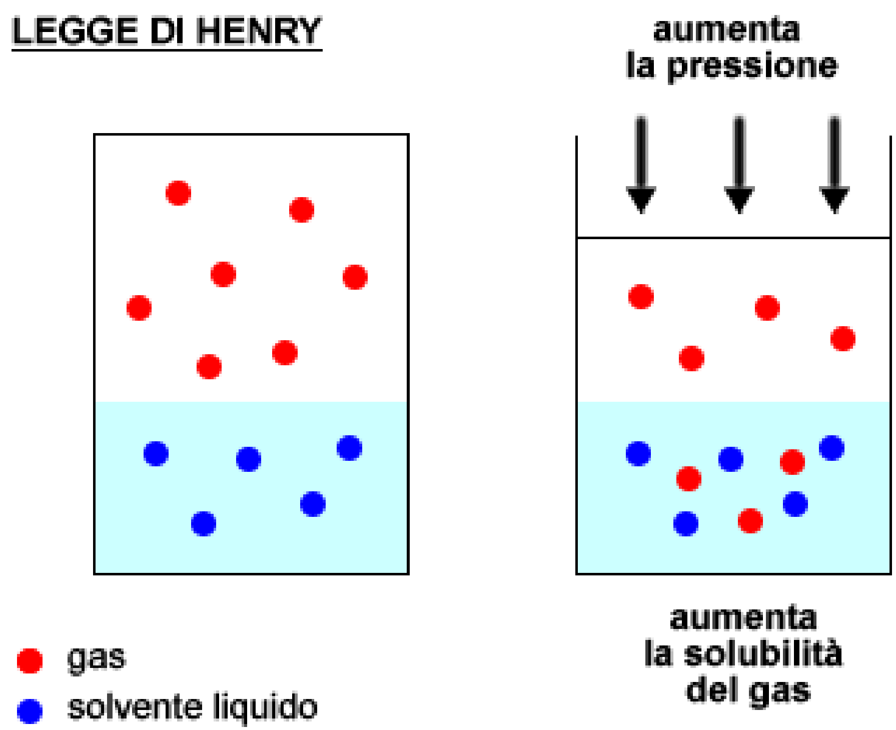
General, Organic, and Biological Chemistry: Structures of Life, 5/e
Karen C. Timberlake

The individual pressure exerted independently by a particular gas within a mixture of gases is known as its **partial pressure,** designated by P_{gas}.

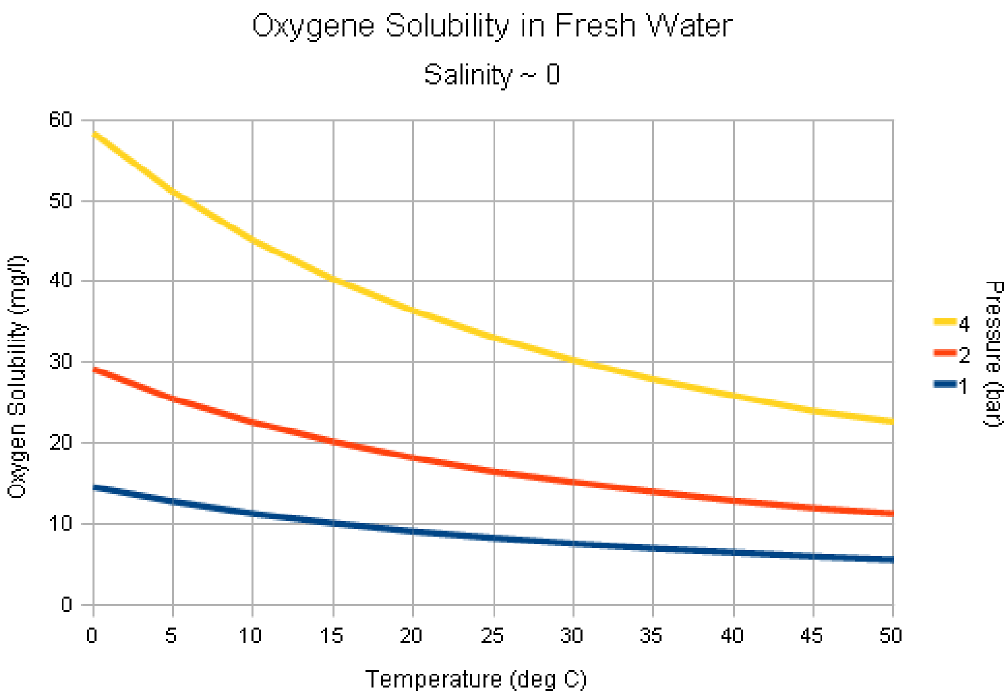
The partial pressure of O_2 in dry atmospheric air, P_{O_2}, is normally about 160 mm Hg. The atmospheric partial pressure of CO_2, P_{CO_2}, is negligible at 0.3 mm Hg.

Henry's law describes the behavior of gases when they come into contact with a liquid, such as blood. Henry's law states that the concentration of gas in a liquid is directly proportional to the solubility and partial pressure of that gas.

- ✓ The greater the partial pressure of the gas, the greater the number of gas molecules that will dissolve in the liquid.
- ✓ The concentration of the gas in a liquid is also dependent on the solubility of the gas in the liquid.



The amount of a gas that will dissolve in the blood depends on the gas's solubility in water and on the partial pressure of the gas in the environment to which the blood is exposed.



Because O_2 is nonpolar, it is very poorly soluble in water. So even if air and water have the same PO_2, the actual concentration is much higher in air than water.

External respiratory processes must meet the demands of size, metabolism, and habitat

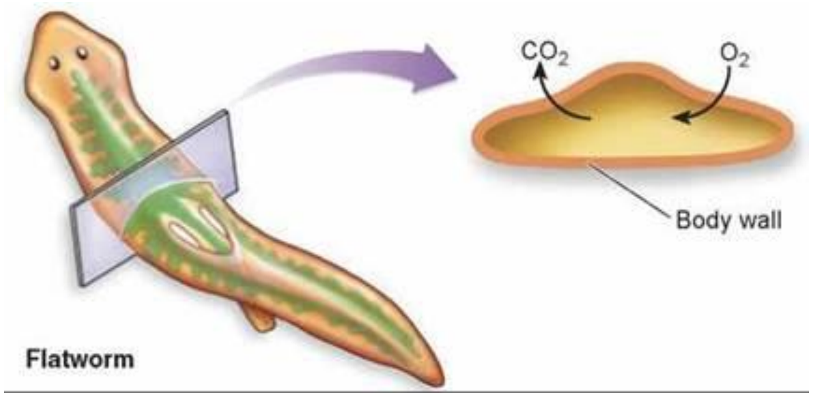
- Respiratory gases diffuse across the plasma membrane of single-celled organisms.
- As indicated by the ΔX component of Fick's law, flattened and thin shapes (which reduce distances compared to more spherical shapes) are the most efficient for exchange of O_2 and CO_2.

Paramecium

In animals, exchange occurs across respiratory surfaces, tissues that are exposed to the environment and across which O_2 and CO_2 diffuse.

Flatworm

Rotifer



What have favored enhancements in gas exchange?

$$Rate\ of\ diffusion\ (Q) = \frac{\Delta P \cdot A \cdot D}{\Delta X}$$

1. Animal *habitats*

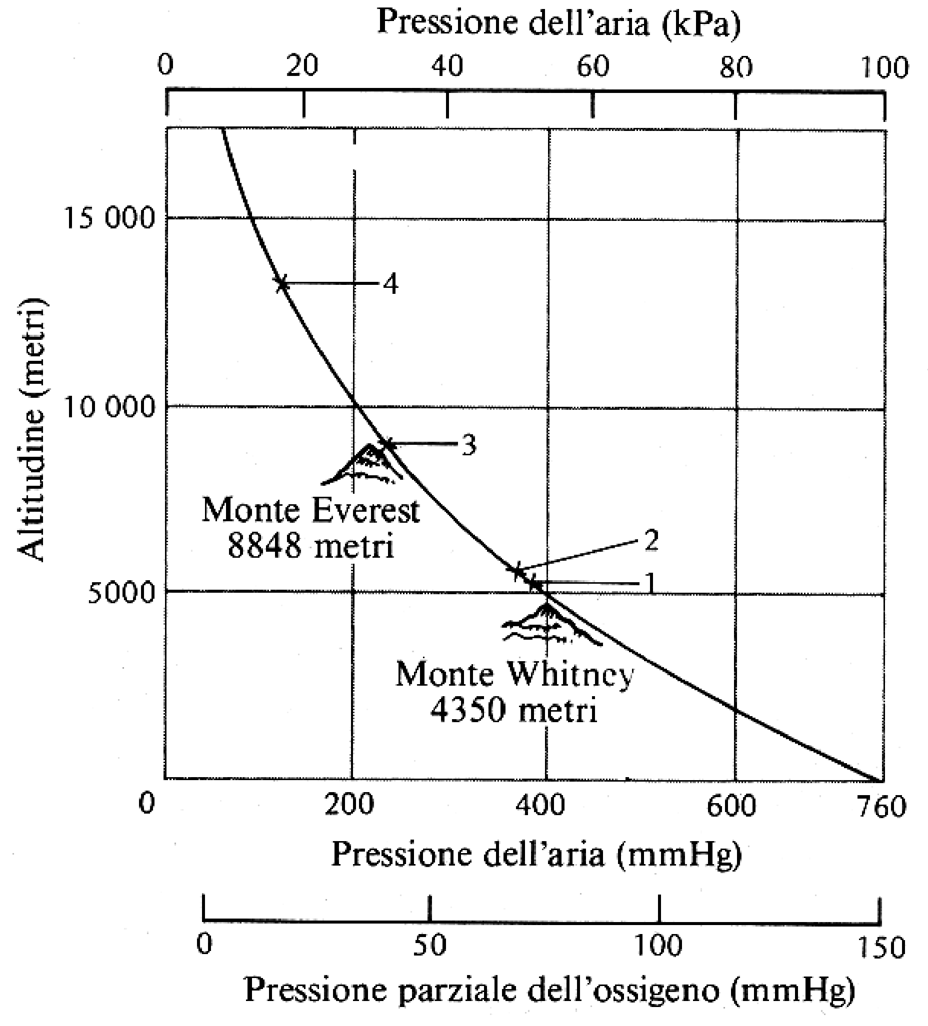
TABLE 11-1 Oxygen Concentration in Various Habitats, in mL per Liter of Medium

