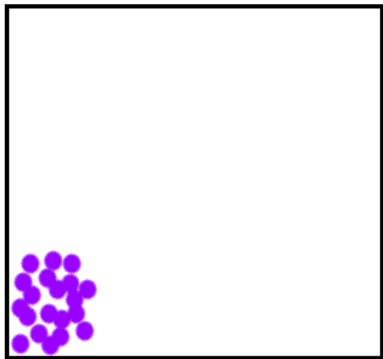


# *Introduction to the Respiratory System*

- Describe primary functions of the respiratory system
- Describe the anatomy of the respiratory system. Identify organs involved
- Define and compare external respiration and internal respiration
- Understand the mechanics of breathing
- Understand diffusion of gases from the lungs into the blood and then to the tissues
- Understand how carbon dioxide is transported in the blood and removed from the body
- Describe the structure of hemoglobin, its importance in gas transport and factors that affect its shape
- Understand **the Oxygen–Hemoglobin Saturation Curve**, which factors affect its shape and implications on physiology
- Describe how respiration is regulated.
- Understand how **acid-base homeostasis** is maintained and how acid-base disturbances are corrected
- Be able to compare and contrast respiratory strategies of different species.

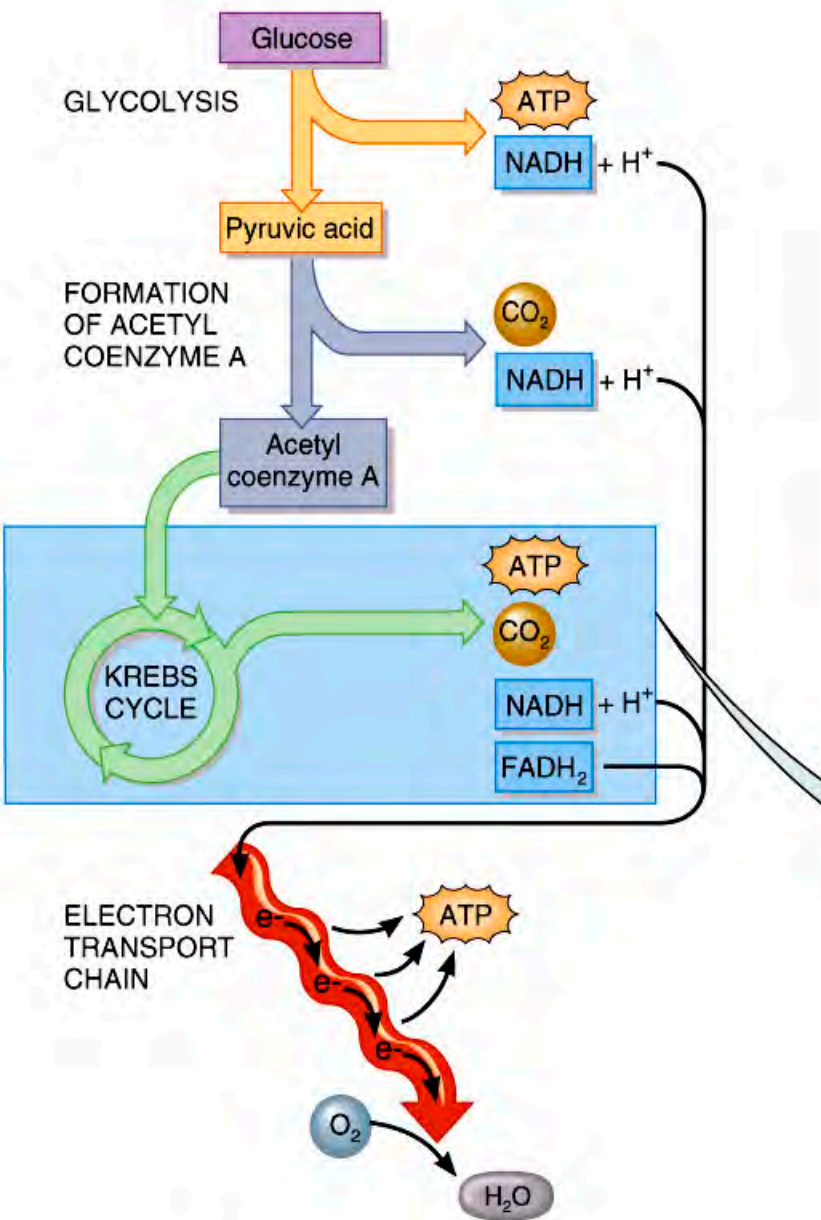
# Definitions

- Respiration = sequence of events that result in the exchange of oxygen and carbon dioxide between the external environment and the mitochondria. Why do we need O<sub>2</sub> and why do we have to exhale CO<sub>2</sub>?
- External respiration = gas exchange at the alveolar membrane (lungs) level
- Internal respiration = gas exchange at the tissue level
- Mitochondrial respiration = production of **ATP** via oxidation of carbohydrates, amino acids, or fatty acids. Oxygen is consumed and carbon dioxide is produced



Diffusion is the movement of substrate molecules from a high concentration to a low concentration.

Gradients can be pressure (gases), electrochemical (ions) or just chemical (glucose)



(a) Cellular respiration

- Mitochondria **consume** O<sub>2</sub> to produce **ATP**
- **Produce** CO<sub>2</sub> in the process. **Where?**
- Organisms must have mechanisms to **obtain** O<sub>2</sub> from the environment and **get rid of** CO<sub>2</sub> . **Why get rid of CO<sub>2</sub>?**
- $\text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}^+ + \text{HCO}_3^-$
- An increase in H<sup>+</sup>, decreases pH

First, we will look at how gases behave.....

# Respiratory systems - diffusion rate

## Fick equation

$$J = -DA \frac{dC}{dx}$$

J = rate of diffusion (moles/sec)

D = diffusion coefficient = how easily a substance can diffuse

A = surface area of the membrane

$dC$  = *concentration gradient*

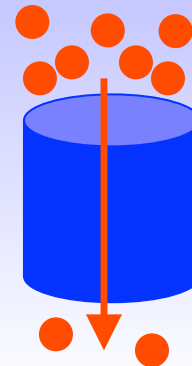
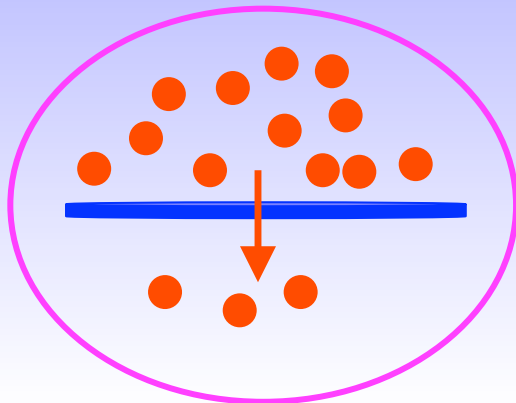
$dx$  = diffusion distance

For gases, we usually use partial pressure rather than concentration  
Gases will move down pressure gradients. Remember this. From high  
Lower pressure

# Respiratory systems - diffusion rate

$$J = -DA \frac{dC}{dx}$$

- Rate of diffusion will be greatest when the diffusion coefficient ( $D$ ), area of the membrane ( $A$ ), and energy gradients ( $dC/dx$ ) are **large**, but the diffusion distance is **small**
- ***\*Consequently, gas exchange surfaces are typically thin = short diffusion distance, with a large surface area***

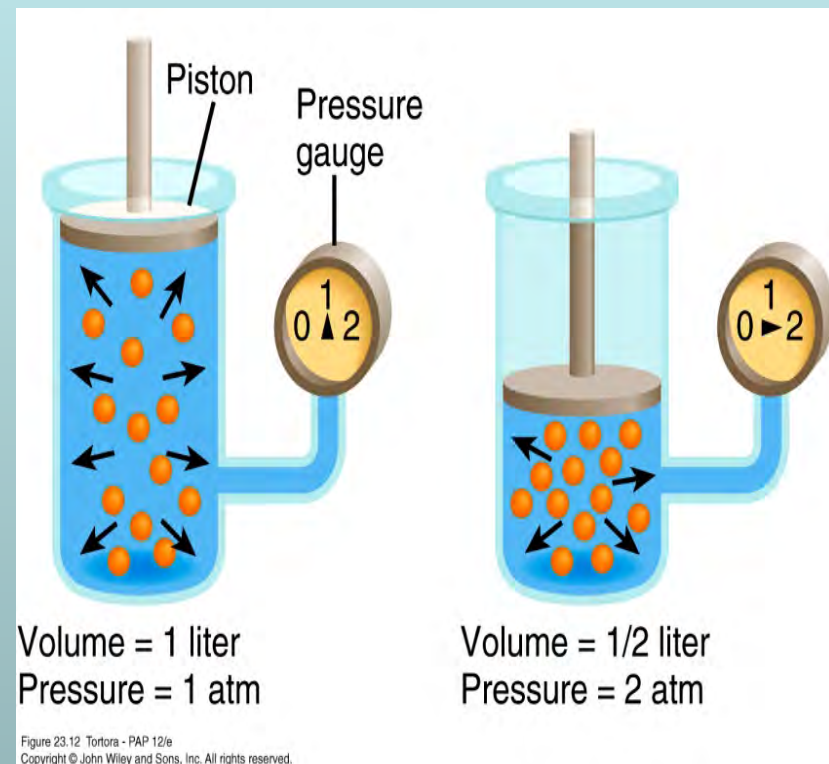
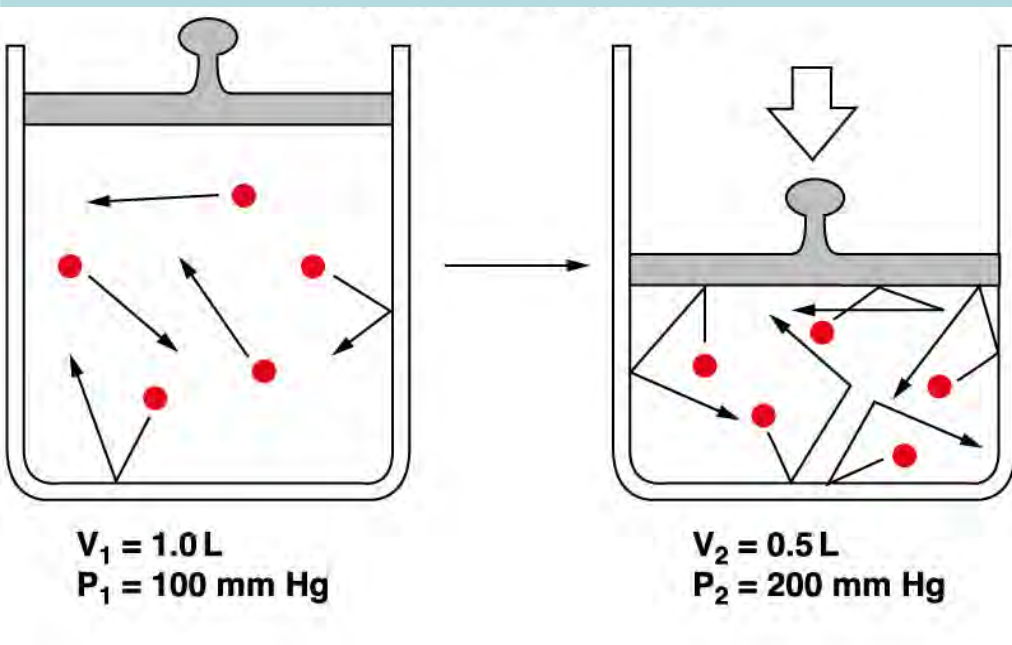


# Pulmonary Ventilation

Boyle's Law = pressure of a gas in a closed container is inversely proportional to the volume of the container

**\*Boyle's Law:  $P_1V_1 = P_2V_2$**

<https://www.youtube.com/watch?v=q6-oyxnkZC0>



**\*Respiratory systems use changes in volume to cause changes in pressure!**

# Gases Dissolve in liquids

## \*Henry's Law

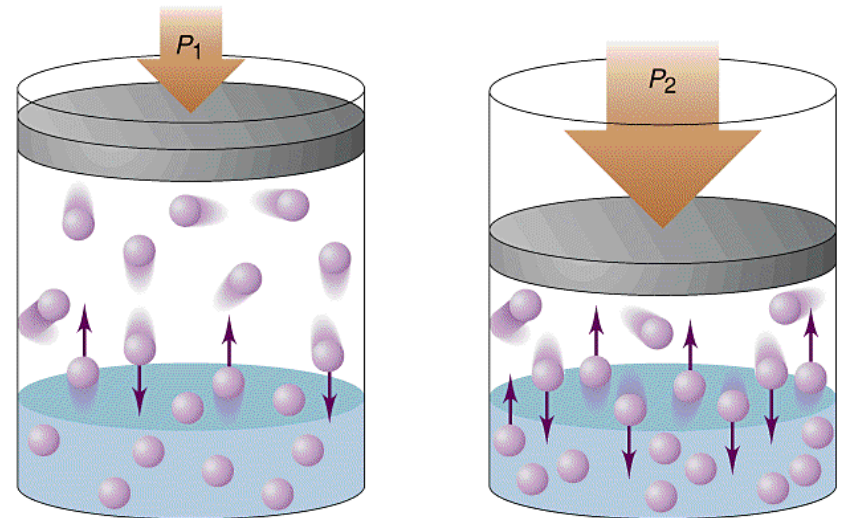
- \*Gases have to dissolve before they diffuse
- When a gas under pressure comes in contact with liquid, the gas dissolves in liquid until equilibrium is reached
- \*At a given temperature the amount of a gas in solution is proportional to partial pressure of that gas
- What is solubility?

★\*Henry's law:  $[G] = P_{\text{gas}} \times S_{\text{gas}}$

★[G] is the concentration of the gas in solution

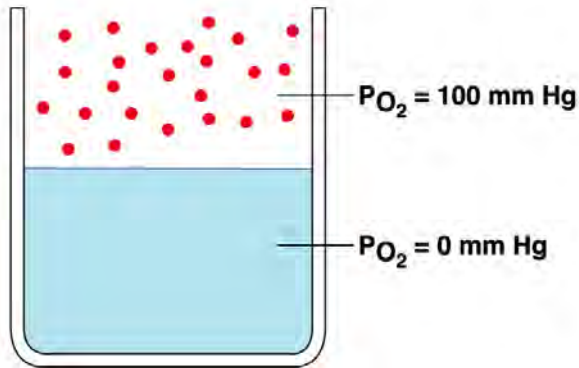
$P_{\text{gas}}$  = Partial pressure of the gas

$S_{\text{gas}}$  = how easily a gas can dissolve in a solution

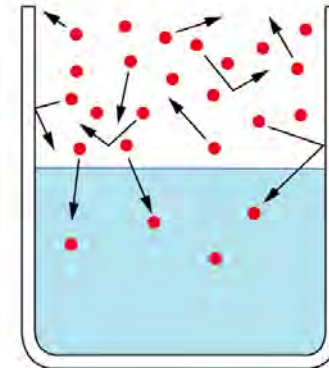


# Gases Dissolve in liquids. Henry's law

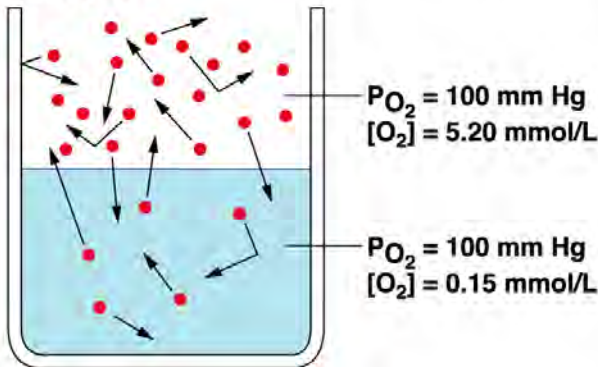
Initial state:  
no  $O_2$  in solution



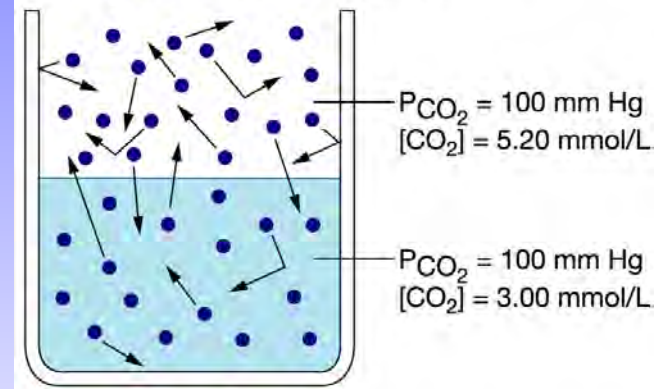
Oxygen dissolves



At equilibrium,  $P_{O_2}$  in air and water is equal. Low  $O_2$  solubility means concentrations are not equal.