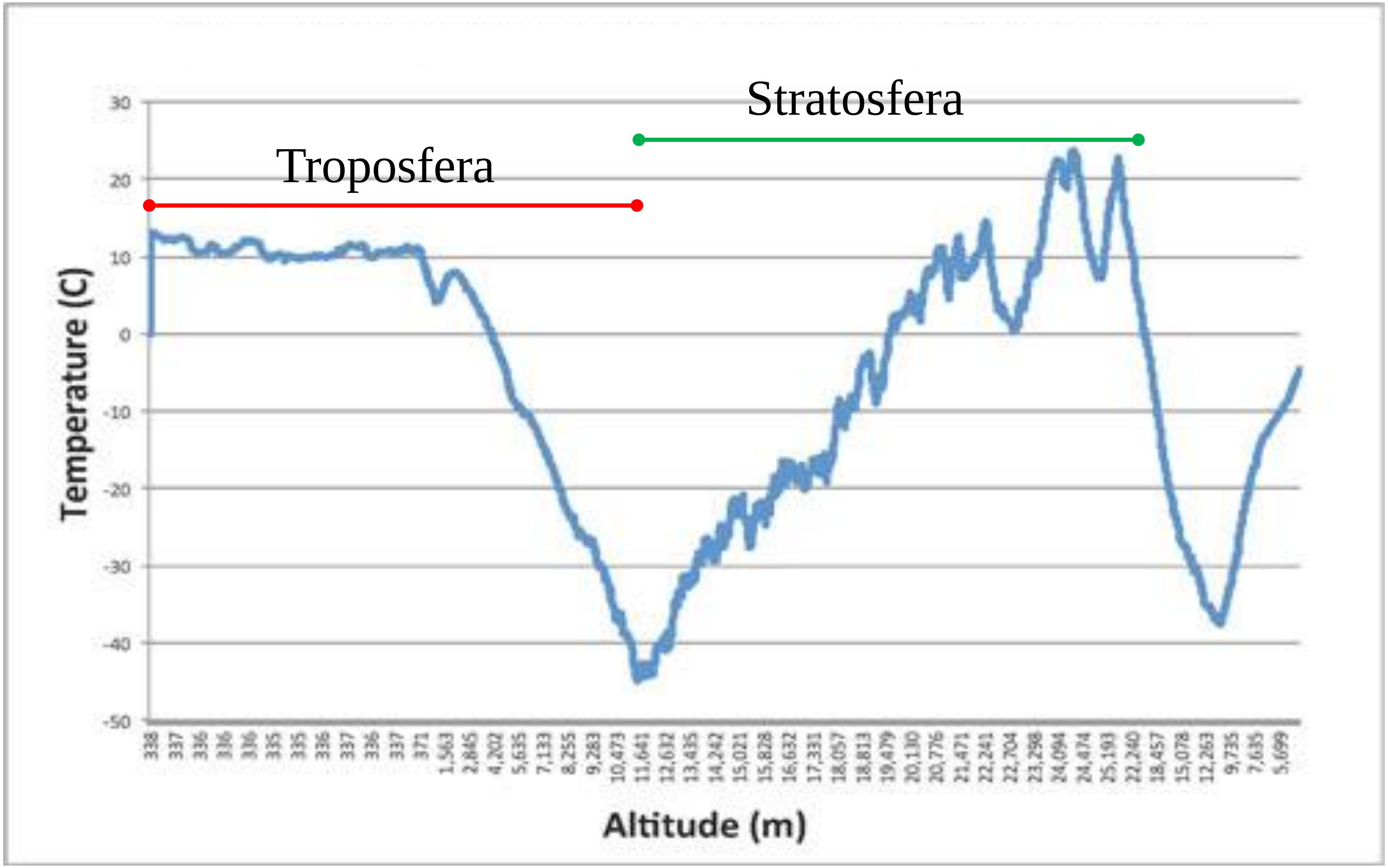
Air at sea level	209
Air at Mount Everest (8,848 m)	59
Fresh water at 0°C (maximum)	10.3
Fresh water at 30°C (maximum)	5.6
Seawater at 0°C (maximum)	8.0
Seawater at 30°C (maximum)	4.5
Seawater in Oxygen Minimum Zones, 200–1,000 m depths	0–0.7

Altitudine e pAtm

Altezza (metri)	Pressione (mmHg)	Percentuale di O_2	pO_2
0	760	20,9	159,1
1500	631	20,9	131,5
3000	514	20,9	108,1
4500	422	20,9	88,3
5500	382	20,9	79,9
6100	349	20,9	73,2
7600	281	20,9	58,8
9200	227	20,9	47,5
10 700	179	20,9	37,5
12 200	141	20,9	29,4

Pressione barometrica e pO_2 alle varie altezze.



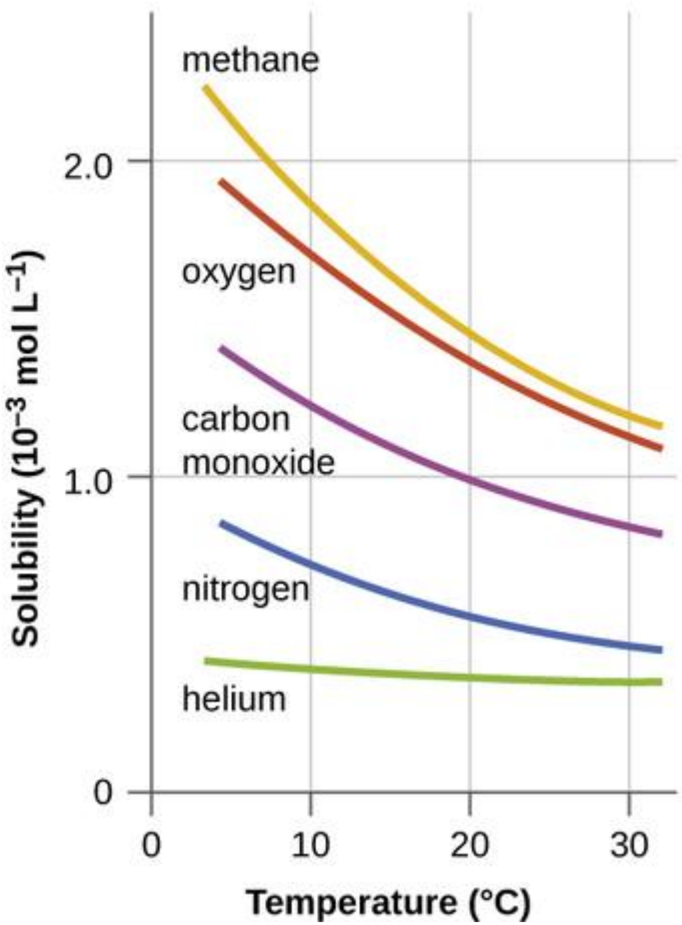

Stratosfera
Troposfera
Temperature (C)
30
20
10
0
-10
-20
-30
-40
-50
338
337
336
336
336
335
335
336
337
336
337
371
1,563
2,845
4,202
5,635
7,133
8,255
9,283
10,473
11,641
12,632
13,435
14,242
15,021
15,828
16,632
17,331
18,057
18,813
19,479
20,130
20,776
21,471
22,241
22,704
23,298
24,094
24,474
25,193
22,240
18,457
15,078
12,263
9,735
7,635
5,699
Altitude (m)

Disponibilità di ossigeno in aria e in acqua

Tabella 11-1 Concentrazioni di ossigeno in vari habitat, espresse in ml per litro di mezzo.

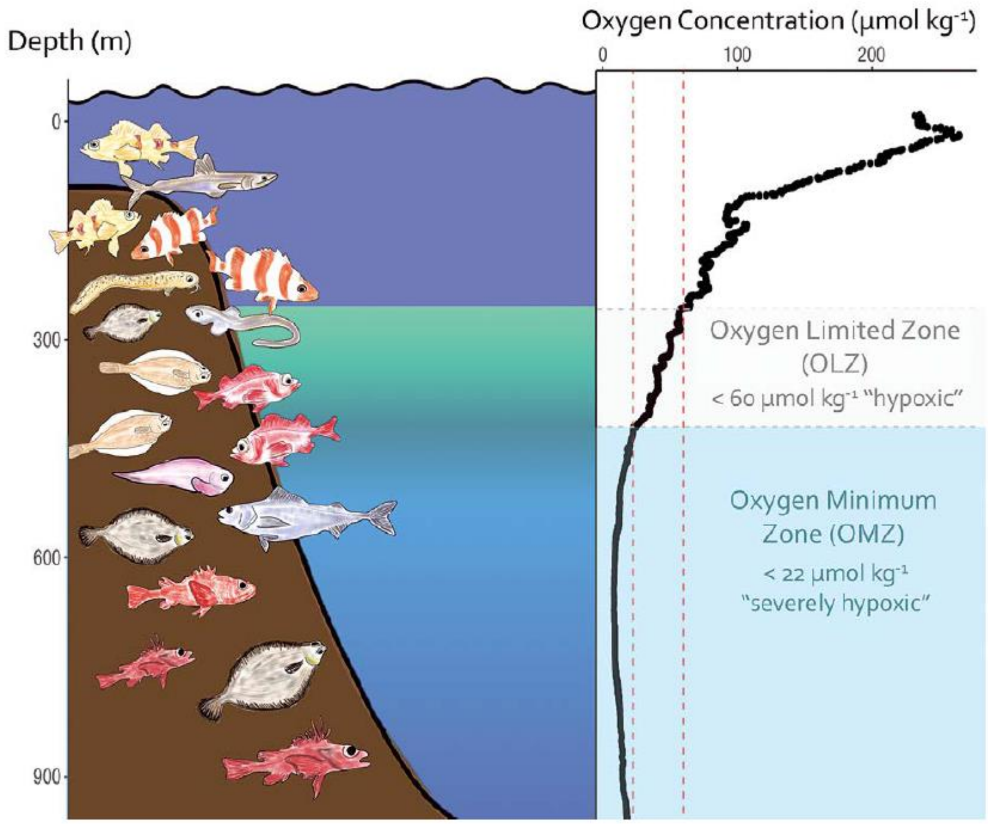
Aria a livello del mare	209 (20,9%)
Aria sul monte Everest (8848 m)	59
Acqua dolce a 0 °C (massima)	10,3
Acqua dolce a 30 °C (massima)	5,6
Acqua di mare a 0 °C (massima)	8,0
Acqua di mare a 30 °C (massimo)	4,5

Note in particular that in water, gas solubility decreases as temperature increases, such that oxygen can be much more available in a cold-water habitat.



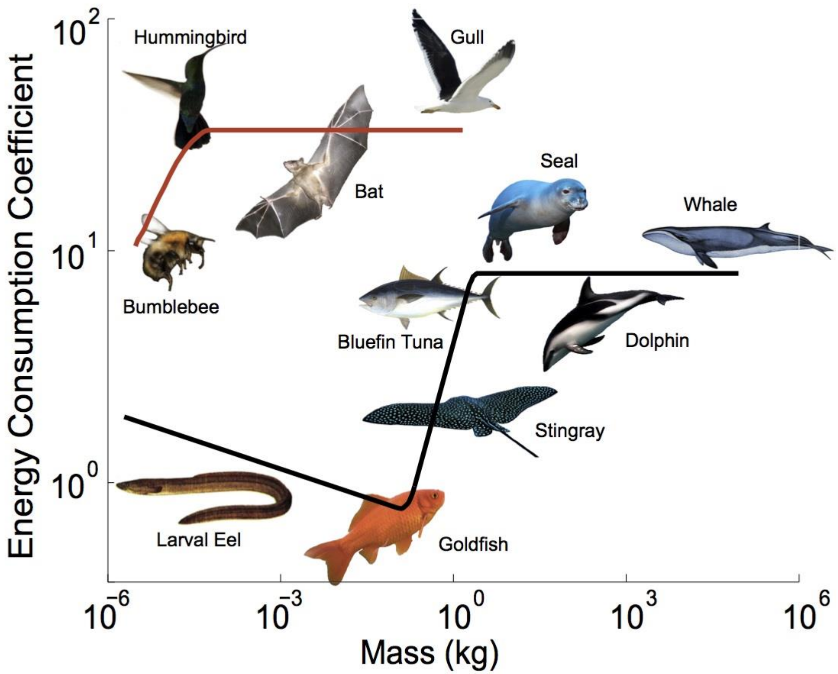
Note also that aquatic habitats, even at their highest O2 content, hold only a fraction of the content of air.

And levels can get much lower in mud (which impedes diffusion much more than sand) and in waters such as the Oxygen Minimum Zones found at intermediate depths in many areas of the oceans.

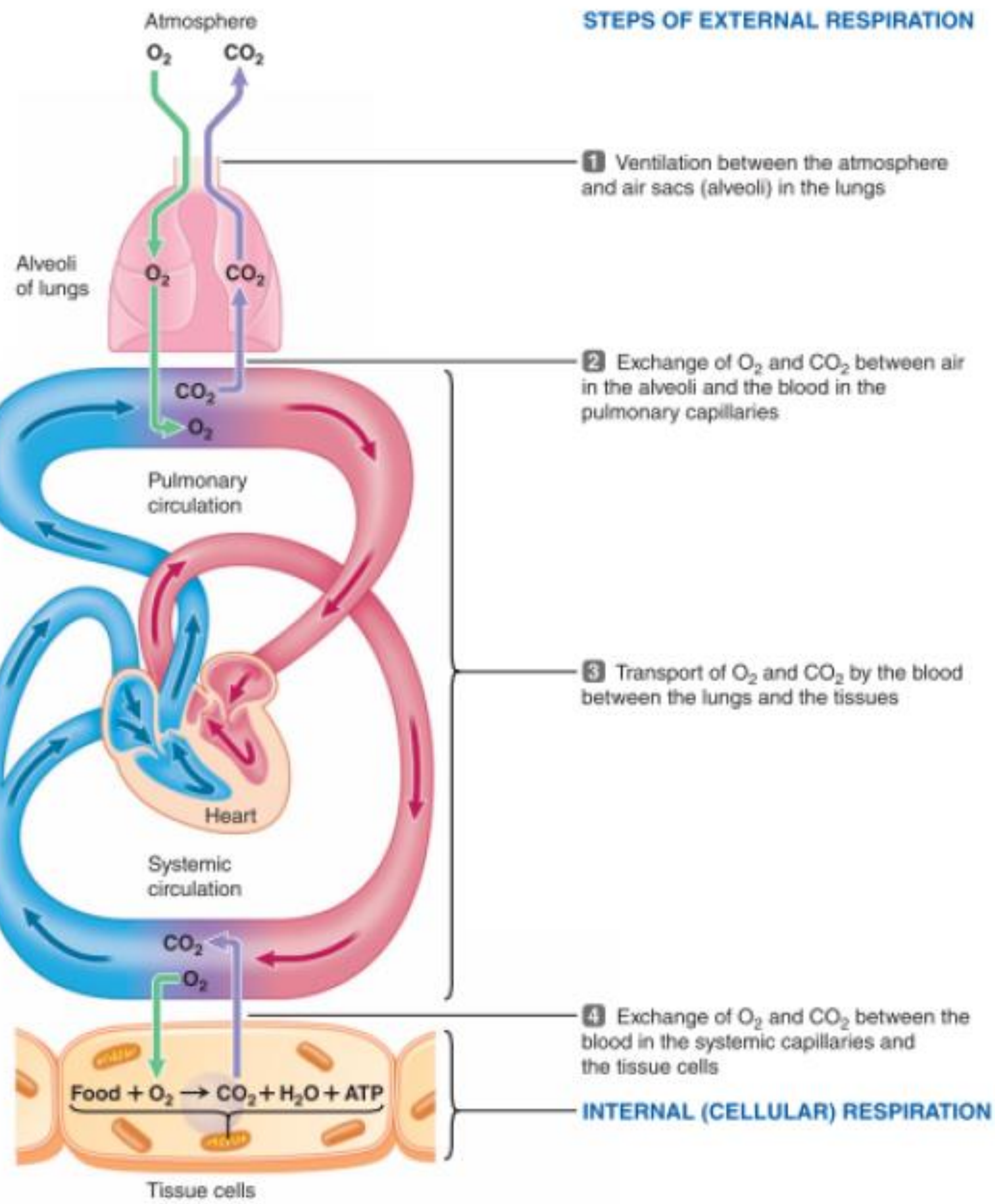


2. Animal size has increased in many phyla since the first animals evolved. As this occurred, diffusion became too slow to cover internal distances in a reasonable time.

3. Animal metabolism vary in their demand for O_2, with the highest demands arising in birds, mammals, some fishes, some cephalopods, and flying insects.



What are the general ways that external respiration has been enhanced in animals that are larger, live in lower-oxygen environments, and/or have more active metabolisms?



Atmosphere
O_2
CO_2
Alveoli of lungs
O_2
CO_2
CO_2
O_2
Pulmonary circulation
Heart
Systemic circulation
CO_2
O_2
Food + O_2 → CO_2 + H_2O + ATP
Tissue cells
STEPS OF EXTERNAL RESPIRATION
1 Ventilation between the atmosphere and air sacs (alveoli) in the lungs
2 Exchange of O_2 and CO_2 between air in the alveoli and the blood in the pulmonary capillaries
3 Transport of O_2 and CO_2 by the blood between the lungs and the tissues
4 Exchange of O_2 and CO_2 between the blood in the systemic capillaries and the tissue cells
INTERNAL (CELLULAR) RESPIRATION

Four broad adaptations at the cellular, organ, and system levels:

<u>1. Ventilation</u> (step 1, respiratory surfaces are provided with a continuous fresh supply of external medium with a high P1 for O_2 keeping gas gradients high in the appropriate directions at step 2.)

<u>2. Respiratory organs</u> (step 2, many animal groups have evolved dedicated gas-exchange organs such as gills, tracheae, and lungs)

$$Rate\ of\ diffusion\ (Q) = \frac{\Delta P \cdot A \cdot D}{\Delta X}$$

I. High D value due to high permeability (a fish gill epithelium is much more permeable to gases than mucus- and scale-covered skin)

II. A low ΔX, using very thin epithelia;

III. A high A value, through specialized folds (evaginations, or “outpockets,” and invaginations, or “inpockets”) that increase surface area for gas diffusion.

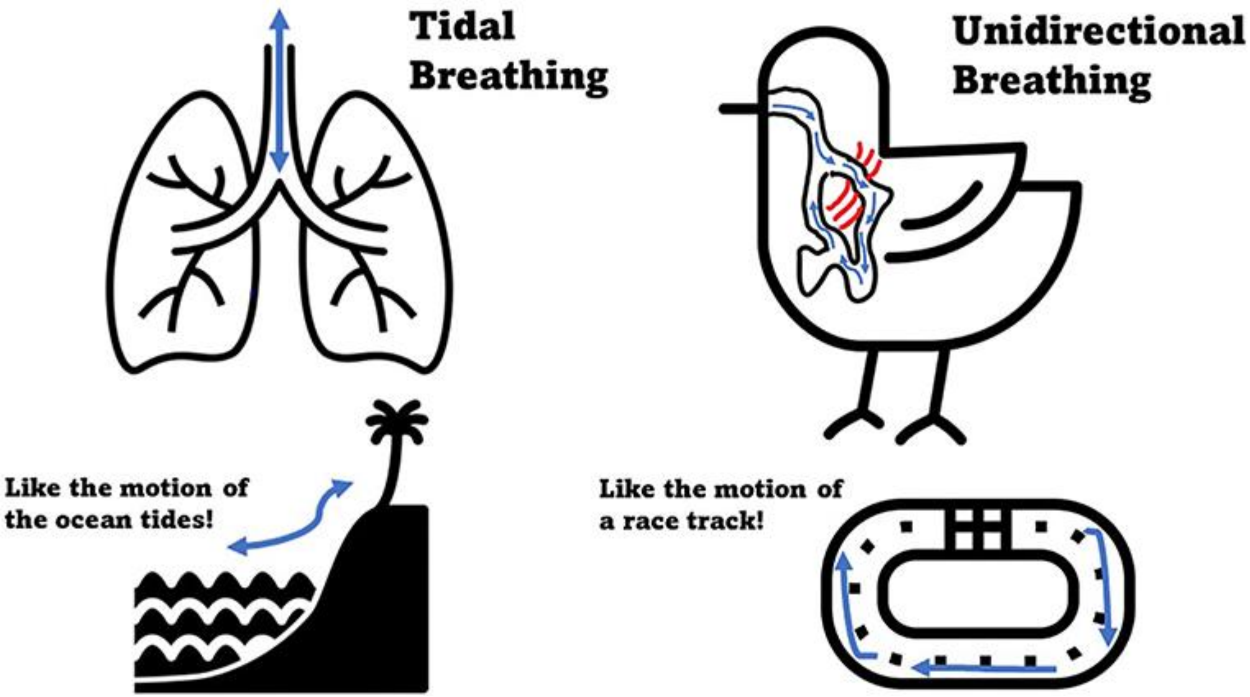
3. Circulation (step 3). At the respiratory surface, ventilation may be complemented by circulatory perfusion, which brings to the exchange surface a continuous supply (P2) of low-O_2 body fluid (with a high P1 for CO_2).

At internal tissues (step 4), which are consuming O_2 and producing CO_2, the circulatory fluid—reoxygenated at the respiratory surface—provides a fresh supply (P1) of high O2 (accompanied by a low P2 for CO_2).

An internal circulatory system may also enhance diffusion at steps 2 and 4 by:

i. increasing *D* (e.g., permeable capillaries)
ii. increasing *A* (e.g., high vascularization)
iii. reducing ΔX (e.g., narrow capillaries in closed circulations, or direct bathing of cells by circulatory fluids in open circulations).

4. Proteins in the circulatory fluid and inside some cells that convert gases between diffusible and non-diffusible forms (For O_2, this mechanism typically involves special respiratory pigments such as hemoglobin and myoglobin)



In **tidal breathing**, the external medium is moved in and out of the same opening, in two distinct steps termed inhalation (or inspiration) and exhalation (or expiration).

In **flow-through breathing,** the external medium enters one opening and leaves through a separate opening.