When  $CO_2$  is at equilibrium at the same partial pressure, more  $CO_2$  dissolves.



***\* $CO_2$  is much more soluble in water than is  $O_2$ . Thus, at the **same partial pressure**, **more  $CO_2$  will be dissolved** in a solution than will oxygen. \*Need a  $O_2$  carrier due to low  $SO_2$***



# Diffusion Rates and molecular weight

**\*Graham's law** = The relative diffusion of a given gas is proportional to its solubility in the liquid and inversely proportional to the square root of its molecular weight:

**\* Diffusion rate = solubility/ $\sqrt{\text{MW}}$**

- O<sub>2</sub> 32 atomic mass units
- CO<sub>2</sub> 44 amu
- In air “solubilities” are the same (1000 ml/L at 20°C). So oxygen diffuses about 1.2 times faster than CO<sub>2</sub> in air.
- However, CO<sub>2</sub> is about 24 times more soluble in aqueous solutions than O<sub>2</sub>. \*CO<sub>2</sub> diffuses about 20 times faster than O<sub>2</sub> in water.

Again, why do we care? If we don't get rid of CO<sub>2</sub>, acid-base homeostasis is mucked up ☹

# Diffusion Rates at a constant temperature

\*\*\*\*\*Combining the Fick equation with Henry's and Graham's laws:

$$\text{*Diffusion rate} = dP_{\text{gas}} \times A \times S_{\text{gas}} / X \times \sqrt{(\text{MW})}$$

At a constant temperature the rate of diffusion is proportional to

- Partial pressure gradient ( $dP_{\text{gas}}$ ) = high to low
- Cross-sectional area (A) = doesn't change much as adult
- Solubility of the gas in the fluid ( $S_{\text{gas}}$ )

and inversely proportional to

- Diffusion distance (X)
- Molecular weight of the gas (MW)

So what do all of these equations really mean?

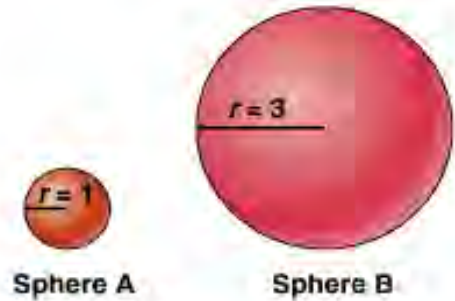
Fish versus Terrestrial animals

# Surface Area to Volume Ratio

- \*As organisms grow larger, their ratio of *surface area to volume* **decreases**
- This **limits the area available for diffusion** and **increases the diffusion distance**

$$J = -DA \frac{dC}{dx}$$

**That's why we need respiratory systems**



Sphere A

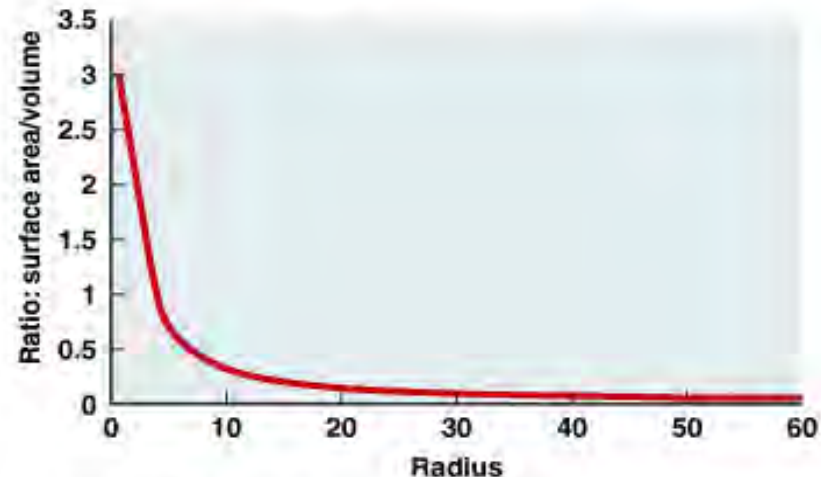
$$\text{Volume} = \frac{4}{3} \pi r^3$$

$$\text{Surface area} = 4\pi r^2$$

$$\frac{\text{Surface area}}{\text{Volume}} = \frac{3(4\pi r^2)}{4\pi r^3} = \frac{3}{r}$$

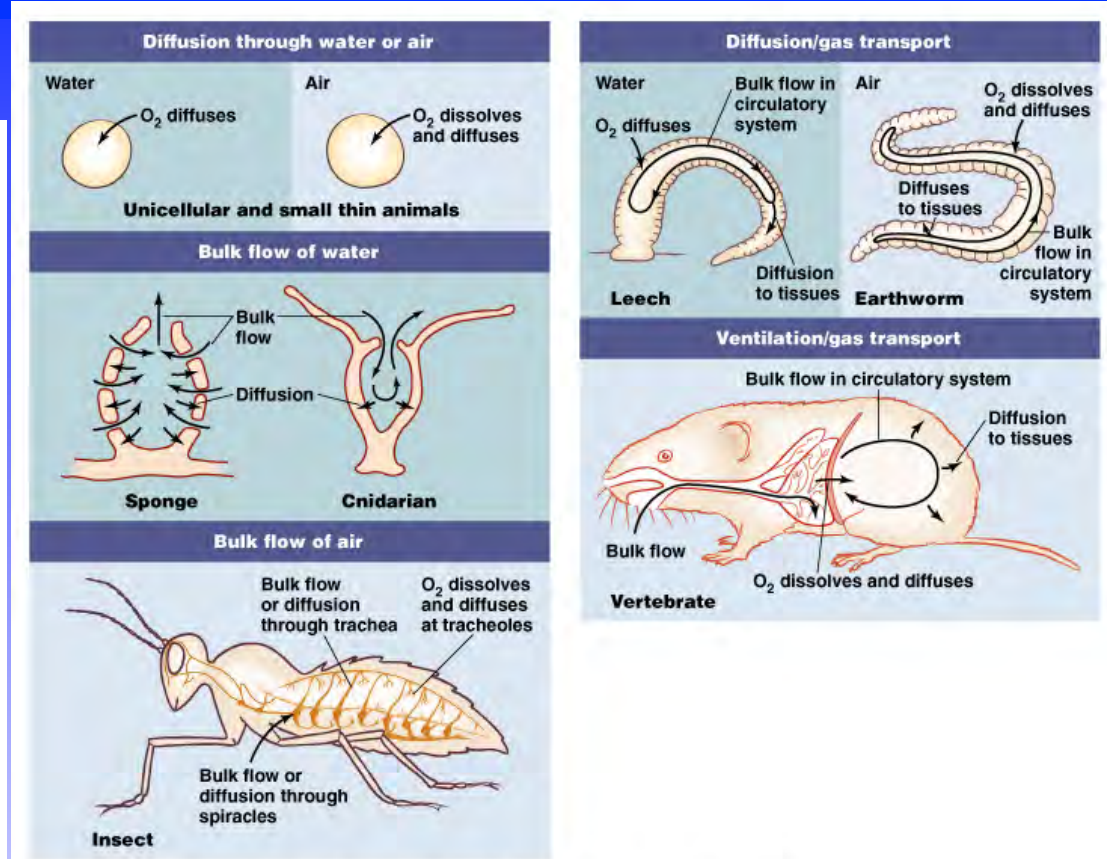
$$\frac{\text{Surface area}}{\text{Volume}} \text{ for sphere A} = 3$$

$$\frac{\text{Surface area}}{\text{Volume}} \text{ for sphere B} = 1$$



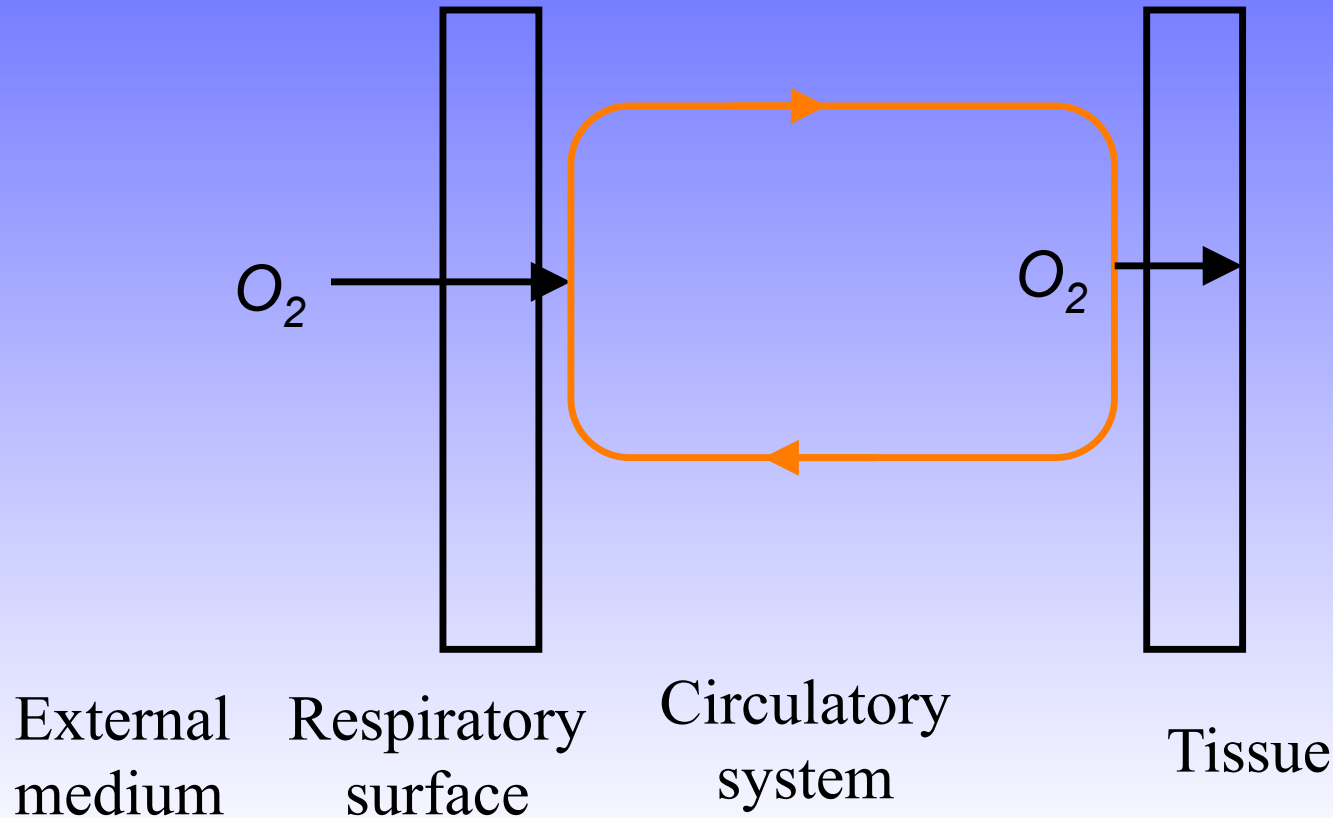
# Respiratory strategies of animals

- \*Unicellular and small multicellular organisms rely on diffusion for gas exchange
- \*Larger organisms must rely on a combination of bulk flow and diffusion for gas exchange, i.e. they need a respiratory system
- \*Bulk flow = large amount of medium = air or water
- \*Then the gases are exchanged by diffusion



# *Most animals have a circulatory system*

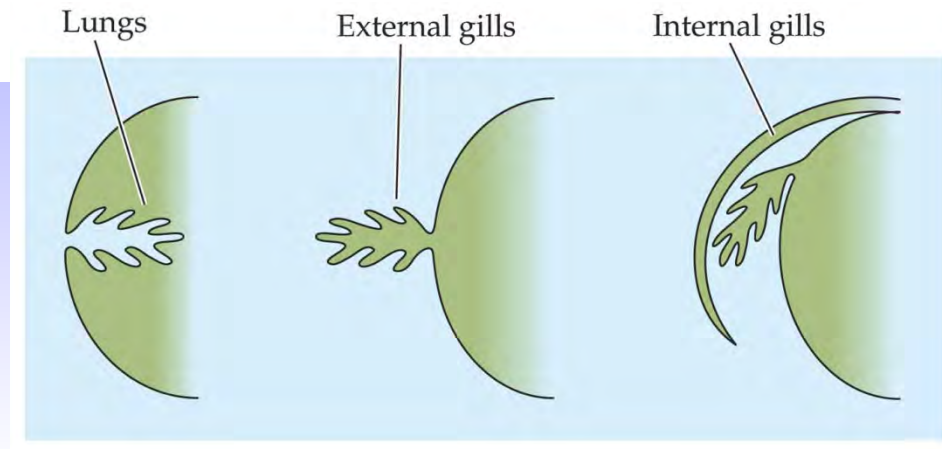
Diffusion of gases across a specialized respiratory surface accompanied by \*circulatory transport



# Respiratory Strategies

Animals more than a few millimeters thick use one of three respiratory strategies

- Circulating the external medium through the body = Sponges, cnidarians (jellyfish) and insects
- Diffusion of gases across the body surface accompanied by **circulatory transport**
  - *Cutaneous respiration = skin*
  - Most aquatic invertebrates, some amphibians, eggs of birds
- \*Diffusion of gases across a **specialized respiratory surface** accompanied by **circulatory transport**
  - Gills = evaginations; lungs = invaginations
  - Vertebrates



# Cutaneous respiration

## Respiration through skin

Found in some aquatic invertebrates and a few vertebrates

### Disadvantages:

- Relatively low surface area
- Conflict between respiration and protection = if skin gets damaged, respiration gets compromised ☹️



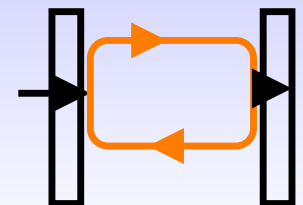
Salamander



Annelid



Lake Titicaca frog



# External gills

## Gills originate as outpocketings = evaginations

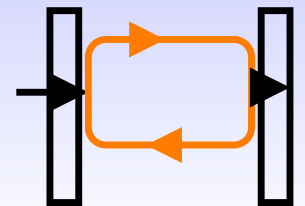
- **Advantages**: high surface area, exposed to medium
- **Disadvantages**: easily damaged, not suitable in air
- Gills dry out and collapse in air. Why is drying out bad? If dried out, gases cannot diffuse because they must first dissolve. If collapse, surface area reduced



Salamander



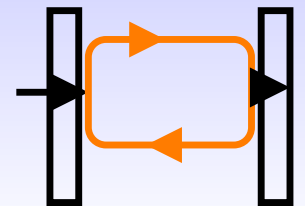
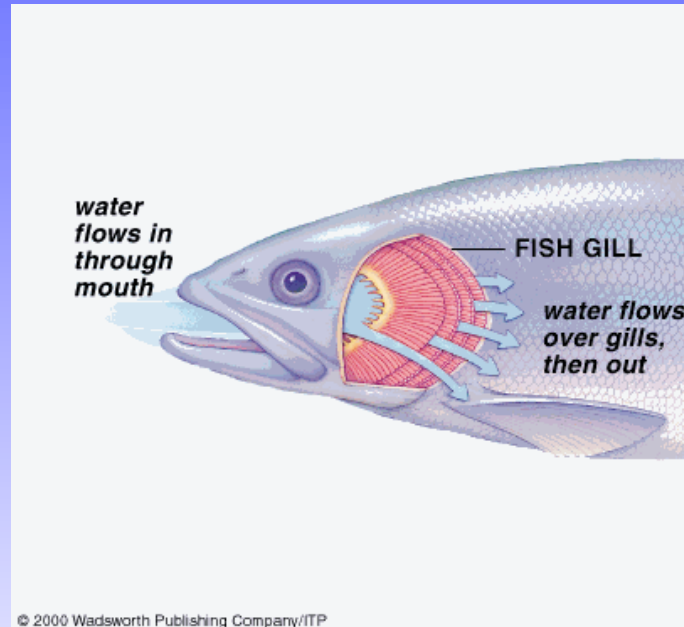
Polychaete