Animali Ossigeno-conformi e Ossigeno-regolatori

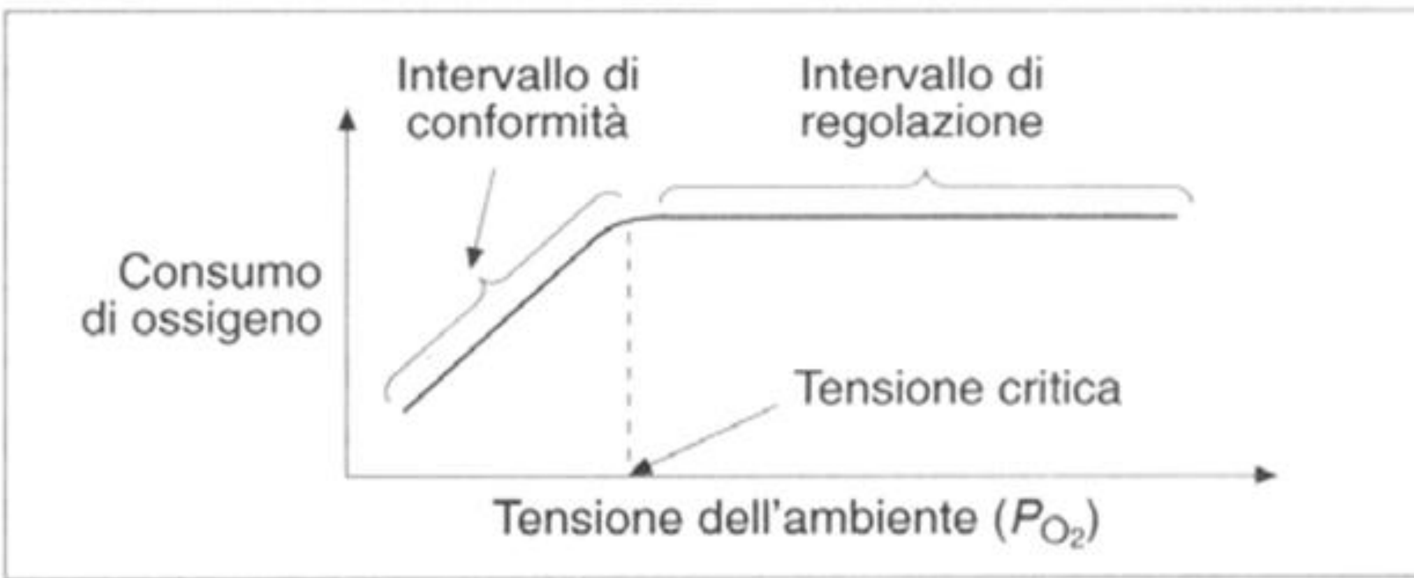
In base al tipo di risposta respiratoria in condizioni di ridotta disponibilità di Ossigeno, gli animali si dividono in:

1. Animali **Ossigeno-conformi** quando il consumo di ossigeno (ed il metabolismo) diminuisce in proporzione alla sua diminuita concentrazione (o PO_2) nell'ambiente; per esempio, alcuni protozoi, i vermi marini ed i parassiti, alcuni molluschi e crostacei, echinodermi.

2. Animali **Ossigeno-regolatori** quando viene mantenuto inalterato il consumo di ossigeno anche in ambienti con PO_2 ridotta : la maggior parte dei protozoi, molti anellidi di acqua dolce e terrestre, molti molluschi e crostacei, tutti gli insetti terrestri e tutti i vertebrati.

Ovviamente, il consumo (ed il metabolismo) resta costante fino ad un livello minimo critico, sotto il quale diventano O_2-conformi

Consumo di O_2 (% del consumo massimo) in funzione della PO_2 dell'ambiente : animali Ossigeno-regolatori



Organi respiratori

Negli animali senza organi respiratori specializzati i gas respiratori entrano ed escono per semplice diffusione, Sono animali di piccole dimensioni (inferiori al millimetro) od organismi con metabolismo molto basso (meduse), perché la diffusione è un processo troppo lento quando le molecole devono viaggiare per più di una frazione di mm.

Sono organi respiratori specializzati

- Le trachee (serie di tubi ramificati tipici degli insetti). Facilitano il movimento dell'O_2
- Le branchie, organi respiratori rivolti verso l'esterno, tramite evaginazione; sono strutture di scambio dei gas.
- I polmoni, organi respiratori rivolti verso l'interno, tramite invaginazione; sono strutture di scambio dei gas.

Un organo respiratorio efficiente ha una superficie di scambio molto estesa, un epitelio di scambio molto sottile.

Water respirers

1. Viscosity: Water has a higher viscosity than air

2. Solubility: O_2 concentration of water is considerably smaller than in the gas phase: 1 L of water at 15˚C contains 7 mL of O_2, whereas 1 L of air contains 209 mL of O_2.

3. Diffusion: The rate of diffusion of gases in water is about 10,000-fold slower than in air.

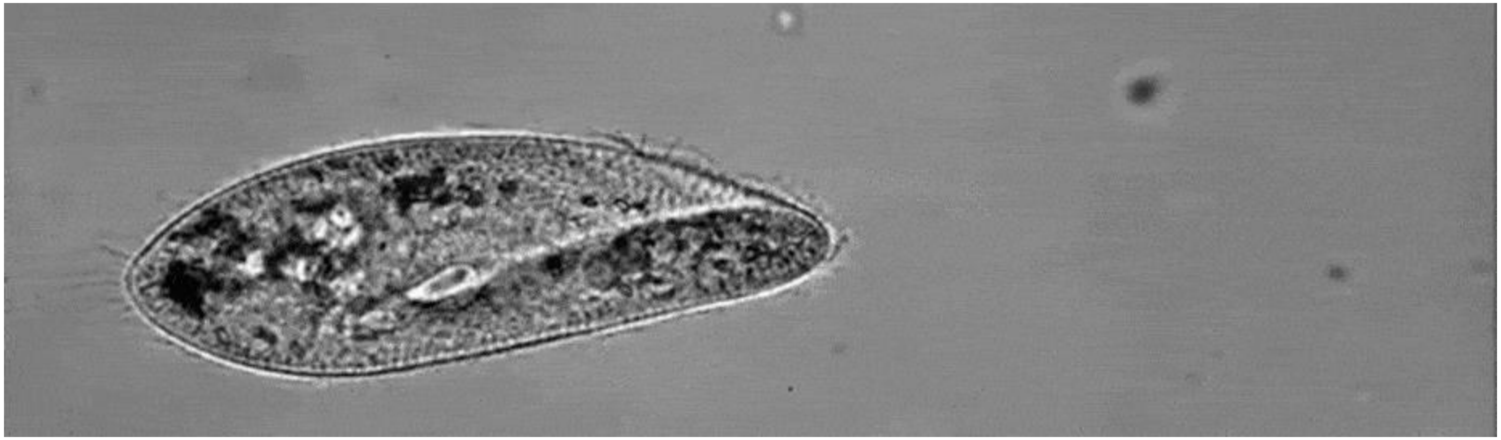
4. Salinity: The solubility of O_2 and CO_2 decrease with increases in salinity.

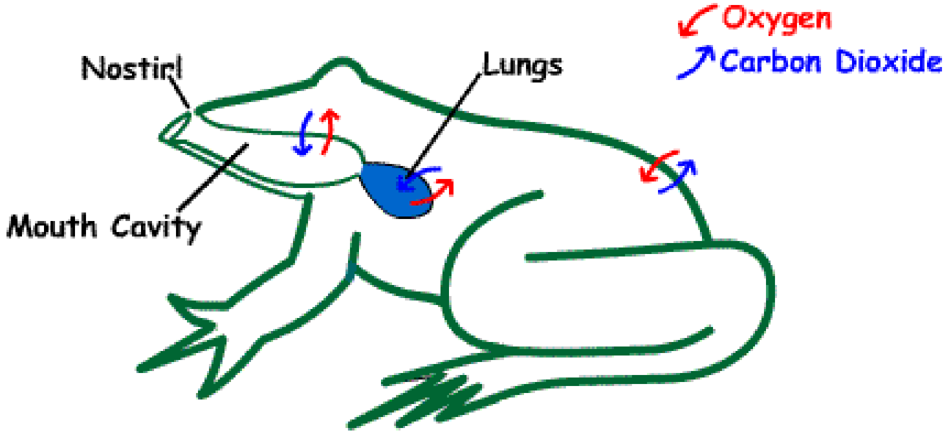
5. Temperature: Diffusion rates for gases increase with temperature in both air and water; however, solubility of O_2 and CO_2 are decreased as ambient temperature increases.

6. Habitat variation: As we noted earlier, the O2 content of water is subject to greater variation than that of air.

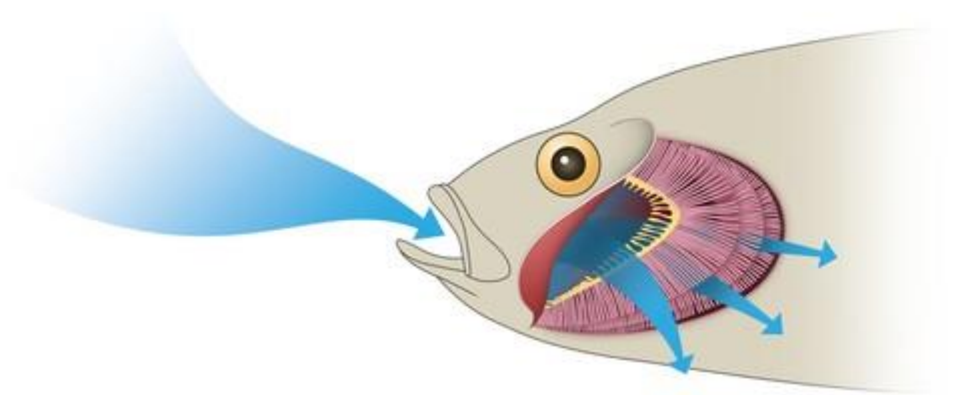
7. Composition: Unlike air, water can contain many life sustaining components other than gases.

How overcome these limitations?

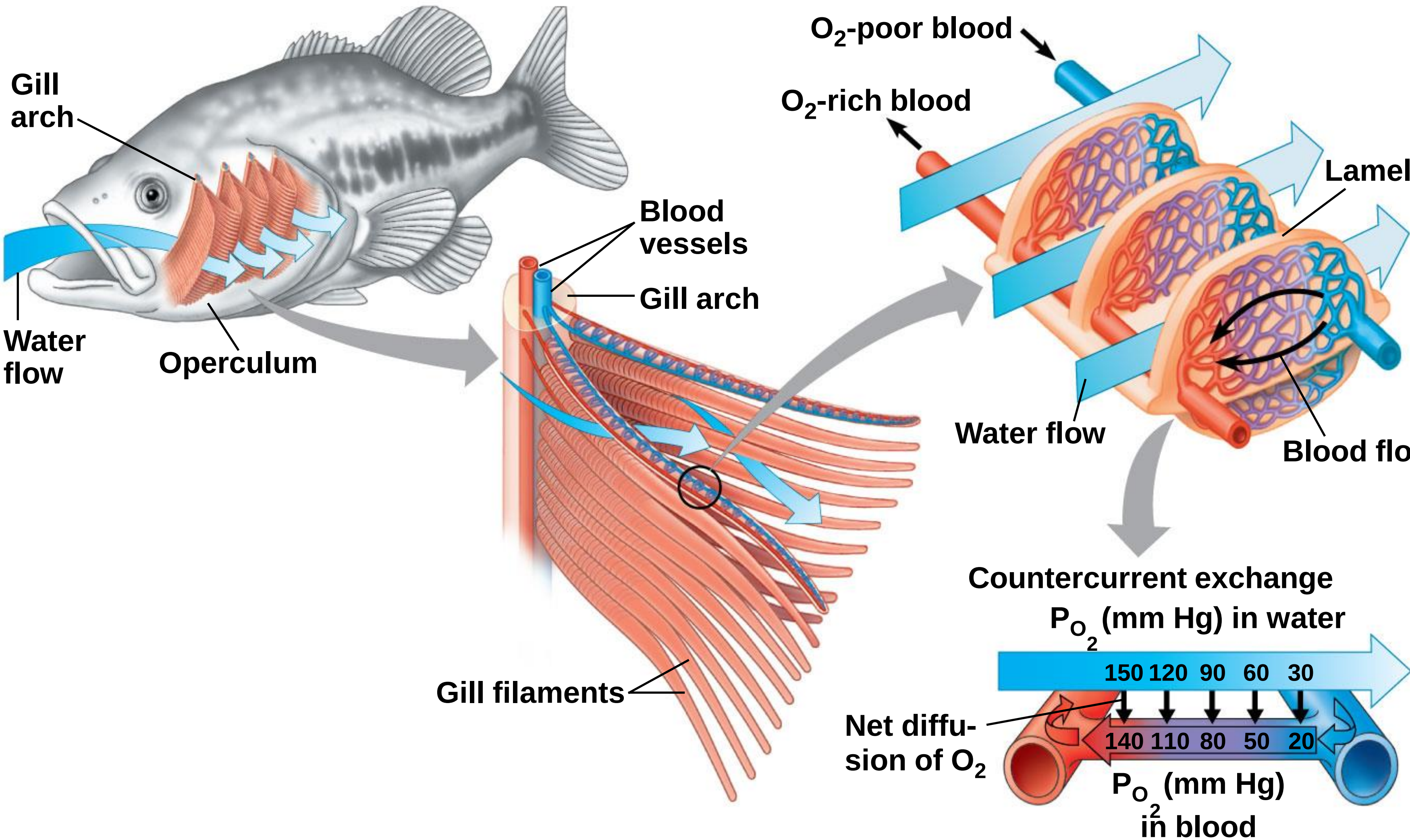




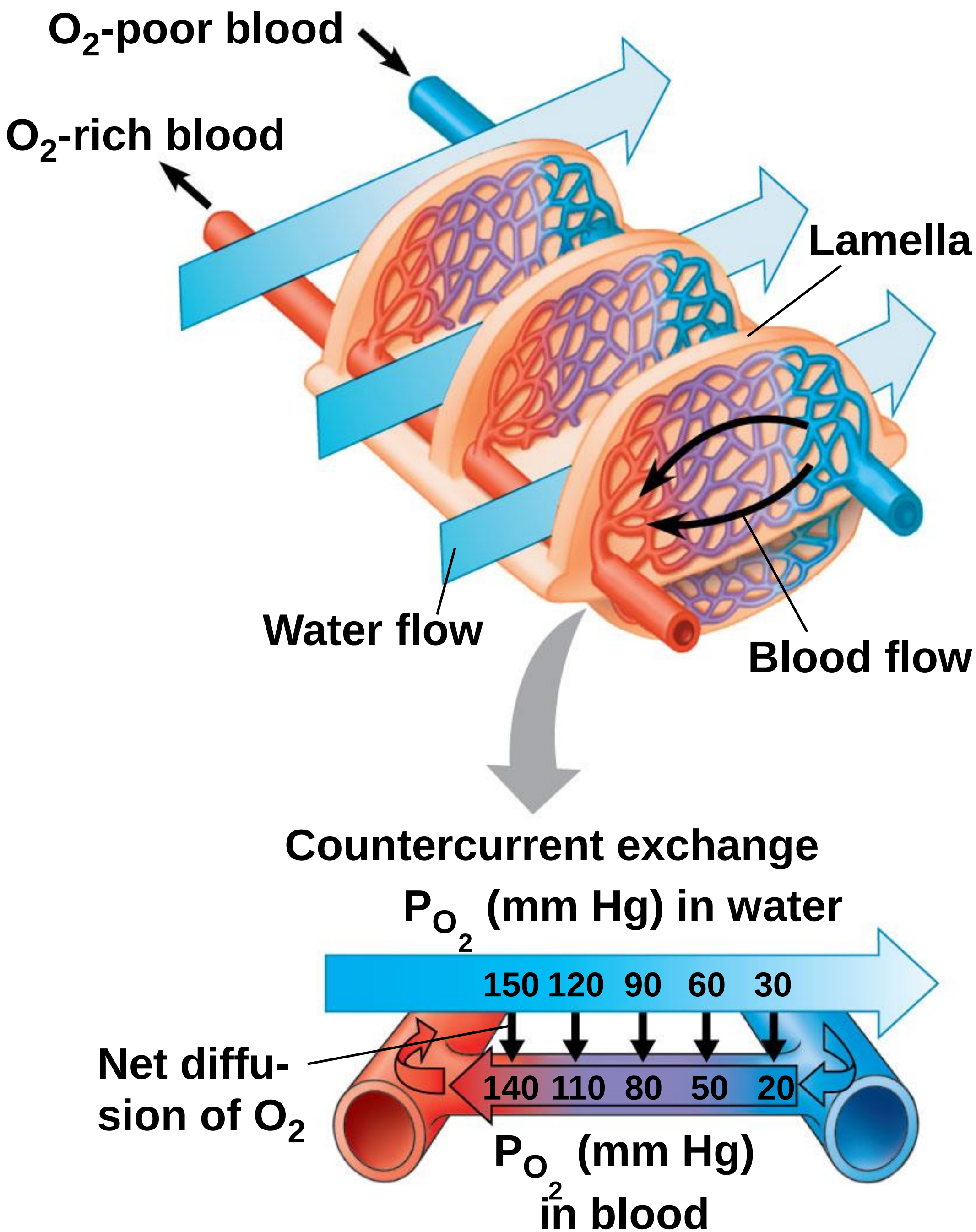
Integument



- Gills are outfoldings of the body that create a large surface area for gas exchange
- Delicate structures because they are composed of thin cell layers for a small ΔX as well as a high A.
- They are also highly perfused by a circulatory system and may have associated flow-through breathing mechanisms.



Gill arch
Water flow
Operculum
Blood vessels
Gill arch
Gill filaments
O_2-poor blood
O_2-rich blood
Lamella
Water flow
Blood flow
Countercurrent exchange
P_{O_2} (mm Hg) in water
150 120 90 60 30
Net diffusion of O_2
140 110 80 50 20
P_{O_2} (mm Hg) in blood



O_2-poor blood
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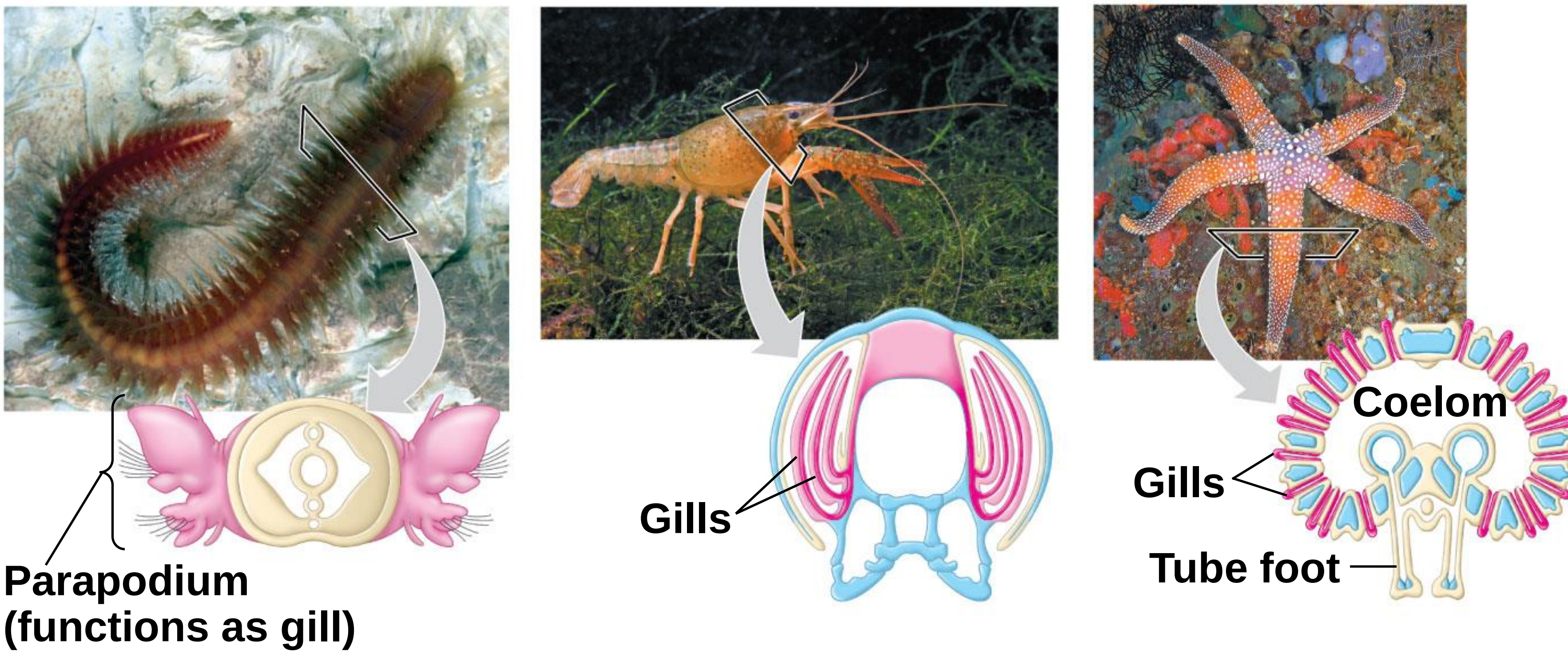
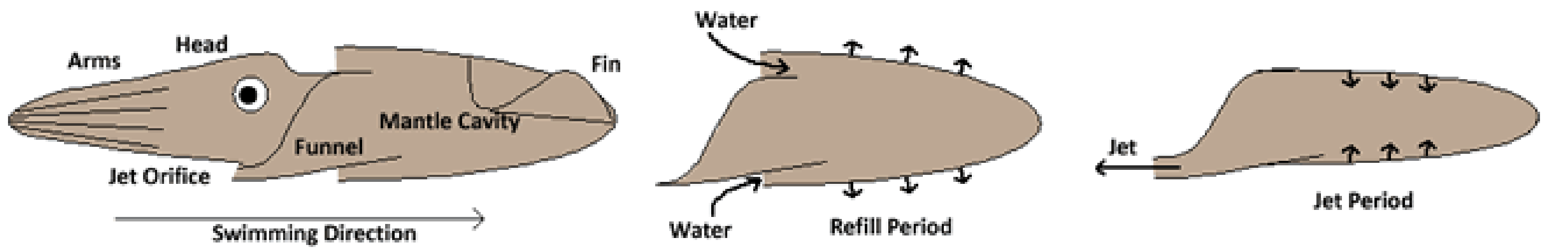