# Internal gills

- **Advantages**: High surface area, *protected*
- **Disadvantages**: not suitable in air = see previous slide, external gills



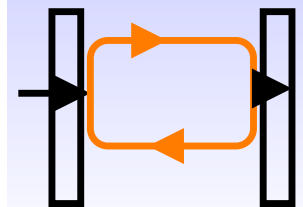
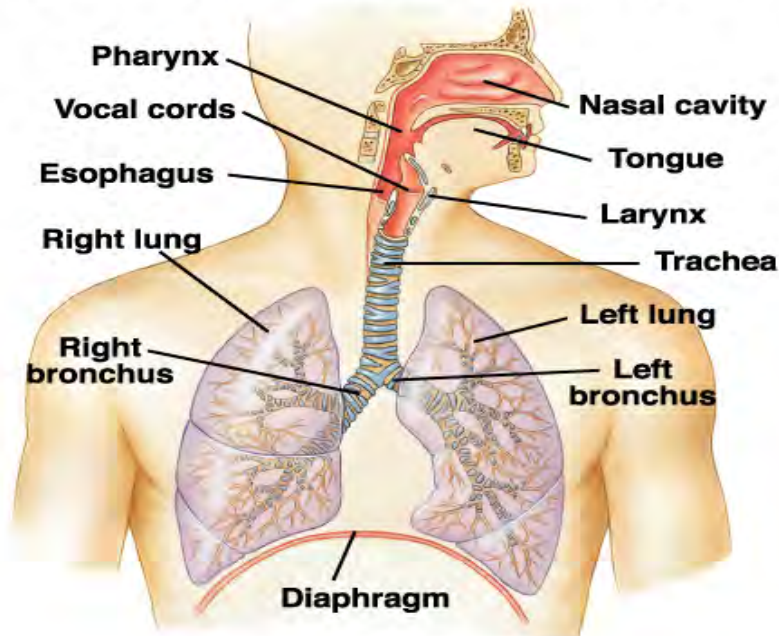
# \*\*Lungs

Originate as infoldings = invaginations

- **Advantages:** High surface area (2 tennis courts), protected, suitable for breathing air
- **Disadvantages:** not suitable in water. Why? O<sub>2</sub> solubility is very low in fluid and diffusion distance has greatly increased

## The respiratory system

The respiratory system consists of the upper respiratory system (mouth, nasal cavity, pharynx, larynx) and the lower respiratory system (trachea, bronchi, lungs). The lower respiratory system is enclosed in the thorax, bounded by the ribs, spine, and diaphragm.



# Ventilation

\***Ventilation** = active movement of the respiratory medium (air or water) across the respiratory surface. Bulk flow = large quantity of air or water

\*\***Flow** =  $\Delta P/R$  = **pressure gradient/resistance**. Flow in the two tubes is equal because pressure gradients are equal. Animals will affect pressure gradients by changing volume. Increase volume to decrease pressure and air/water will go down pressure gradients



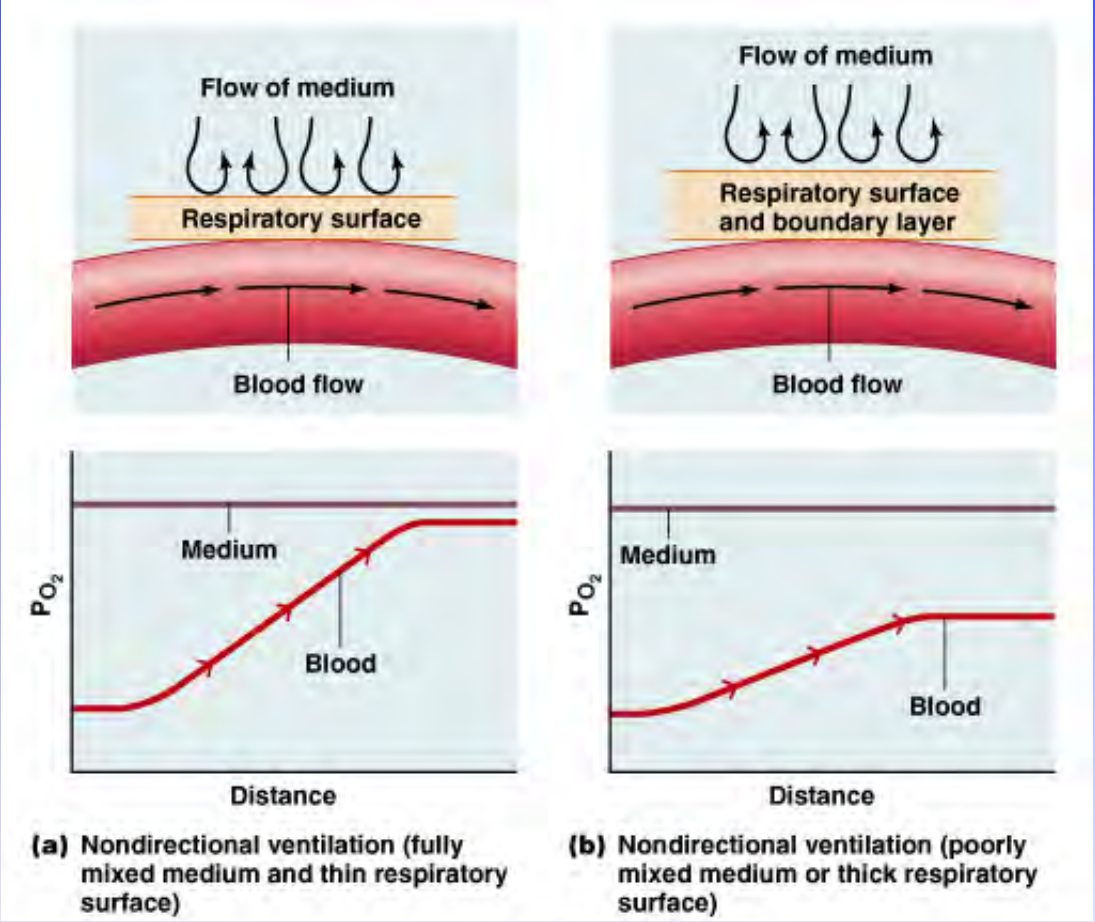
## Types of ventilation

- *Nondirectional* - medium flows passing the respiratory surface in an unpredictable pattern = air across frog skin
- \*Tidal - medium moves in and out the same structure = lungs in mammals
- *Unidirectional* - medium enters the chamber at one point and exits at another = in fish.. More later

**Note:** \*Air and water will move down pressure gradients.

# Nondirectional ventilation

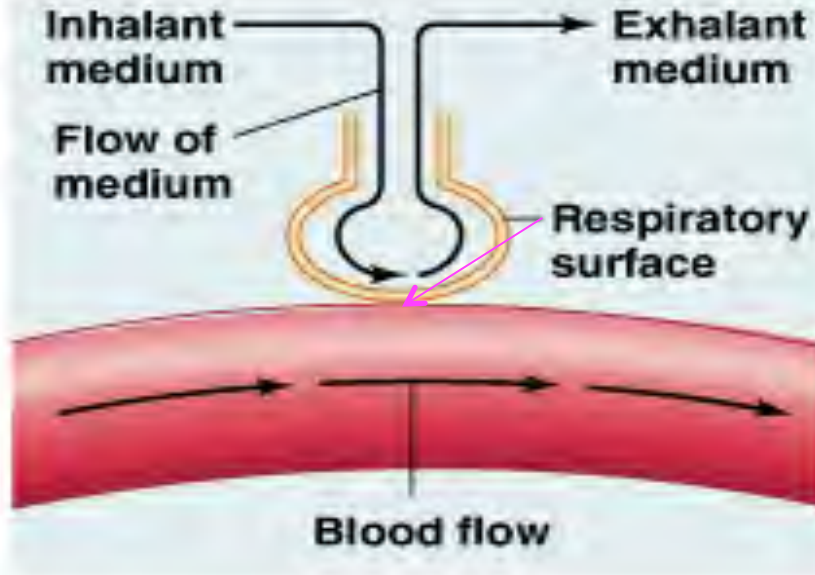
Medium flows past the respiratory surface in an unpredictable pattern



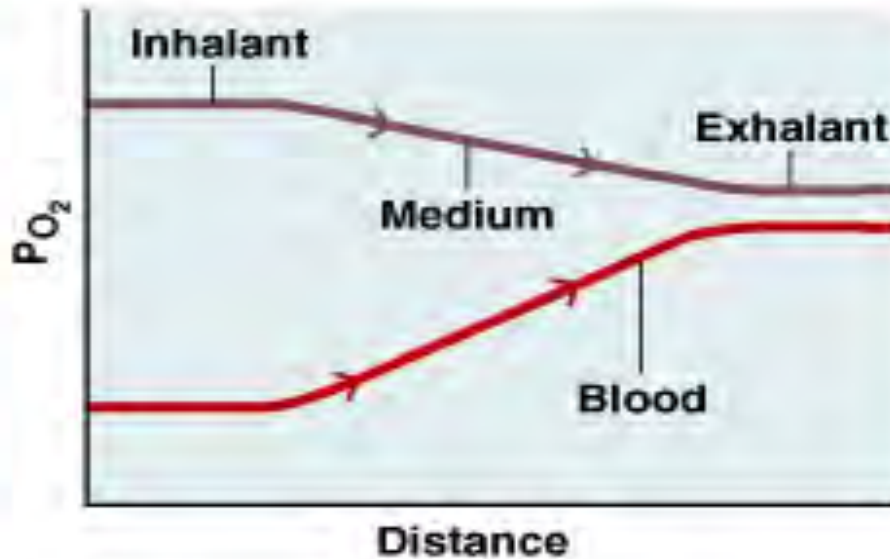
Example **frog skin**:  
If frog is ill and has barrier such as slime on skin, less  $O_2$  can be picked up across skin

# **\*\*Tidal ventilation**

Medium moves in and out the same structure



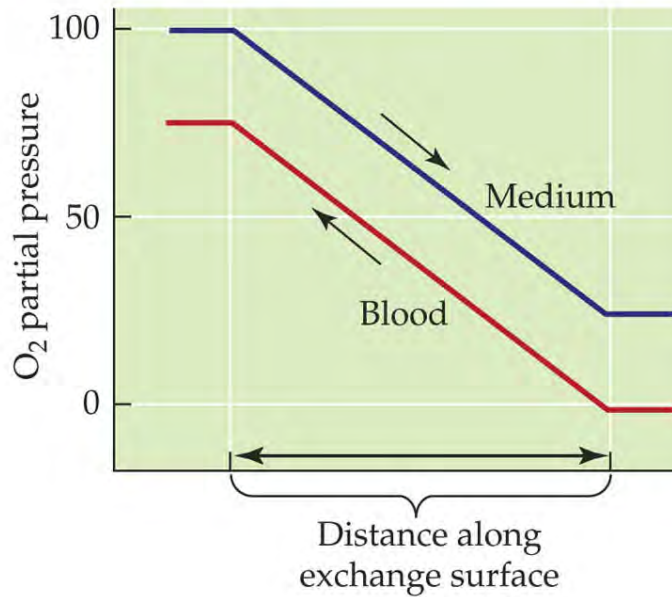
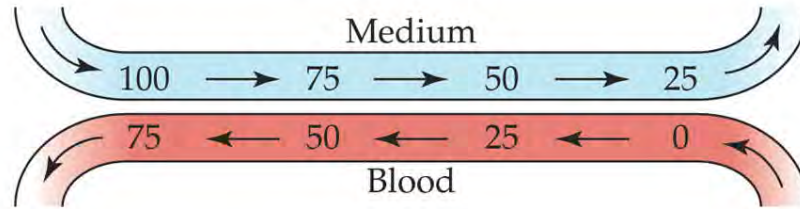
*Lungs*



Why less Oxygen at exhalant?

# Gas exchange - unidirectional ventilation

(b) Countercurrent gas exchange



Fish: water in at mouth  
and out at operculum

Blood flow is countercurrent

Maintain a gradient and so blood

Can be maximally oxygenated  
= almost to saturation

ANIMAL PHYSIOLOGY, Figure 21.4 (Part 2) © 2004 Sinauer Associates, Inc.

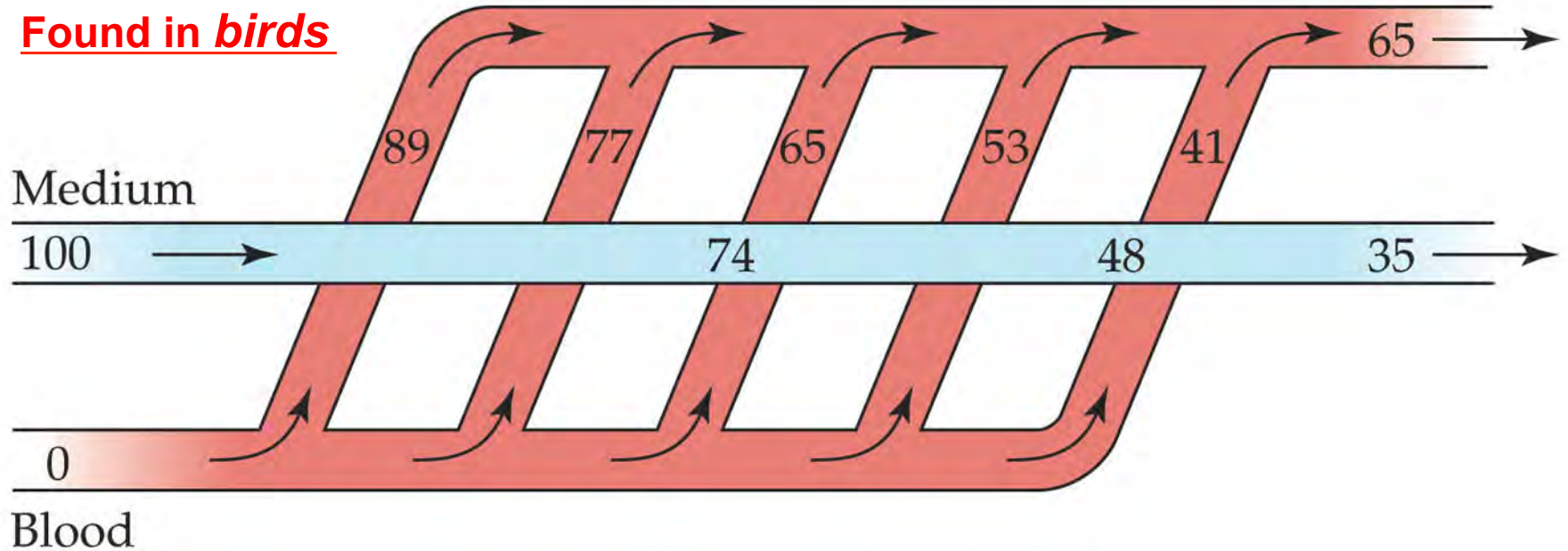
Maintain gradient.

**\*\*\*PO<sub>2</sub> of blood approaches that of the inhalant medium**

# Gas exchange - unidirectional ventilation

Cross-current gas exchange

**Found in birds**

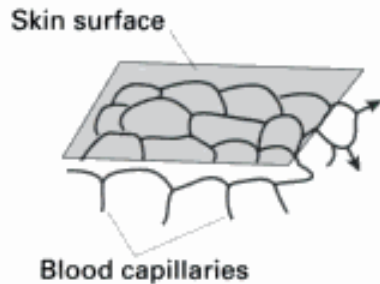


***The  $P_{O_2}$  of arterial blood is derived from a mixture of all serial air-blood capillary units and exceeds that of the exhaled  $P_{O_2}$ .***

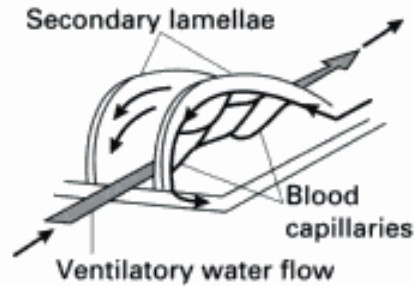
$$(89+77+65+53+41)/5 = 65$$

# Types of ventilation - Summary

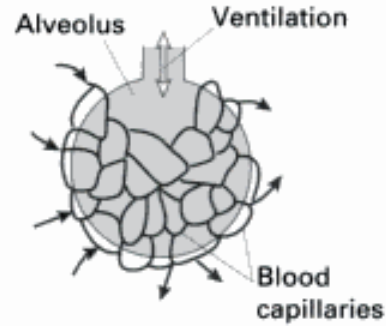
**Amphibian skin**



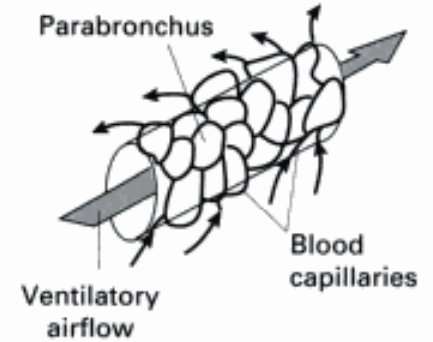
**Fish gills**



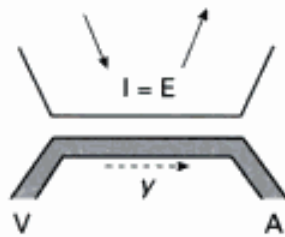
**Mammalian lung**



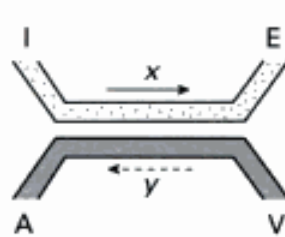
**Bird lung**



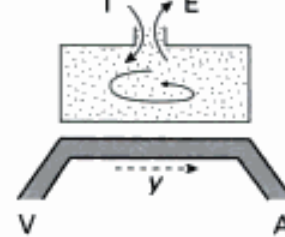
**'Open'**



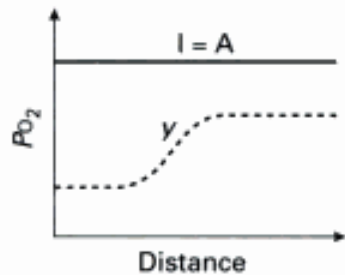
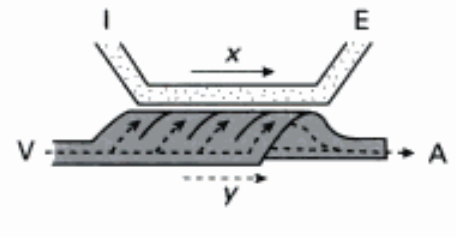
**Countercurrent**



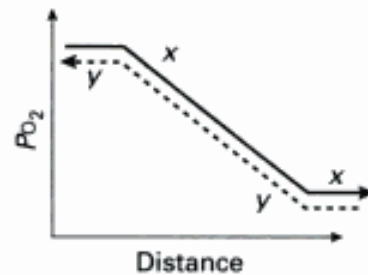
**'Pool'**



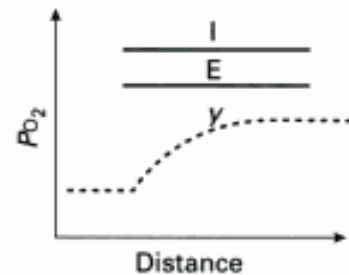
**Crosscurrent**



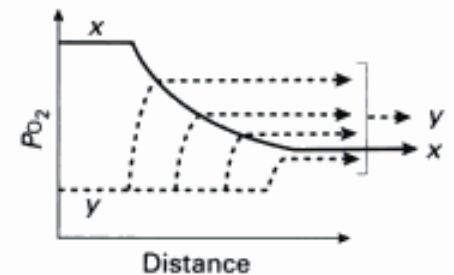
(a)



(b)



(c)



(d)



# Ventilation and Gas Exchange

*Because of the different physical properties of air and water, animals use different strategies depending on the medium in which they live*

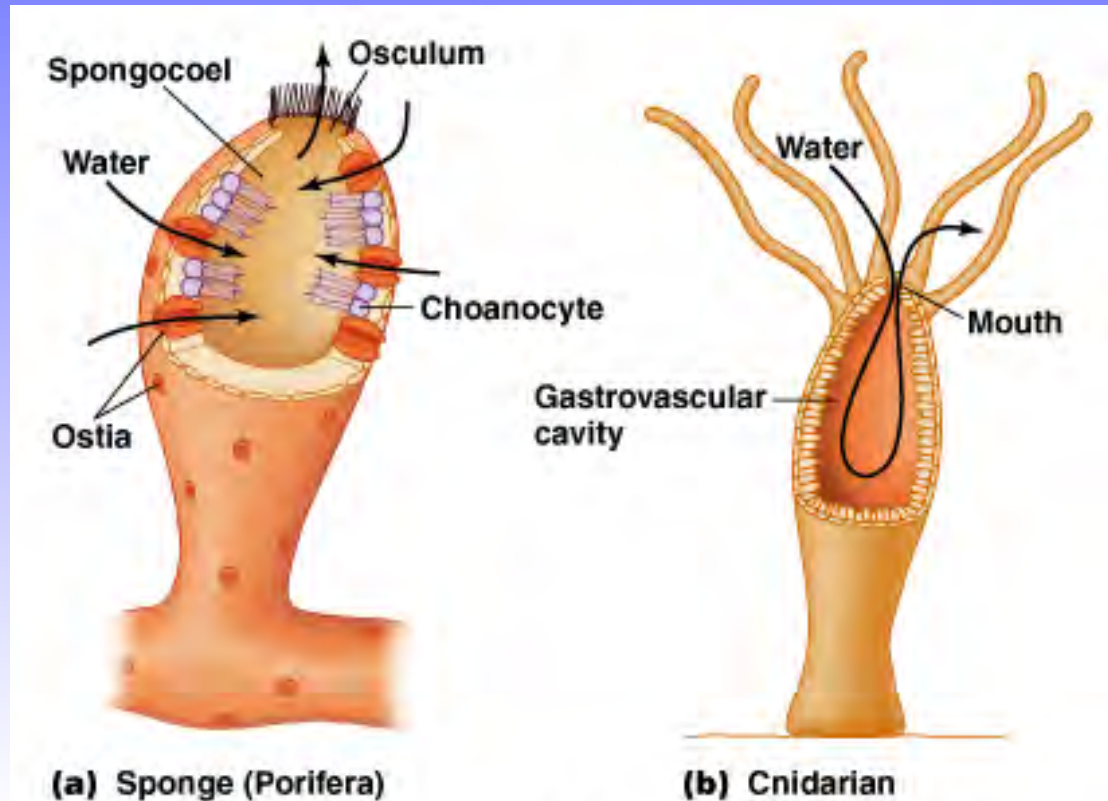
## Differences

- **[O<sub>air</sub>] greater than [O<sub>water</sub>]**. Think Henry's law....
- Water is more dense and viscous than air. Fick's equation....
- Evaporation is only an issue for air breathers
  
- Solubility of O<sub>2</sub> in water a lot less so fish/aquatic animals have to worry more about O<sub>2</sub>

What strategies are being used? Next slides

# *Sponges and Cnidarians - in water*

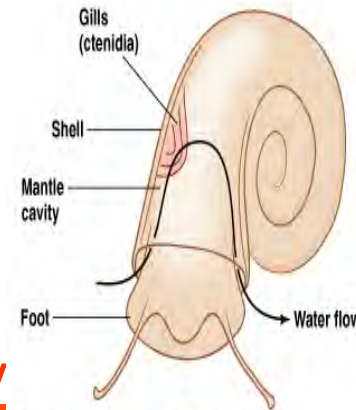
- Circulate the external medium through an internal cavity
- In sponges flagella move water in through *ostia* and out through the *osculum*. *Flagella in humans = sperm*
- In cnidarians (jellyfish) muscle contractions move water in and out through the mouth



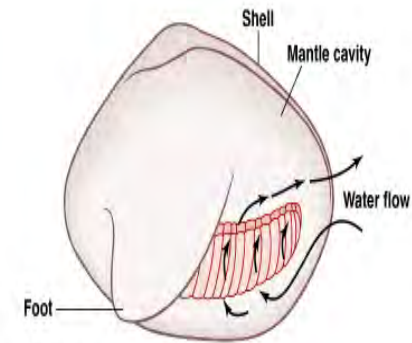
# Molluscs - in water

## Two strategies for ventilating their gills and mantle cavity

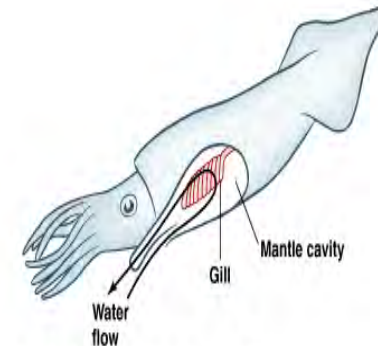
- Beating of cilia on gills move water across the gills unidirectionally . Cilia are structures that beat rhythmically and move “stuff”
  - Blood flow is countercurrent
  - Snails and clams
- Muscular contractions of the mantle propel water unidirectionally through the mantle cavity past the gills
  - Blood flow is countercurrent
  - Cephalopods (squid)



(a) Gastropod mollusc (e.g., aquatic snail)



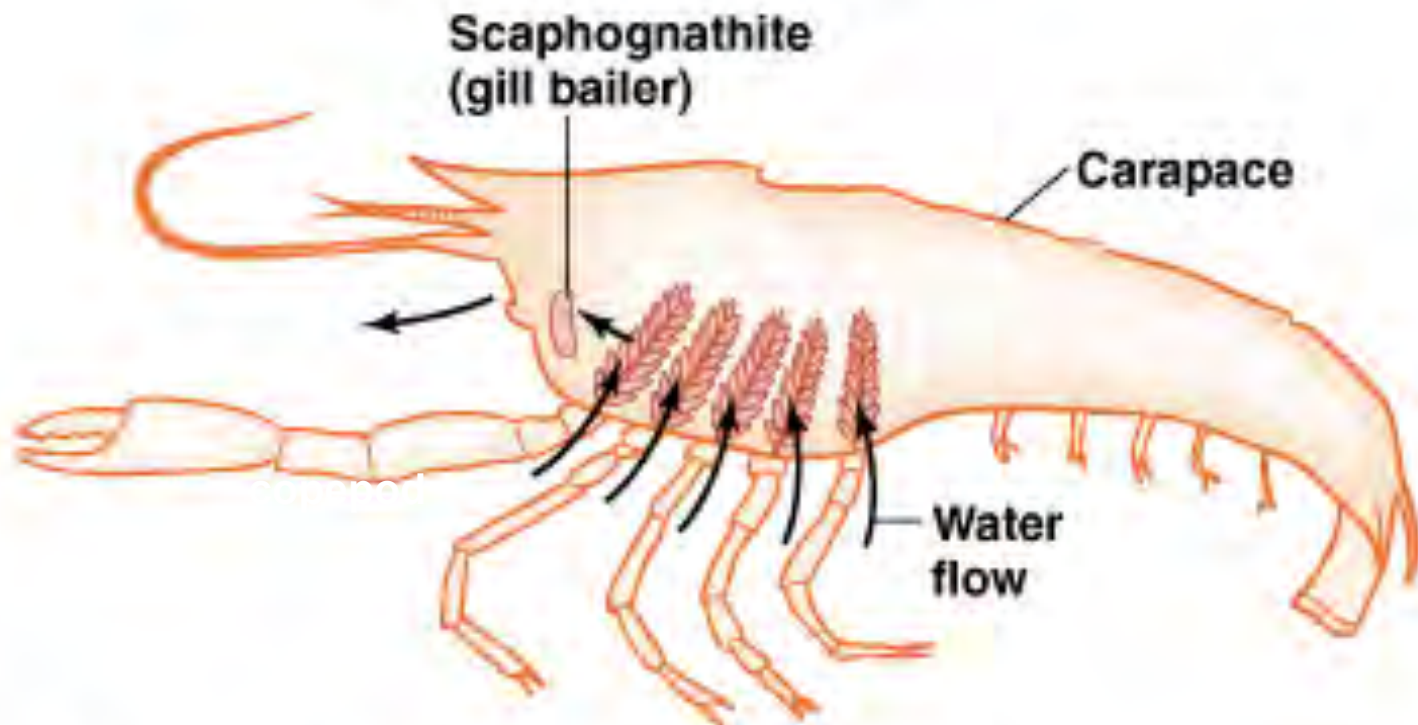
(b) Lamellibranch mollusc (e.g., clam)



(c) Cephalopod mollusc (e.g., squid)

# Crustaceans - in water

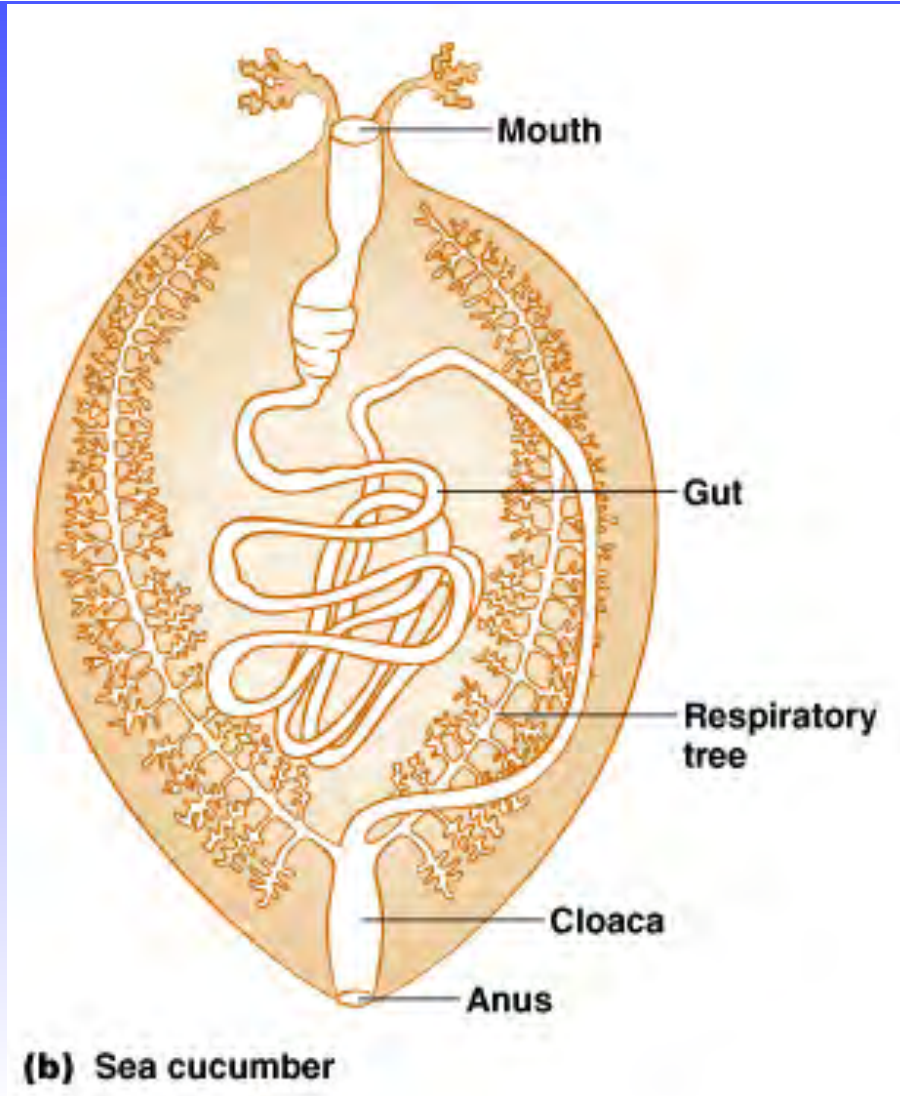
- Shrimp, crabs and lobsters, have gills derived from **modified appendages** located within a branchial cavity
- Movements of the **gill bailer** propels water out of the branchial chamber; the **negative pressure sucks water across the gills**