(a) Marine worm

(b) Crayfish

(c) Sea star

Breathing muscles in water provide rapid and often flow-through transport

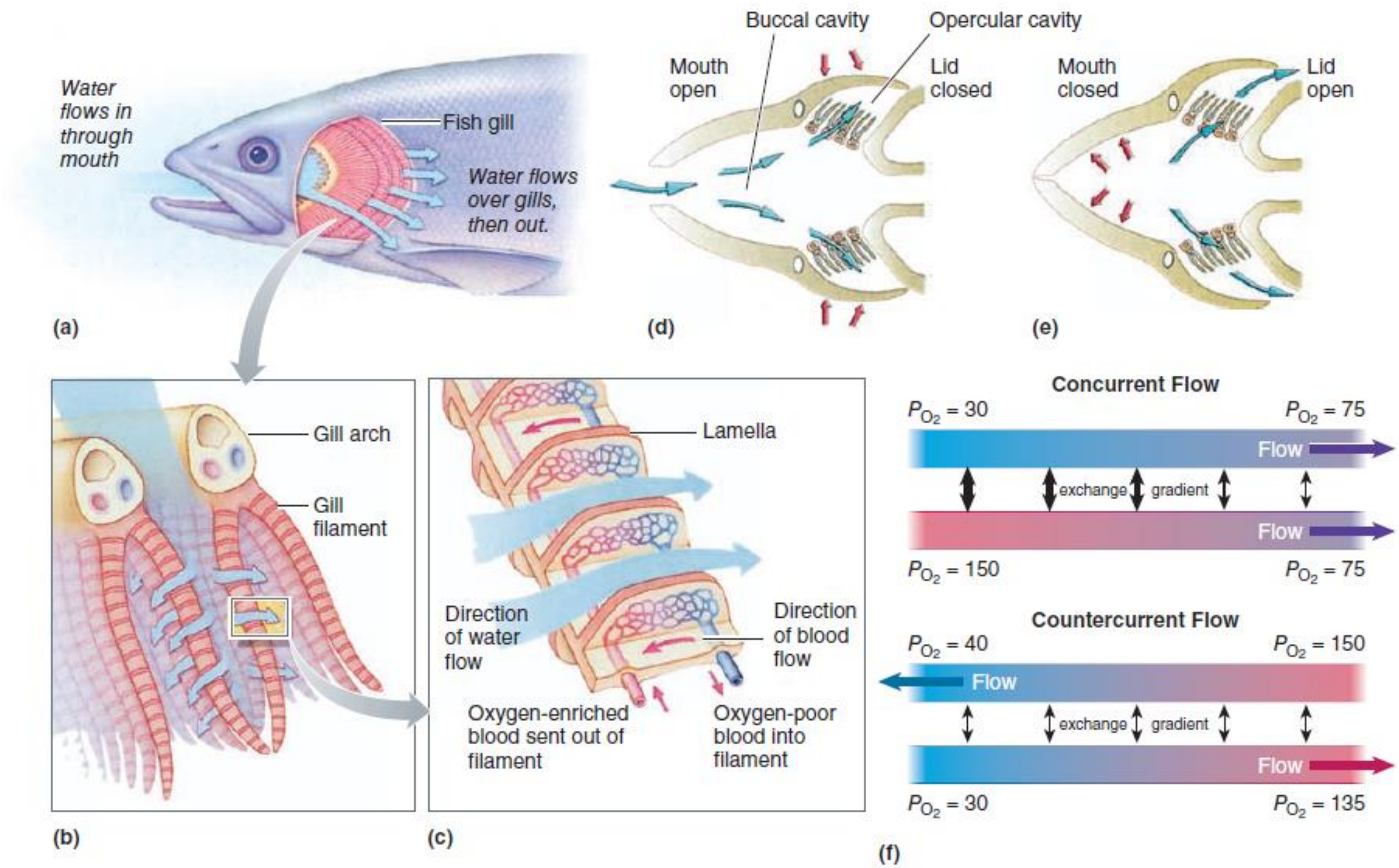


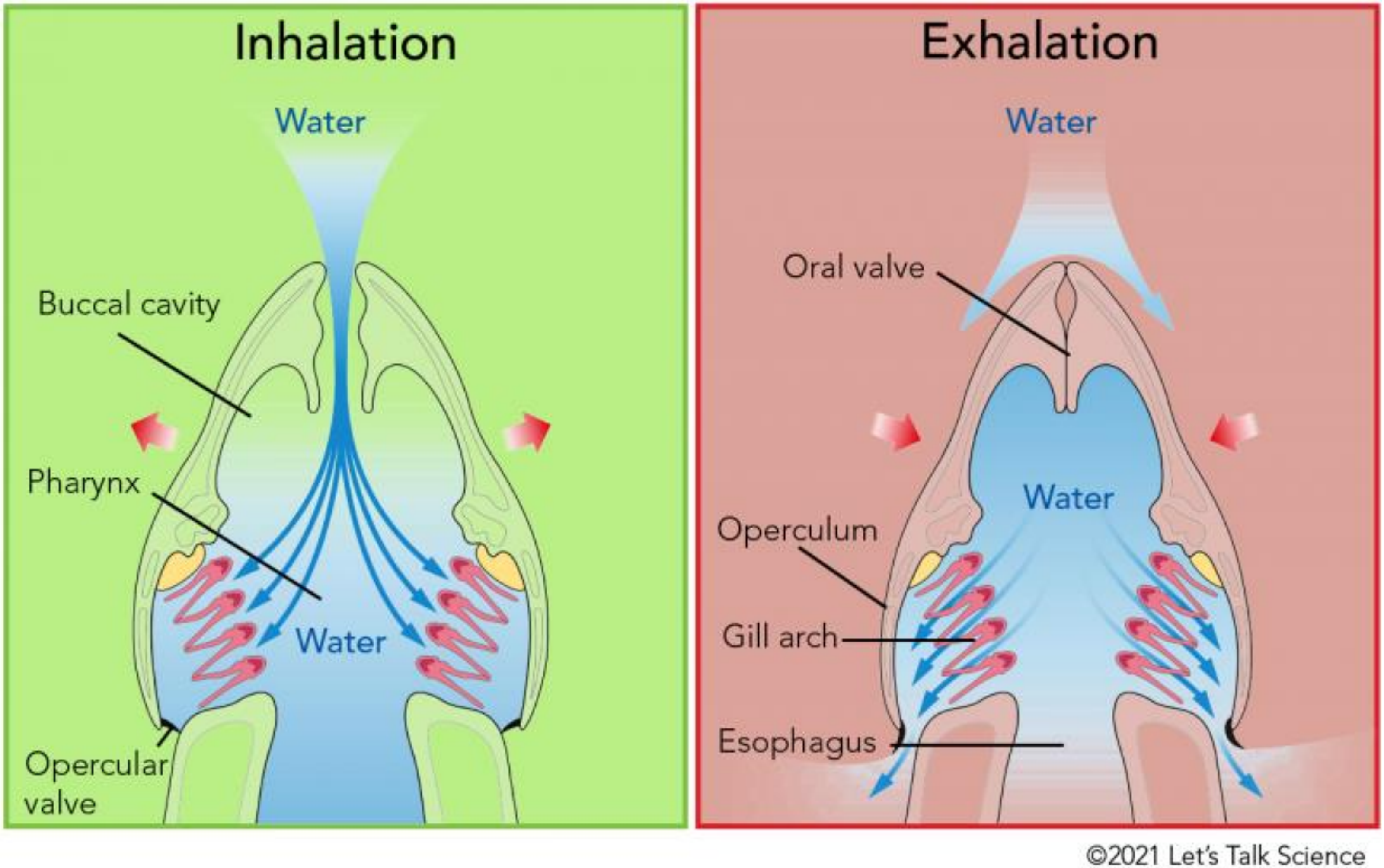
During inhalation, the funnel closes, and the mantle cavity expands, drawing in large amounts of water to ventilate the gills rapidly.

To exhale, the mantle opening seals up and the funnel opens, whereupon the mantle contracts and squirts the water out the siphon.

In particularly active fishes another flow-through type of muscular pump is readily seen.

Water is pumped over the gills by skeletal muscle pumps in the **buccal** (mouth) and **opercular cavities.** Ventilation of the gills operates by a cycle of negative and positive pressure gradients.



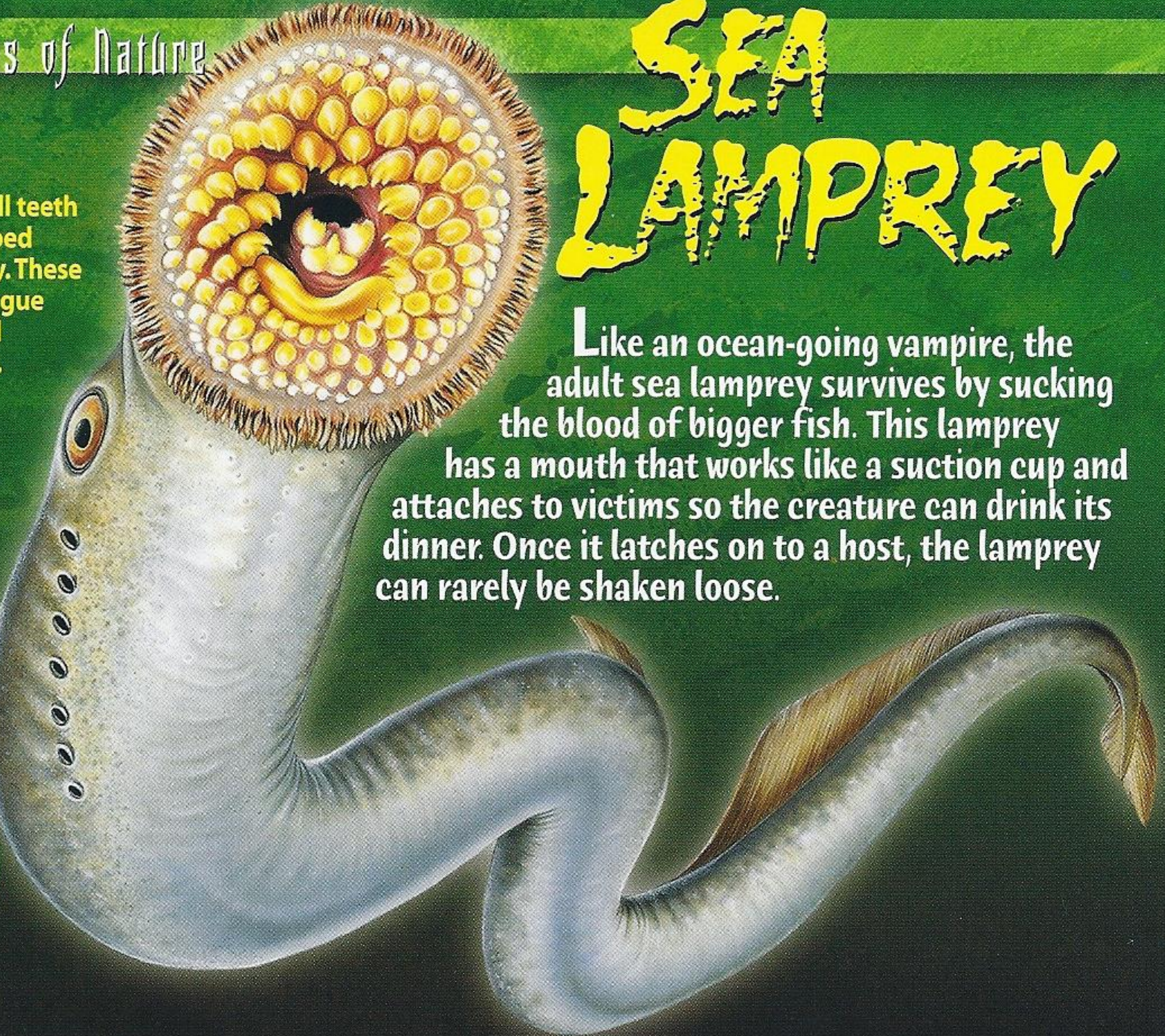


During the inhalation phase, fish pull water in through their oral valve to their buccal cavity. From there the water is pushed towards their gills. The opercular valve is closed at this point. During the exhalation phase, the oral valve is closed and the opercular valve is opened. Water passes over the gills and out through the opercular valve.

ARD 30

Nightmares of Nature

SEA LAMPREY



AMP DOWN: Rows of small teeth side the creature's disk-shaped outh help it clamp onto prey. These eth and a jagged-edged tongue rape away a fish's scales and t the victim's blood flowing.

GGIE SIZE: The adult sea mprey fills up on blood by eying on the largest fish it n find. Many victims don't rvive, and the lucky ones at do make it have und scars left on eir skin.

Like an ocean-going vampire, the adult sea lamprey survives by sucking the blood of bigger fish. This lamprey has a mouth that works like a suction cup and attaches to victims so the creature can drink its dinner. Once it latches on to a host, the lamprey can rarely be shaken loose.

Creature Features

PECIES: *Petromyzon marinus*

SIZE: Length up to 3 ft.; Weight up to 5.5 lbs.

HABITAT: Along the Atlantic oasts of North America and rope, and in the Great Lakes

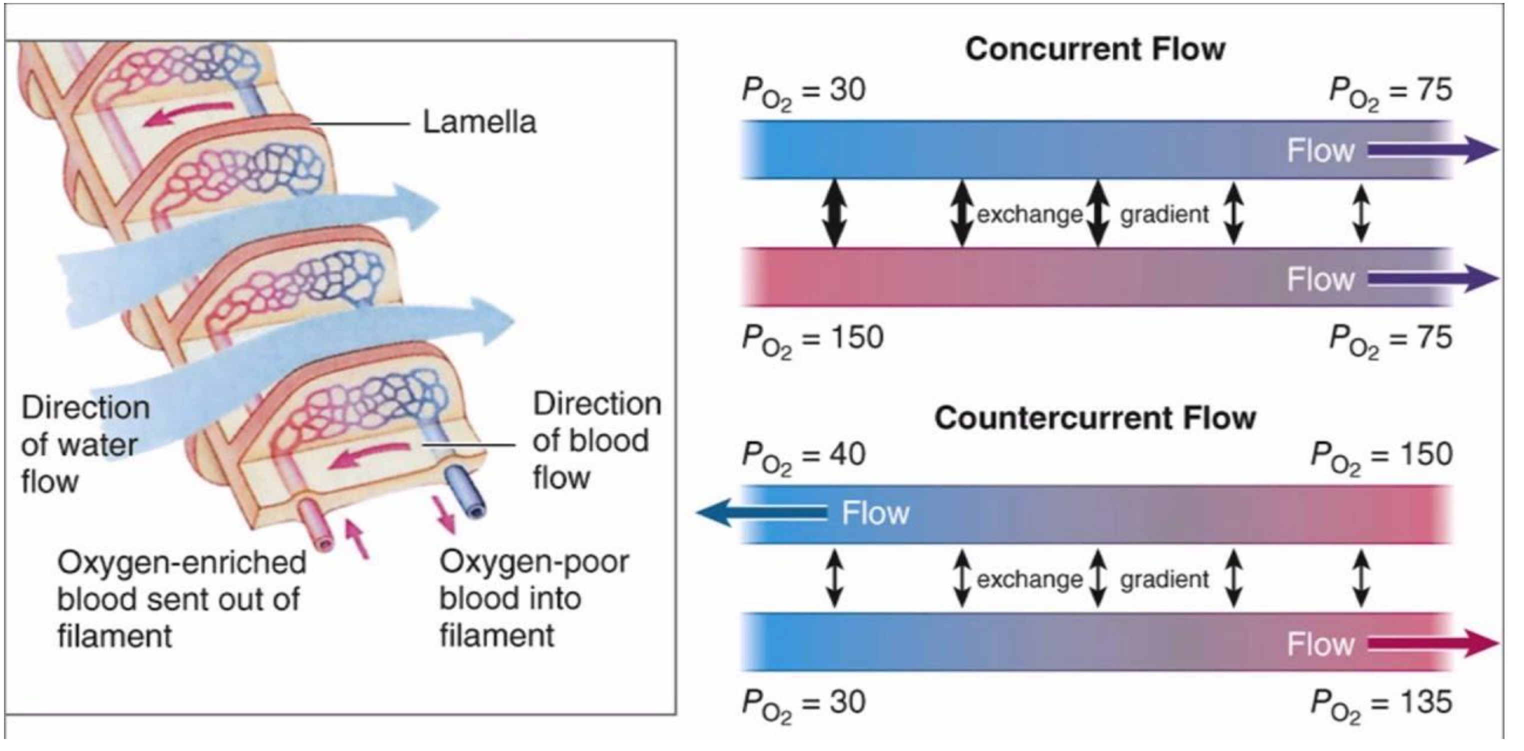
EY: Young eat tiny organisms, dults feed on blood of fish

LIFESPAN: Up to 9 years

Ram Ventilation

- Tuna swim continuously with mouth open to maintain a constant flow of water over gills
  - Fish alter the degree of mouth opening during ram ventilation to keep drag to the minimum
  - Some species (mackerel) change from pumped to ram ventilation as their swimming speed increases to between 0.5 – 0.8 m/sec
    - Reduces energy cost of maintaining opercular pumping at higher swimming speed

Countercurrent blood flow enhances gas pressure gradients in fishes



There is a positive ΔP at every point, keeping gases diffusing into the blood. This anatomical arrangement permits the O2 content of arterial blood to exceed that in the respired water.

Aquatic respiratory systems can perform numerous non-respiratory functions

- Feeding (i.e. plankton)
- Nutrient and mineral uptake
- Involved in the regulation of osmotic and ionic balance.
- 75% of the ammonia excreted by the fish is through the gills.
- The gills also help the fish osmoregulate (equalize body pressures).

Physiology of respiration in invertebrates

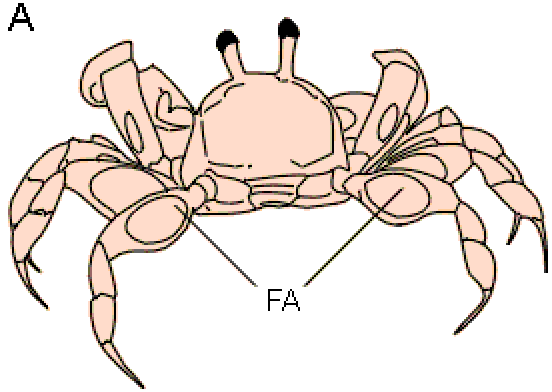
I Pro e i Contro della respirazione in aria

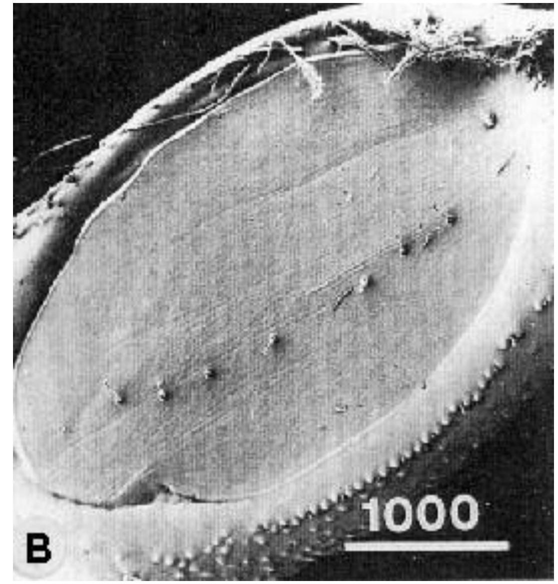
La respirazione in aria è vantaggiosa rispetto a quella in acqua per numerosi motivi:

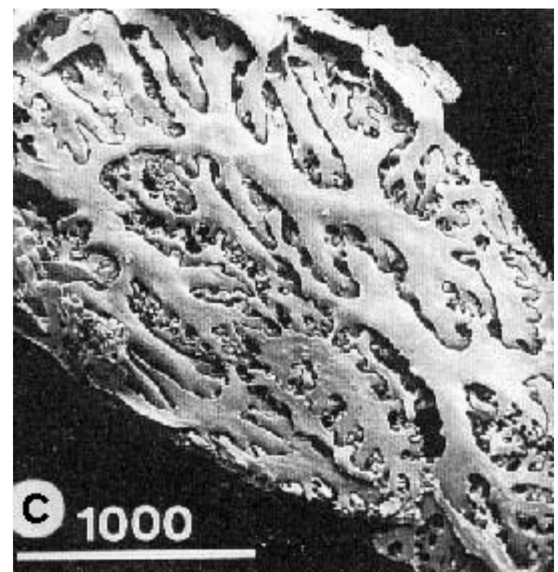
i. In aria la concentrazione dell'O_2 è molto maggiore;
ii. la diffusione dell'O_2 è più veloce (circa 10.000 volte superiore a quello dell'acqua);
iii. muovere l'aria richiede meno energia, perché la massa e gli attriti sono minori;

La respirazione in aria tende però a disidratare gli organismi.

A



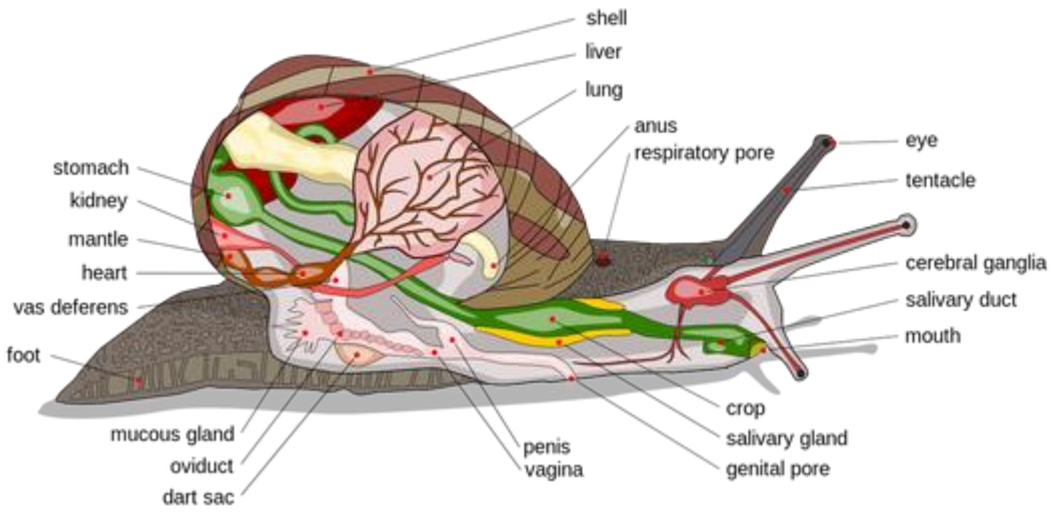




Land slugs and snails use skin, mantle tissue, or lungs

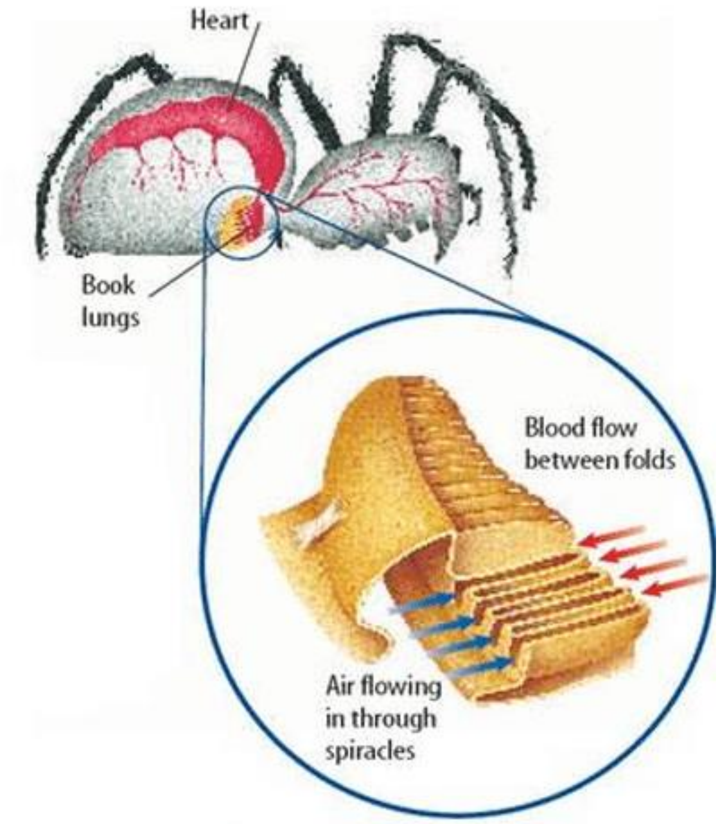
Mollusks are primarily aquatic. Some species are semiterrestrial in the intertidal zone, where they are exposed alternately to water and air. They generally use the same (gill) structures for gas exchange with air or water.
However, these animals limit exposure of their epithelial surfaces to the atmosphere because of desiccation risk.