Decapod crustacean (crayfish)

# Echinoderms - in water

- **Sea cucumbers** use muscular contractions of the cloaca and the *respiratory tree* to breathe water *tidally* through the anus

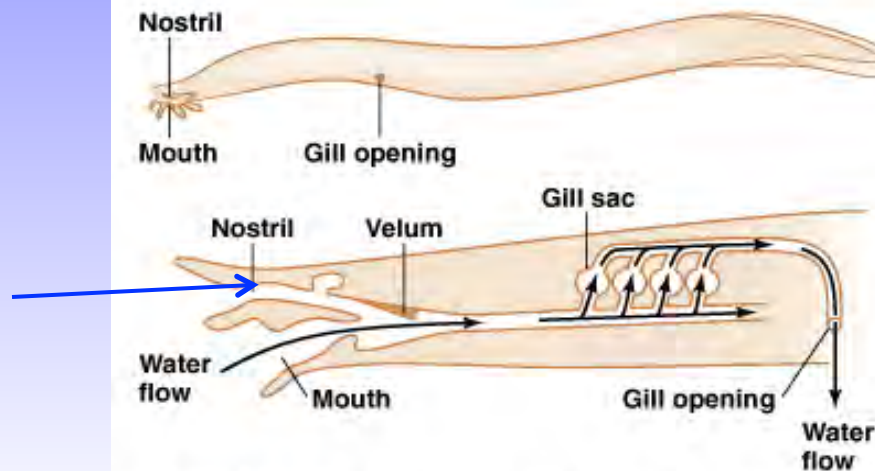
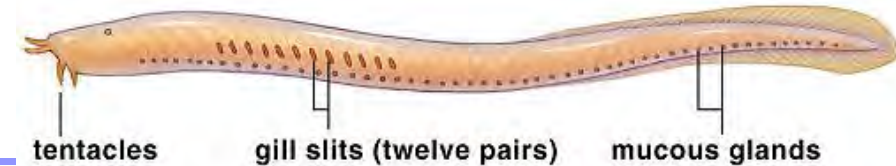


# Jawless Fishes - Hagfish - in water

Lamprey and hagfish have **multiple pairs of gill sacs**

## Hagfish

- A muscular pump (= **velum**) propels water through the respiratory cavity
- Water enters the **median nostril** and leaves through a gill opening
- Flow is **unidirectional**
- Blood flow is **countercurrent**



(a) Hagfish (side view and longitudinal section)

# Jawless Fishes - Lamprey - in water

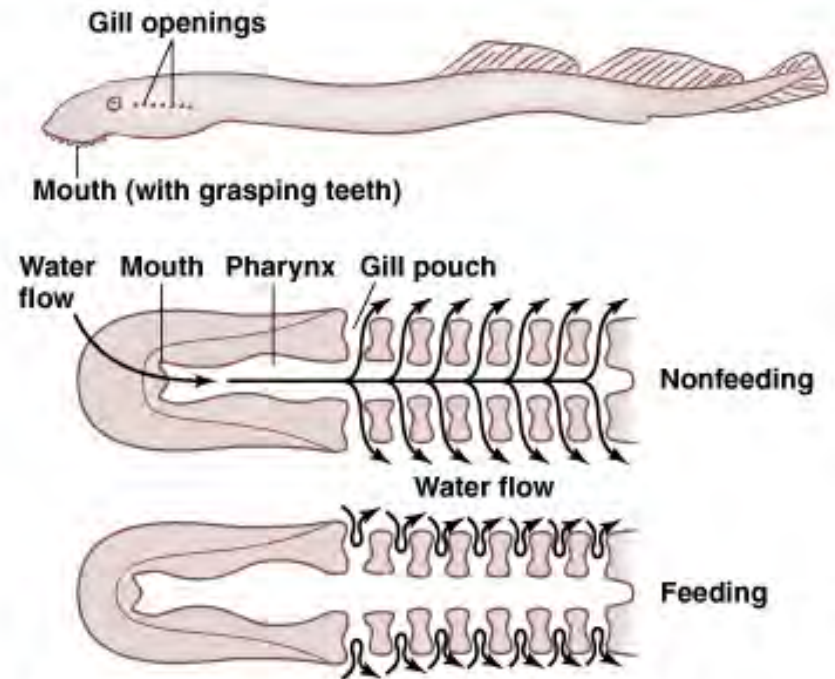
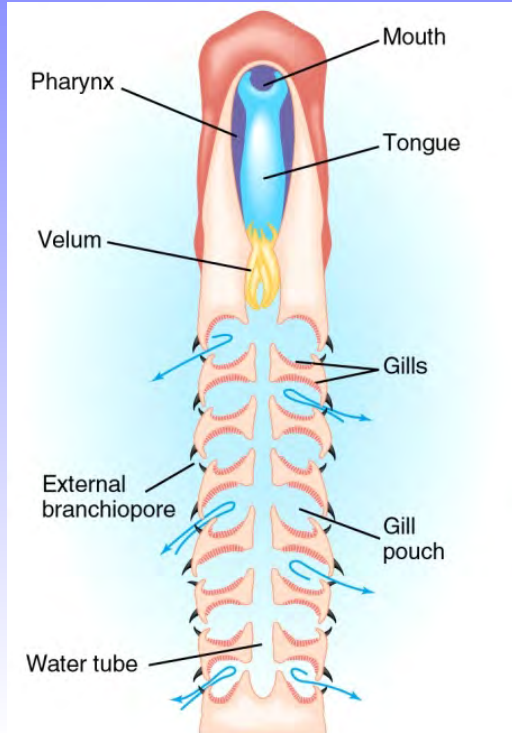
## Lamprey

- Ventilation is similar to that in hagfish when **not feeding**
- When feeding the mouth is attached to a prey (**parasitic**)
- Ventilation is **tidal** though the gill openings when feeding



**b Lamprey gill openings (seven pairs)**

©2001 Brooks/Cole - Tho



**(b) Lamprey (side view and longitudinal section)**

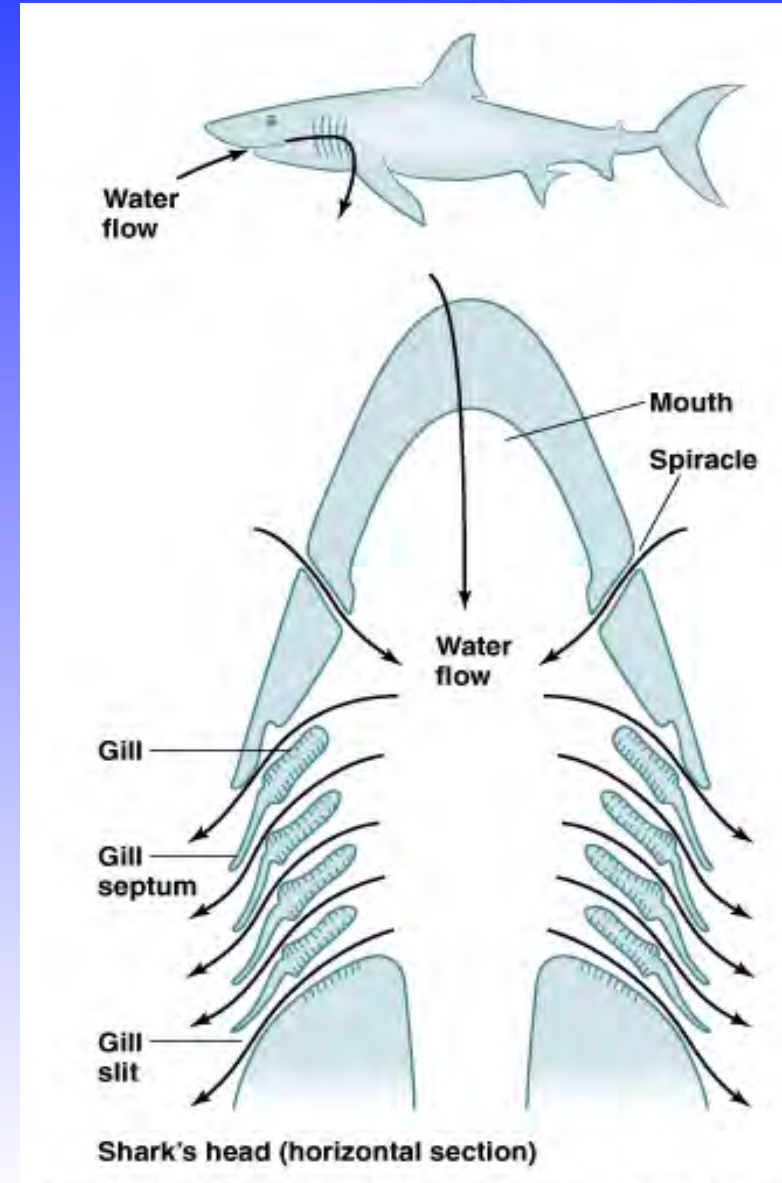
# **\*\*Elasmobranchs - sharks, skates and rays - in water**

## **Steps in ventilation**

- **Expand the buccal cavity** = this increases the volume and so **decreases the pressure** and water flows down pressure gradients
- **Increased volume** sucks fluid/water into the buccal cavity via the **mouth and spiracles (hoels/pores)**
- Mouth and spiracles close
- Muscles around the buccal cavity contract forcing water past the gills and out the external gill slits
- **Water flow is unidirectionally**

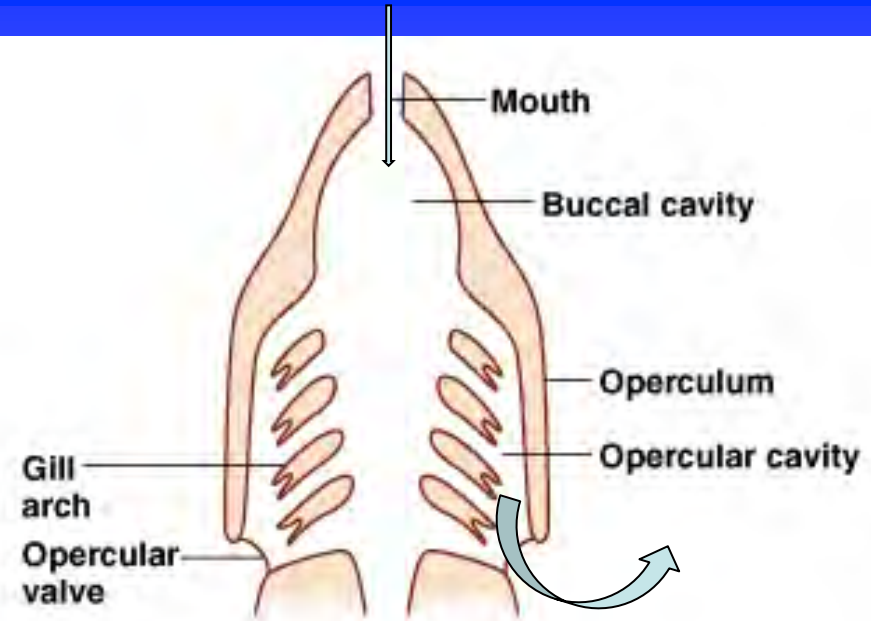
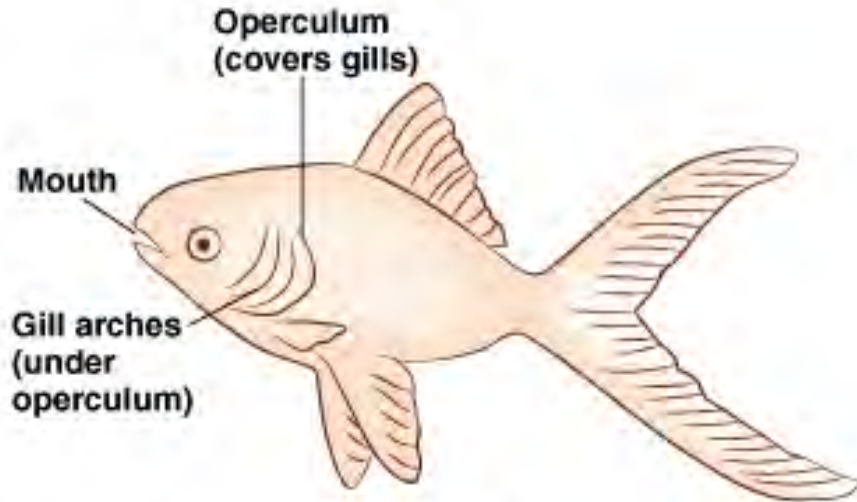
**Blood flow is countercurrent**

**\*Buccal = relating to mouth**





# Teleost Fishes - in water

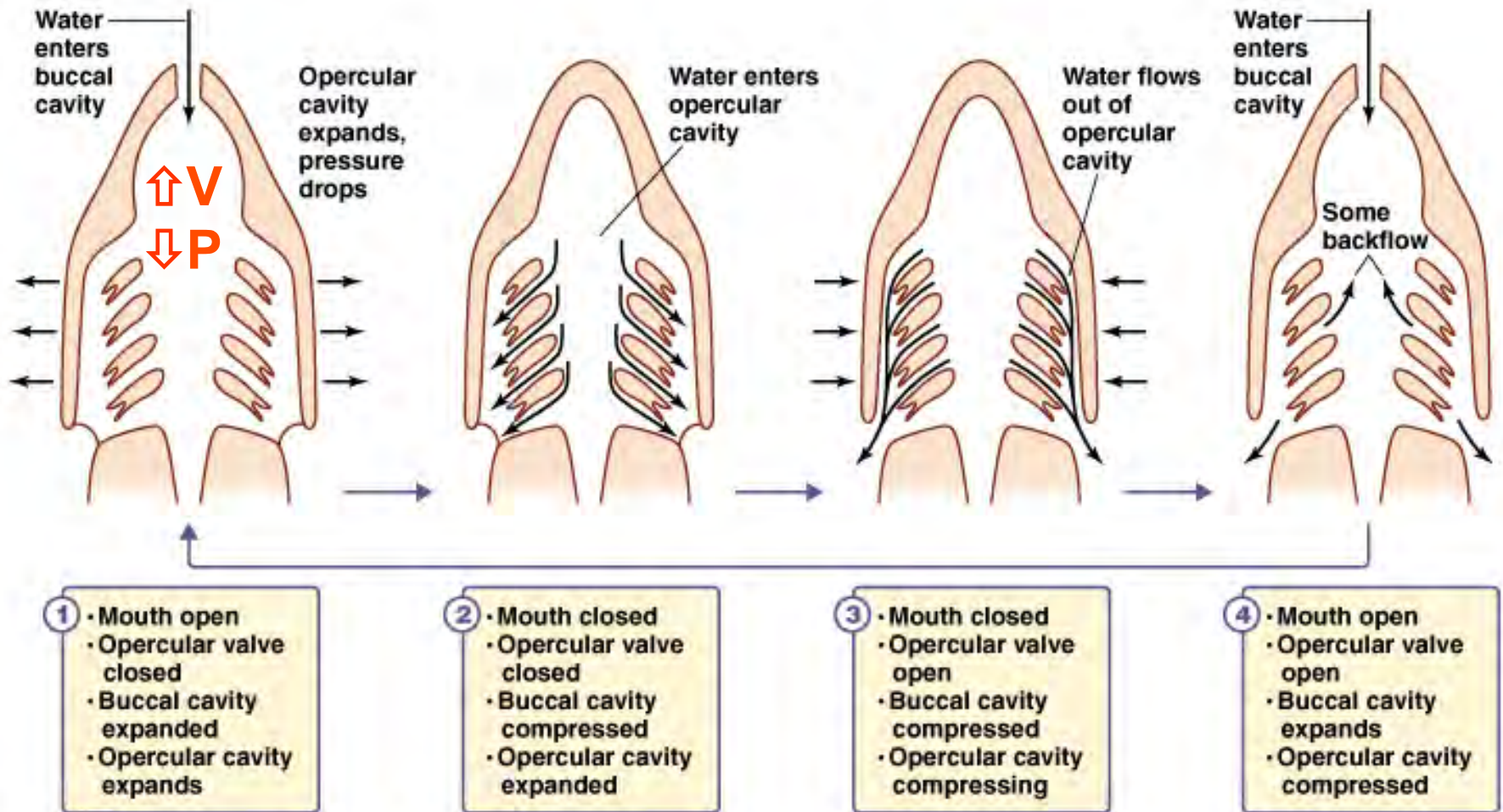


**(a) Teleost fish (lateral view and horizontal section)**

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Water flows in via the mouth, out via the opercular opening

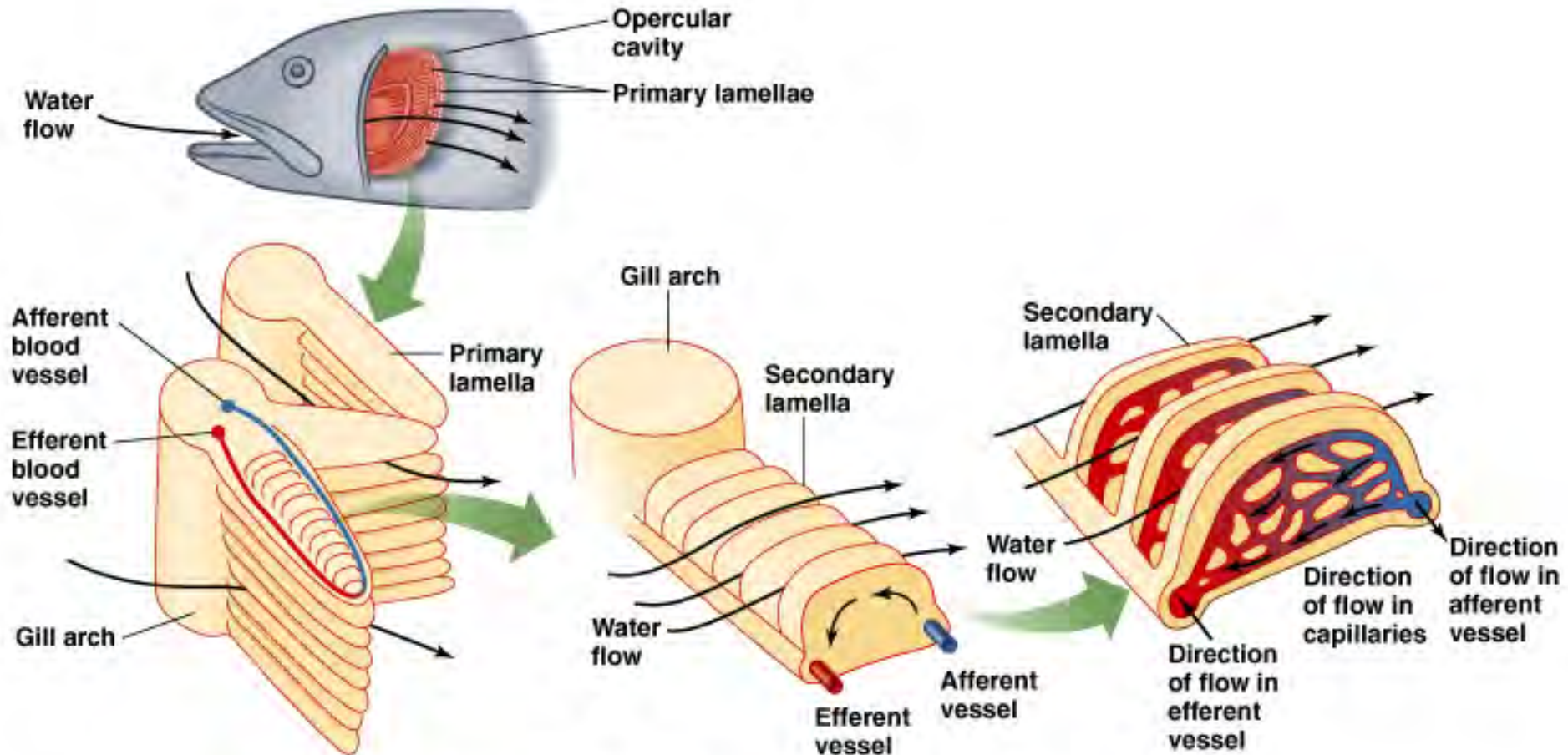
# Teleost Fishes



(b) Ventilatory cycle of teleosts

# More about fish Gills

**Fish gills are arranged for *countercurrent flow***



# Water breathers

*Outline and list:*

*Which water breathing animals use cilia, muscular contractions. Sponges*

*How is water brought into respiratory structure? What is the common method? Movement of water through gills*

# *Ventilation and Gas Exchange in Air*

- Arthropods (eeeekkkk)
- Vertebrates

# Ventilation - terrestrial molluscs

- The “pulmonate” molluscs lack gills (or have highly reduced gills)
- Instead, mantle cavity is highly vascularized
- Garden snails and terrestrial slugs are pulmonates
- Pumping of the mantle cavity moves air in and out



[https://www.google.com/search?q=pulmonate+lung&source=lnms&tbm=isch&sa=X&ei=MMqLU-37FsmTqgb724D4Dw&ved=0CAYQ\\_AUoAQ&biw=1440&bih=817#q=pulmonate+lung+slugs&tbm=isch&facrc=\\_&imgdii=\\_&imgcr=GPRFDb2RpYJE6M%253A%3BdyNmp\\_2HzkoJSM%3Bhttp%253A%252F%252Fwww.comoxvalleynaturalist.bc.ca%252Fassets%252Fimages%252Fmisc%252Fbanana\\_slug.jpg%3Bhttp%253A%252F%252Fwww.comoxvalleynaturalist.bc.ca%252Fknowing\\_nature%252F2005%252Fslugs.html%3B300%3B225](https://www.google.com/search?q=pulmonate+lung&source=lnms&tbm=isch&sa=X&ei=MMqLU-37FsmTqgb724D4Dw&ved=0CAYQ_AUoAQ&biw=1440&bih=817#q=pulmonate+lung+slugs&tbm=isch&facrc=_&imgdii=_&imgcr=GPRFDb2RpYJE6M%253A%3BdyNmp_2HzkoJSM%3Bhttp%253A%252F%252Fwww.comoxvalleynaturalist.bc.ca%252Fassets%252Fimages%252Fmisc%252Fbanana_slug.jpg%3Bhttp%253A%252F%252Fwww.comoxvalleynaturalist.bc.ca%252Fknowing_nature%252F2005%252Fslugs.html%3B300%3B225)

# *Arthropods (eeeeeeek)*

- Crustaceans = crabs, woodlice and sowbugs
- Chelicerates = spiders and scorpions
- Insects



*Magdalene  
Gift from Agnes Lacombe*

# Crustaceans

## Terrestrial crabs

- Respiratory structures and the processes of ventilation are similar to marine relatives, but
  - Gills are stiff so they do not collapse in air
  - Branchial cavity is highly vascularized and acts as the primary site of gas exchange
  - Movements of the *gill bailer* propels air in and out of the **branchial chamber**
  
- Remember: \*Gills in marine animals collapse and dry out in air.



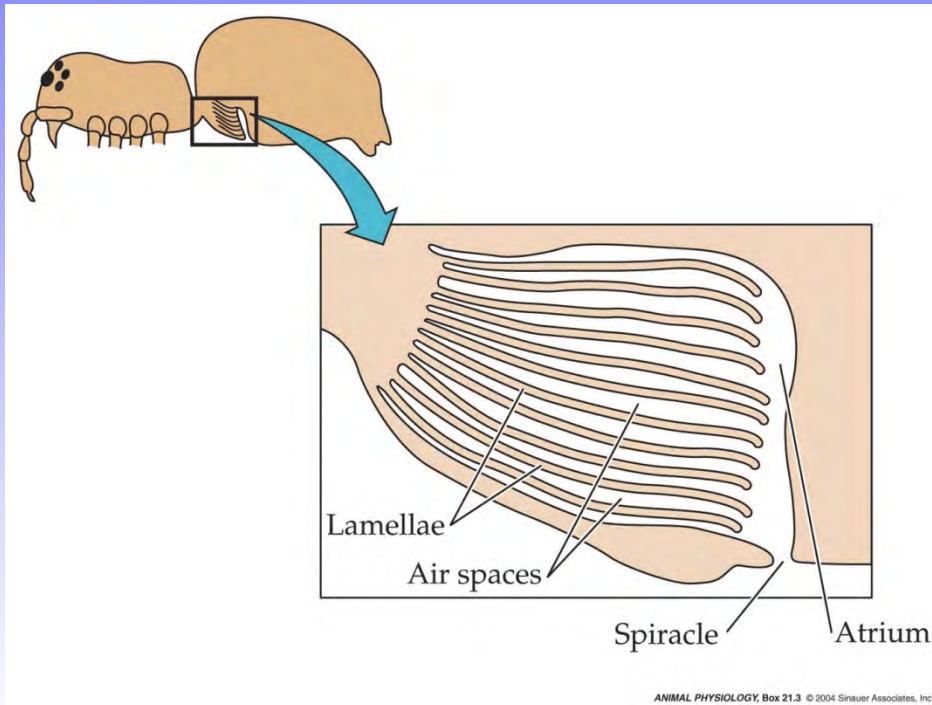
# Chelicerates - Spiders and scorpions

## Have four book lungs

- Consists of 10-100 lamellae = high surface area
- Open to outside via spiracles
- Gases diffuse in and out

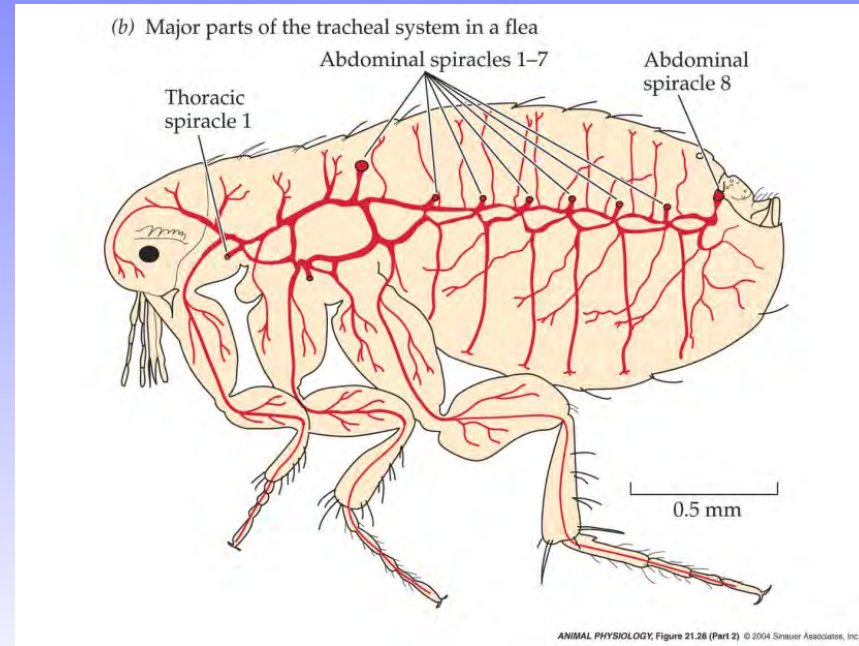
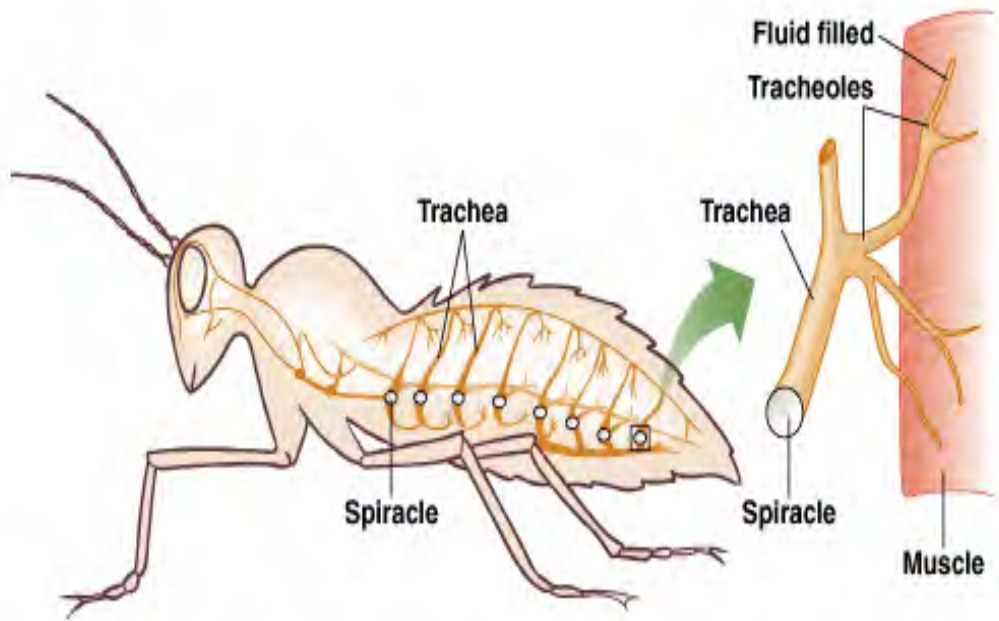
## Some spiders also have a *tracheal system* – series of air-filled tubes

- Oxygen diffuses into the trachea and dissolves in the interstitial fluid before diffusing into the tissues. \*Interstitial fluid = outside cells



# Insects

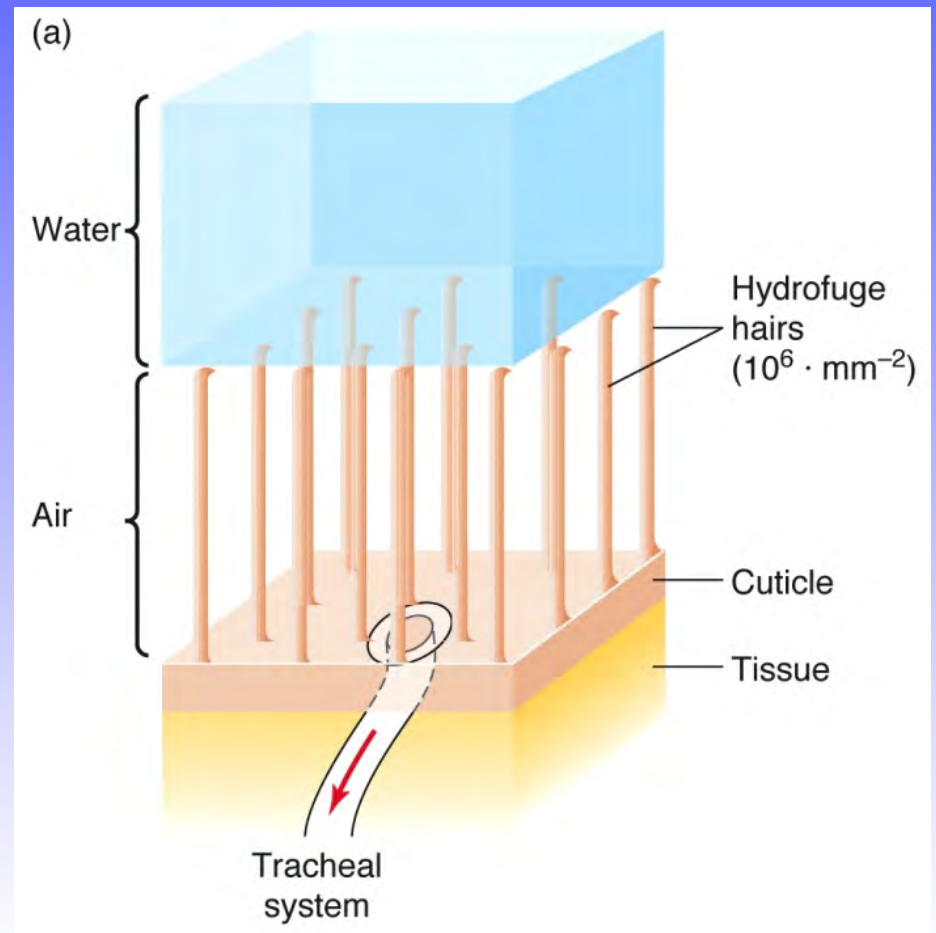
- Have an **extensive tracheal system** - series of **air-filled tubes**
- **Tracheoles** – terminating ends of tubes that are filled with **hemolymph**
- Oxygen **dissolves in the hemolymph = blood of insects**
- Open to outside via **spiracles**
- **Gases diffuse in and out**
- **High diffusion coefficient of oxygen in air allows oxygen to diffuse through the tracheal system**