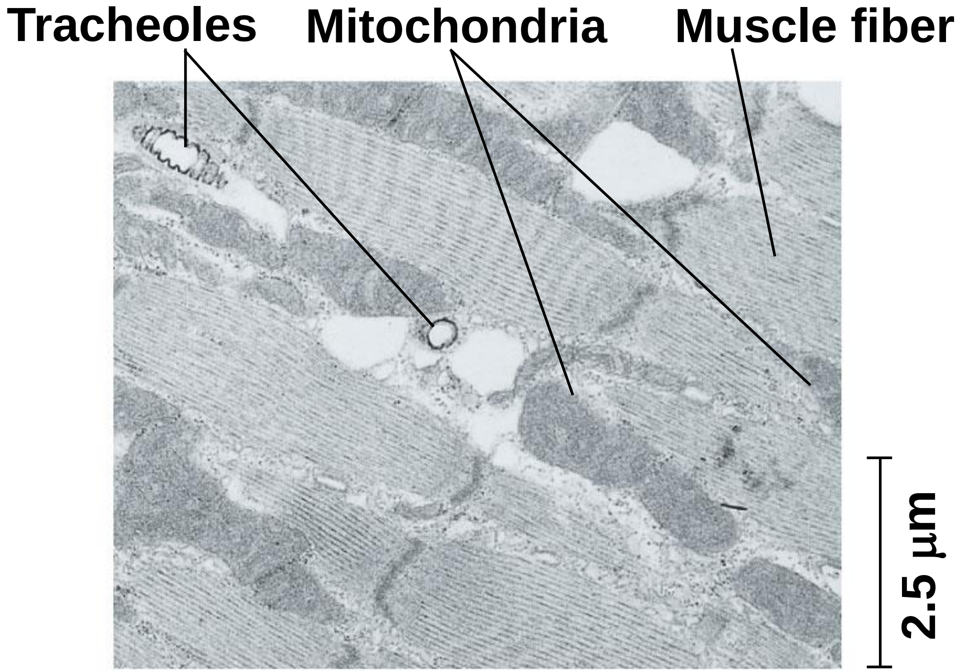
Snails and slugs become terrestrial. The most successful groups are the pulmonate ("lung-bearing") snails, some of which have adapted to deserts.

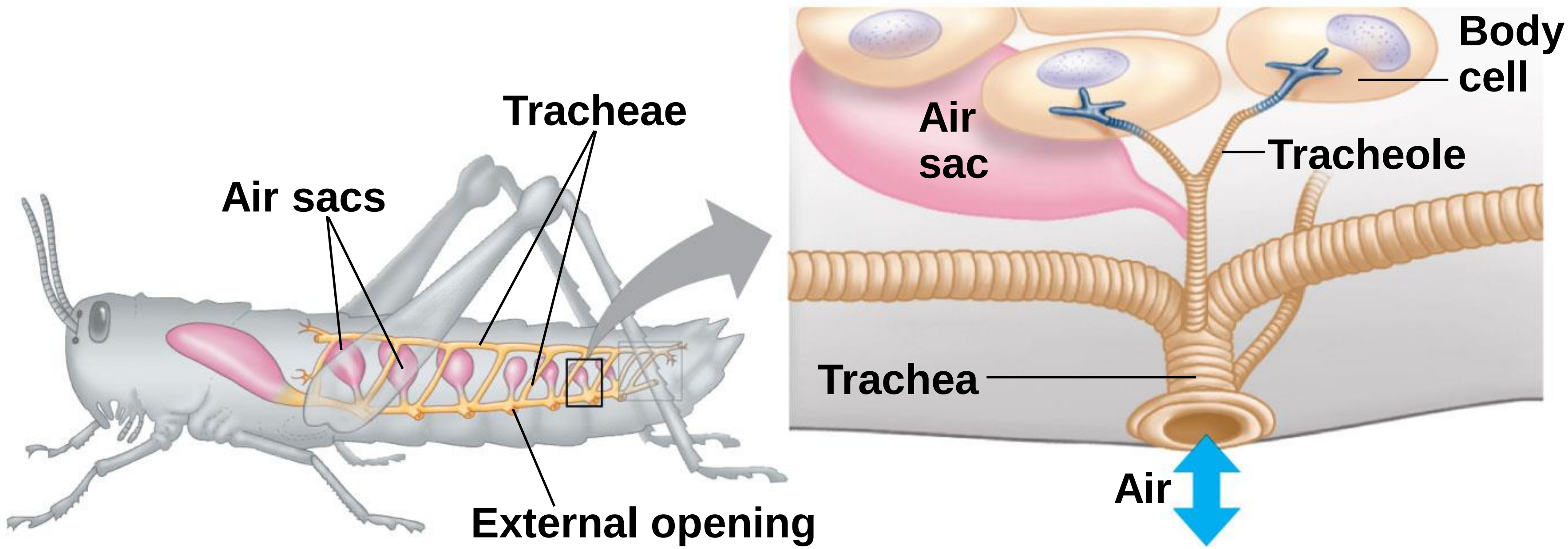


Arachnids use book lungs or tracheae

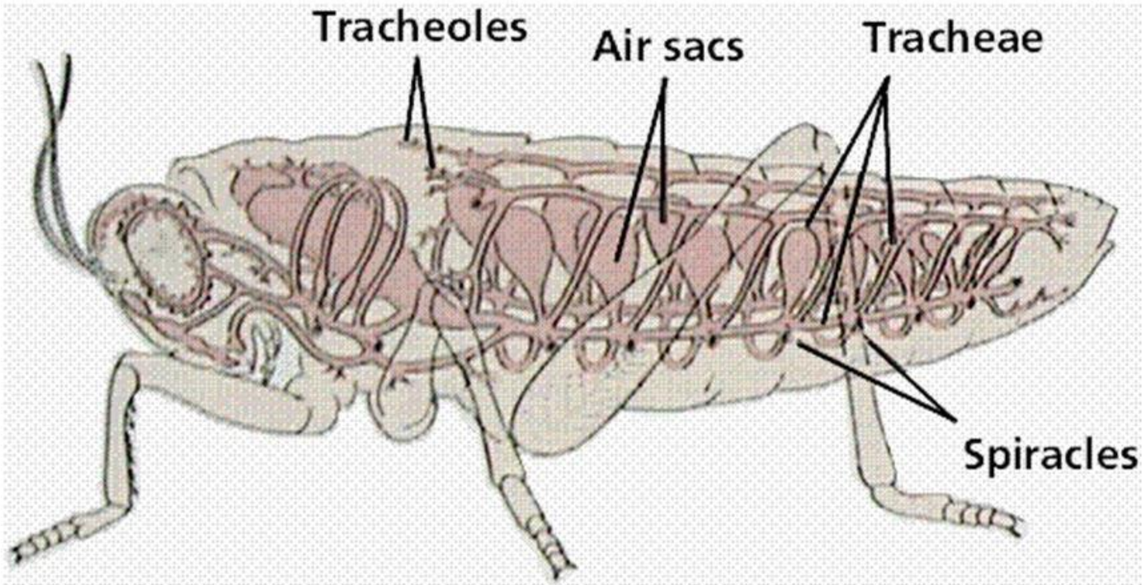
Arachnids represent a class of animals consisting of spiders, scorpions, ticks, and mites. The arachnid respiratory system consists of two main organs- the trachea and the book lungs. Only spiders have both tracheae and book lungs.




Tracheoles
Mitochondria
Muscle fiber
2.5 µm

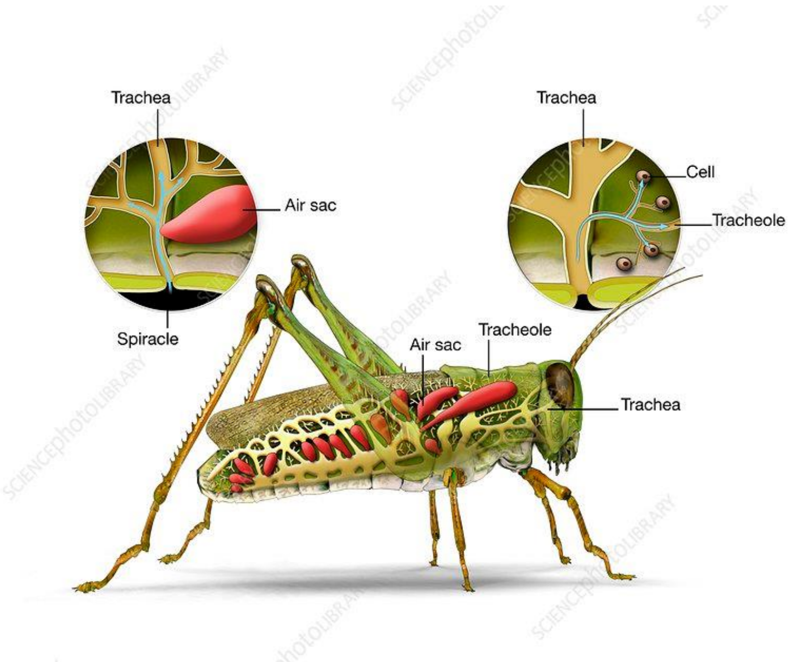

Tracheae
Air sacs
External opening
Body cell
Air sac
Tracheole
Trachea
Air

The Insect Gas Exchange System



- The tracheal system of insects consists of tiny branching tubes that penetrate the body
- The tracheal tubes supply O2 directly to body cells
- The respiratory and circulatory systems are separate
- Larger insects must ventilate their tracheal system to meet O2 demands

Thin-walled expansions of the tracheæ known as air sacs occur in those insects which have well-developed powers of flight.



each air sac, when compressed, expels the air from the tracheæ between it and the spiracle. As reservoirs the sacs could be of little use to aerial insects, for the oxygen they contain would last but a very short time during flight.

Why are there no giant insects?

Tracheae pump air directly to muscles → are actually much more effective at delivering O2 than the vertebrate blood system, which requires many more stages and the relatively slow pumping of a liquid.

Tracheae take up a proportionally greater part of an insect body as body size increases. That is, the tubes must increase in width more than body size increases in order to deliver enough, taking up too much space.