# Something "cool" about aquatic insects



- Most aquatic insects breathe air
- Mosquito larvae have “snorkel”



# *Air breathing vertebrates*

- Air breathing evolved in fishes
- Aquatic habitats can become **hypoxic = low O<sub>2</sub>**
- Under these conditions, the ability to breathe air is a substantial benefit

We will discuss

- Air-breathing Fish
- Amphibians
- Reptiles
- Birds
- **Mammals**

# Evolution of air breathing

*Air breathing has evolved multiple times in fishes*

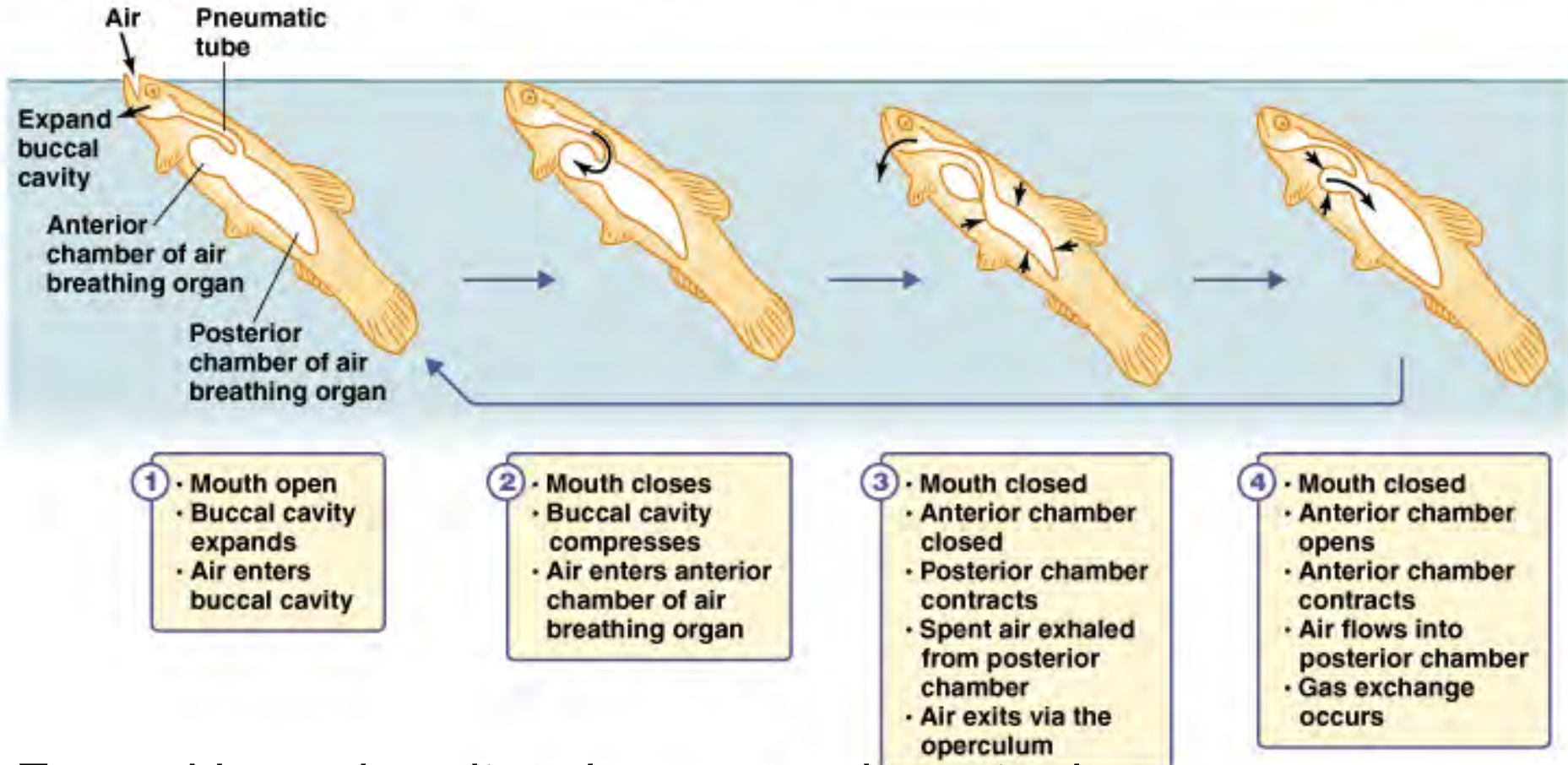
## Types of respiratory structures

- Reinforced gills that do not collapse in air = such as stiff gills
- Mouth or pharyngeal cavity for gas exchange = highly vascularized = lots of superficial blood vessels in mouth or pharyngeal cavity to take up O<sub>2</sub>
- Vascularized stomach = blood vessels in stomach take up O<sub>2</sub>
- Specialized pockets of the gut = also high vascularized
- Lungs

*Ventilation is tidal using buccal force similar to other fish = helps to push air into respiratory structure*

Note: Some fish use “aquatic surface respiration” when hypoxic = Swim to the surface and ventilate gills with water from the thin well-oxygenated water layer near surface

# Air-breathing fish



*Expand buccal cavity = increase volume to decrease pressure*  
*Very little mixing of fresh and old water ☺*

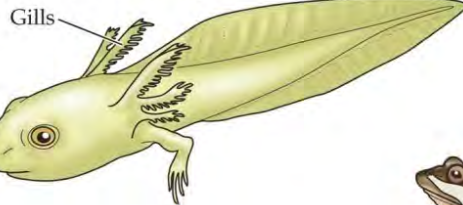
# Amphibians - ventilation

## Types of respiratory structures

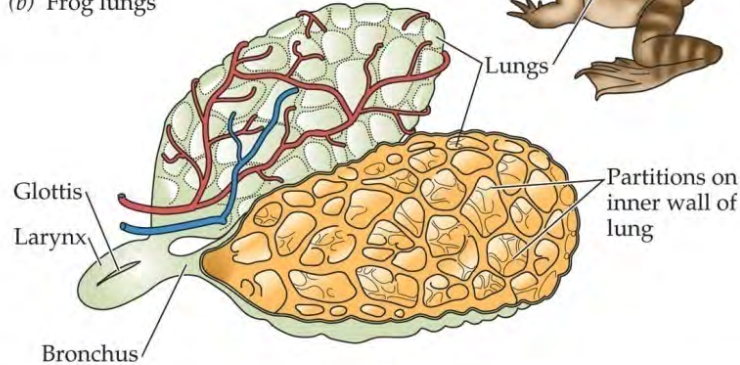
- Cutaneous respiration = use skin
- External gills – what were advantages/disadvantages?
- Simple bilobed lungs; more complex in terrestrial frogs and toads

## Ventilation is tidal using a buccal force pump

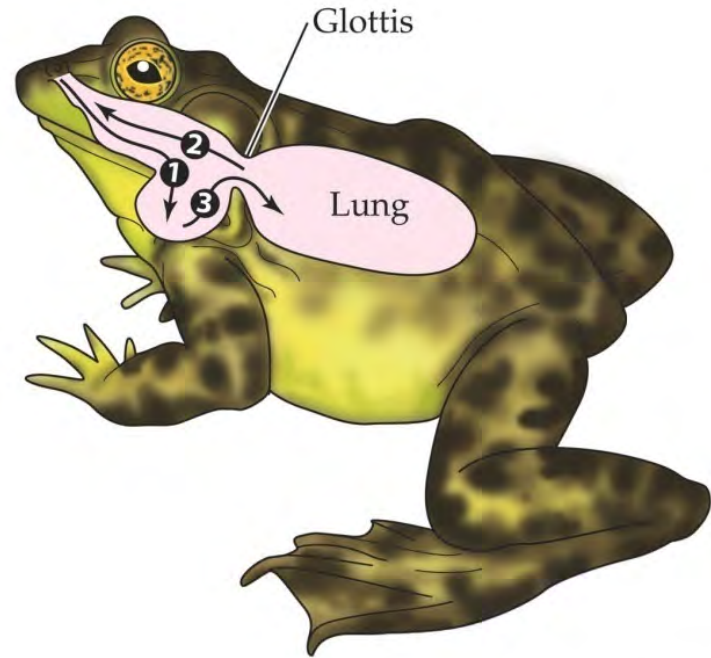
(a) Salamander larva with gills



(b) Frog lungs

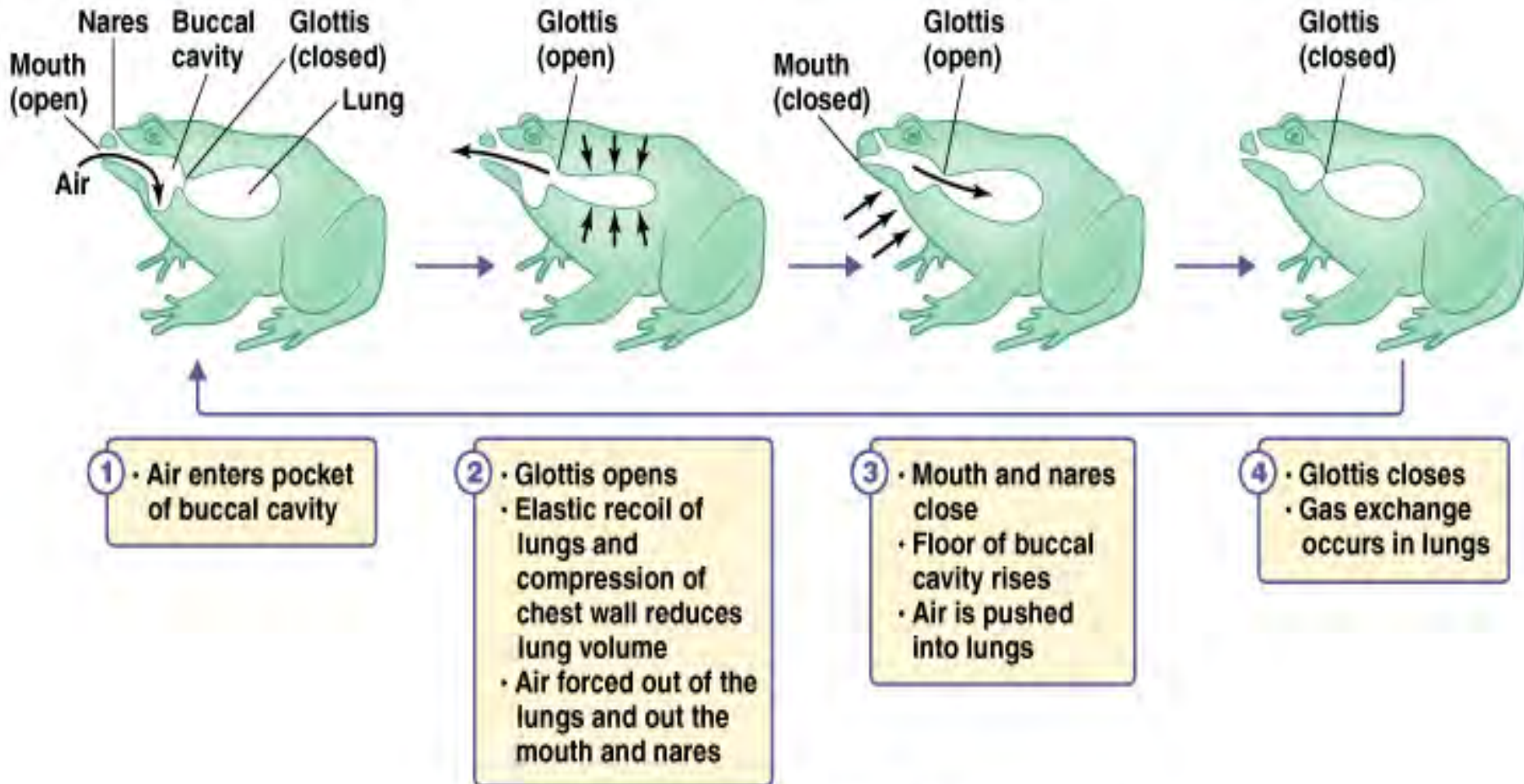


ANIMAL PHYSIOLOGY, Figure 21.13 © 2004 Sinauer Associates, Inc.



ANIMAL PHYSIOLOGY, Figure 21.14 © 2004 Sinauer Associates, Inc.

# Amphibians



Ventilation is tidal using a buccal force pump



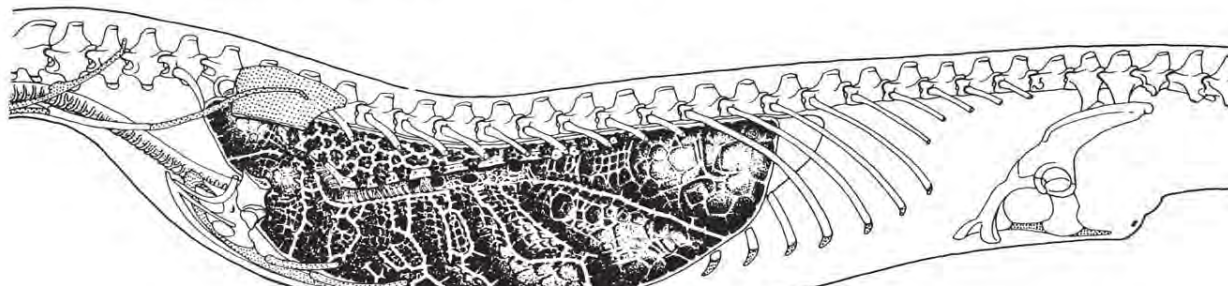
# Reptiles (ex: lizard)

- Have two lungs
- Can be simple sacs with honeycombed walls or highly divided chambers in more active species
  - More divisions result in more surface area

## Ventilation

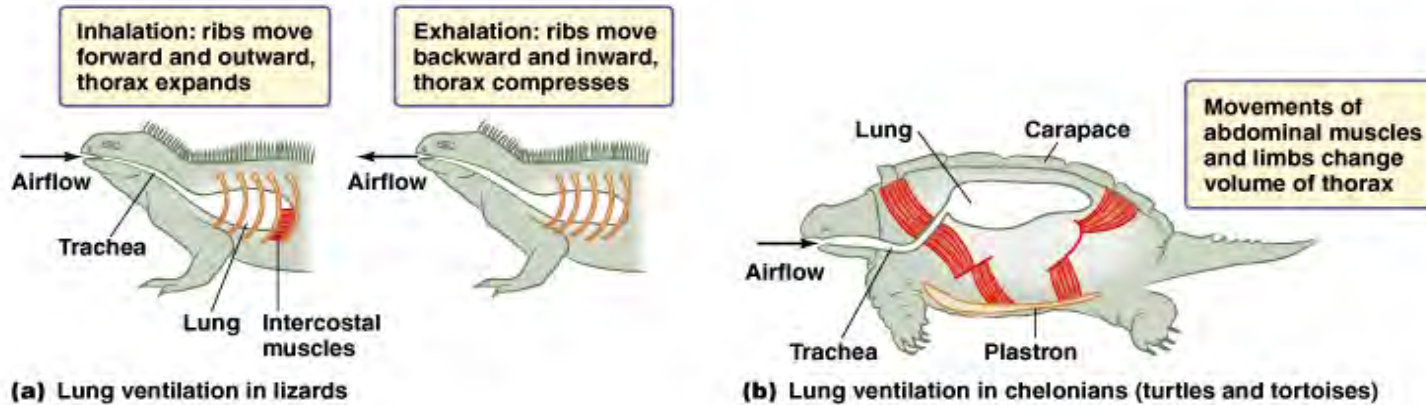
- Tidal
- Rely on suction pumps
- Results in the separation of feeding and respiratory muscles
- Two phases: inspiration and expiration
- Use one of several mechanisms to change the volume of the chest cavity. Why do we need to change the volume? To decrease pressure

(c) A multicameral lung in a monitor lizard



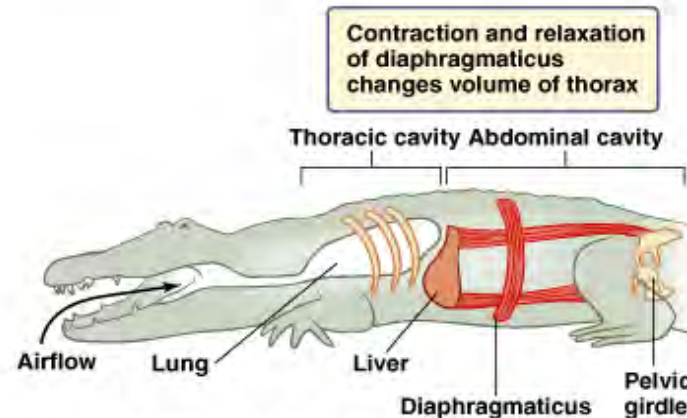
# Reptiles: mechanisms to change the volume

- Snakes and lizards: use **\*\*intercostal muscles**
- Turtles and tortoises: use **\*abdominal muscles**
- Crocodylians: **\*\*Diaphragmaticus muscles contract** which **decreases the volume in the abdominal cavity** and **increases the volume of the lungs**. As a result **pressure in the lungs decreases**.



(a) Lung ventilation in lizards

(b) Lung ventilation in chelonians (turtles and tortoises)



(c) Lung ventilation in crocodylians

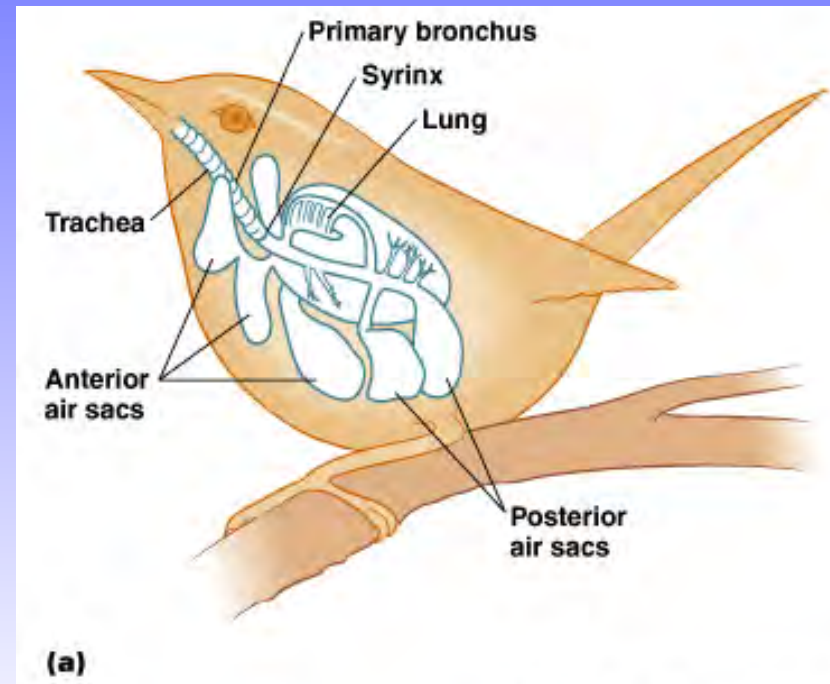
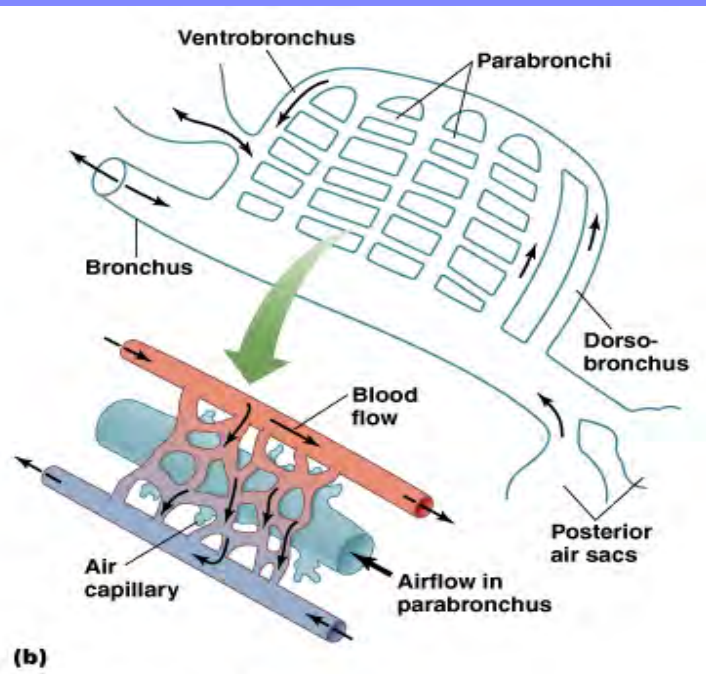
# Ventilation in birds and mammals

- Birds use unidirectional ventilation
- Mammals use \*tidal ventilation



# Birds

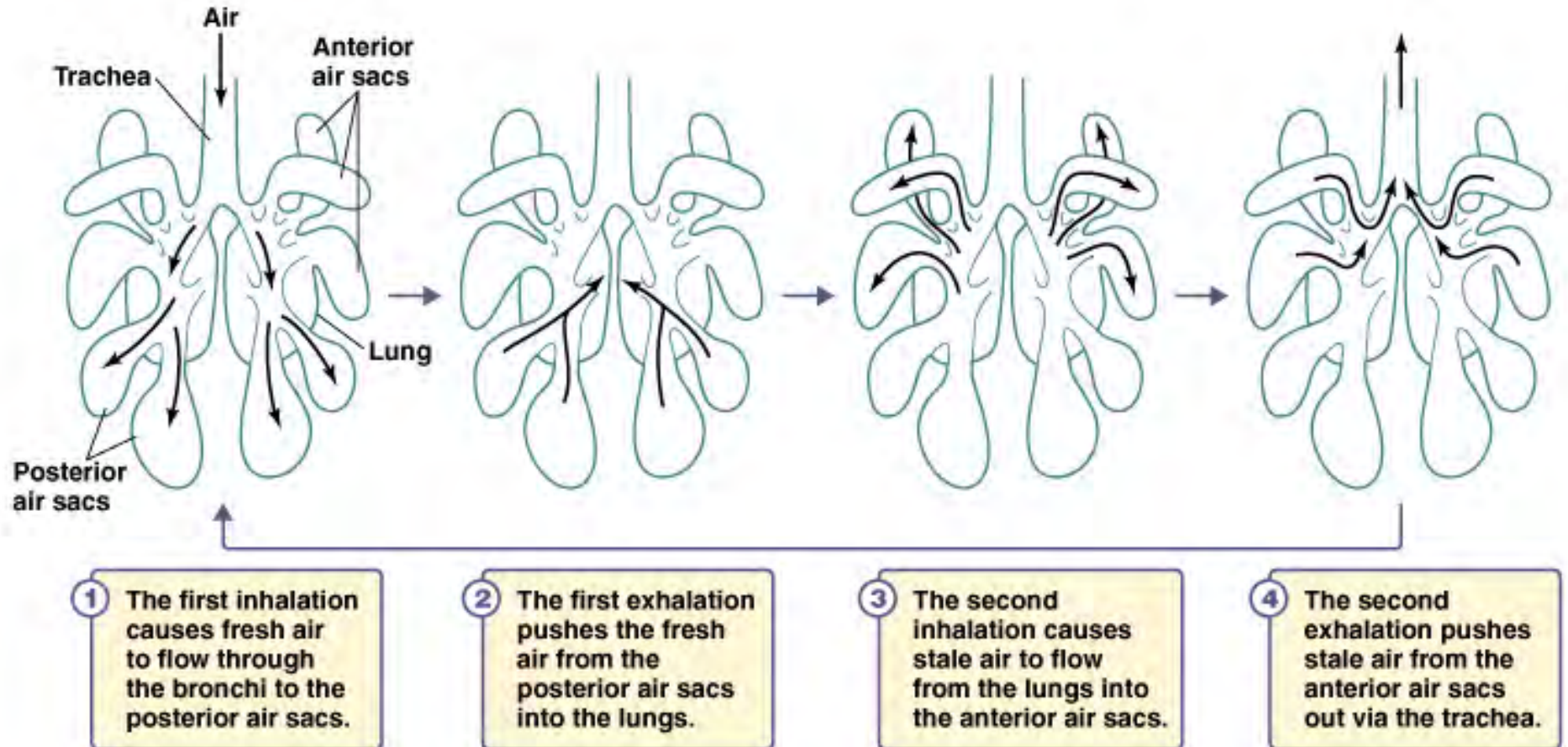
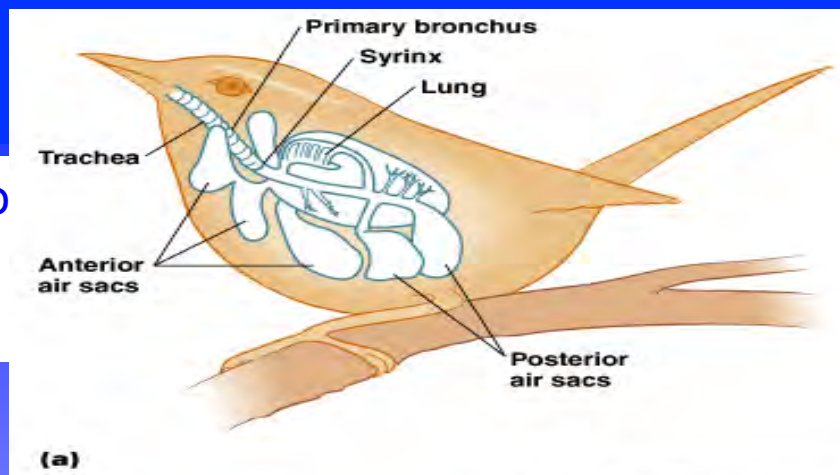
- \*Lung is stiff and changes little in volume – So how can birds change volume?
- Rely on a series of flexible air sacs. Air sacs allow them to increase volume and decrease pressure
- Gas exchange occurs at parabronchi
- Air sacs = no gas exchange = function is to move air through respiratory tract



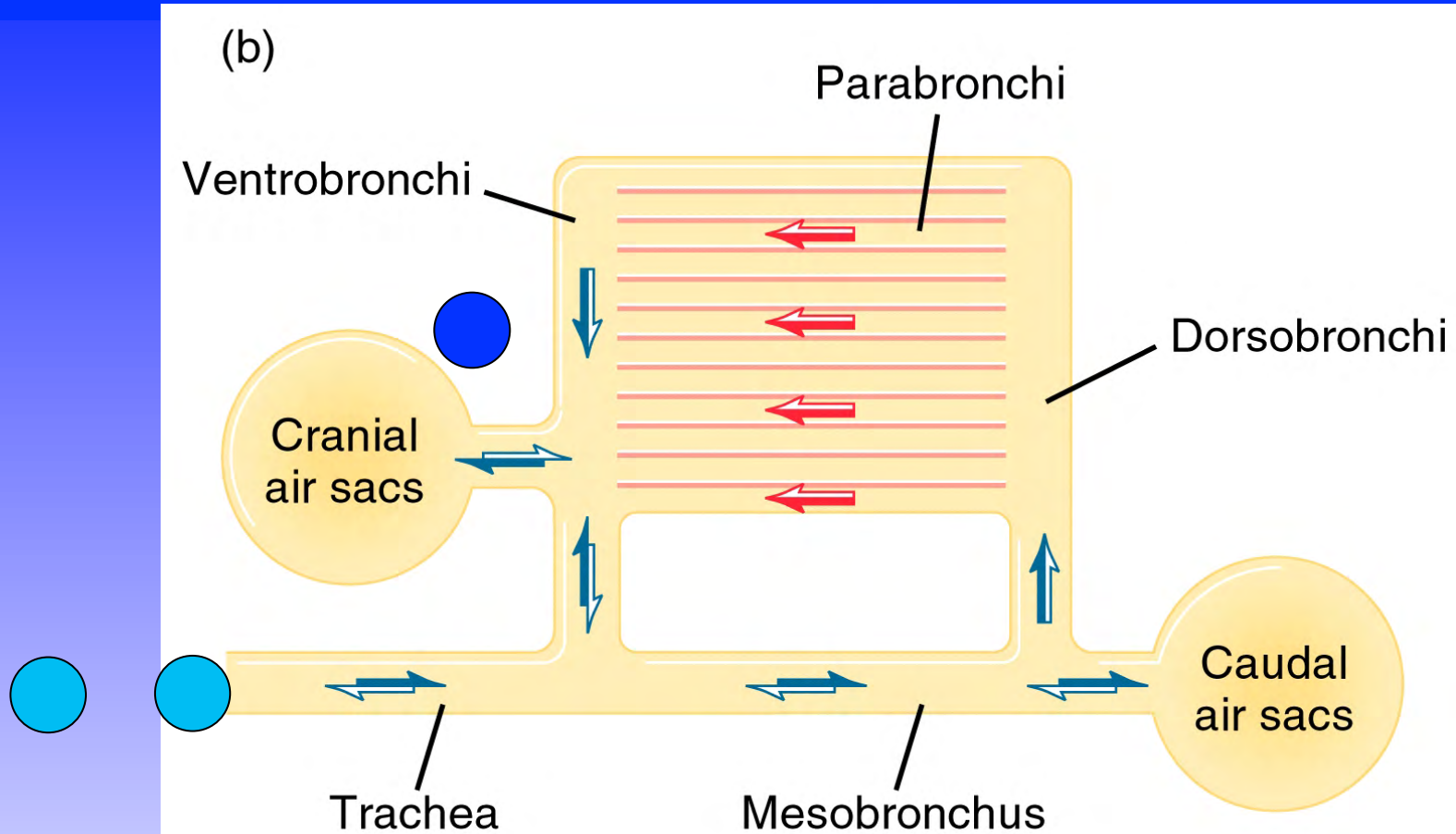
\*\*\*\*Oxygen extraction efficiency high (up to 90%)

# Bird Ventilation

Requires **two cycles of inhalation** and exhalation  
Air flow across the respiratory surfaces is **unidirectional**



# Bird Ventilation



Inhalations expand air sacs  
Exhalation = compress air sacs

Inhale = air into caudal or anterior air sacs  
Exhale = air into lungs = gas exchange = O<sub>2</sub> into blood  
Inhale = air into cranial or posterior air sacs  
Exhale = air out

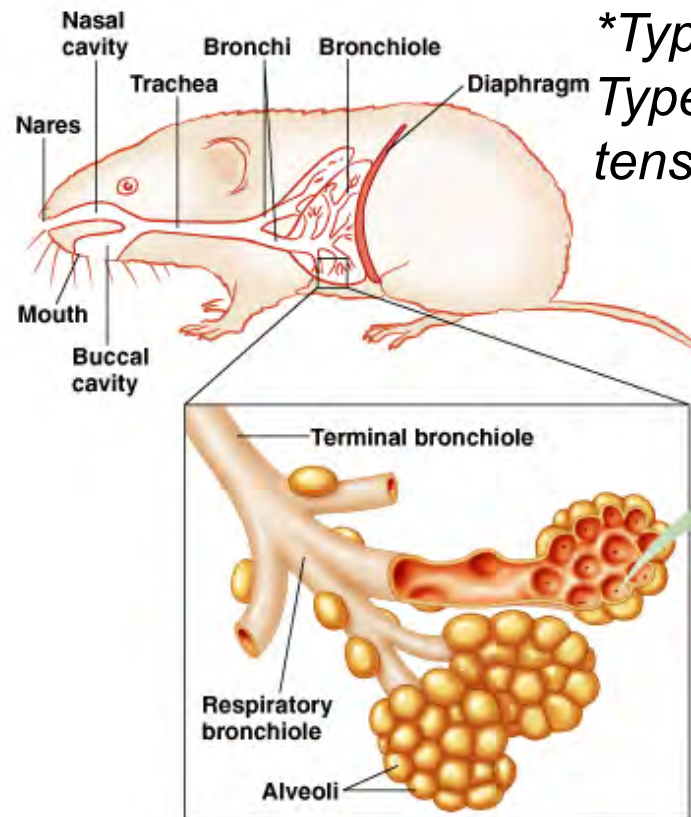
# \*Mammals

## \*Two main parts

- Upper respiratory tract: Nasal cavity, mouth, pharynx, larynx trachea
- Lower respiratory tract: trachea, lary bronchi and lungs

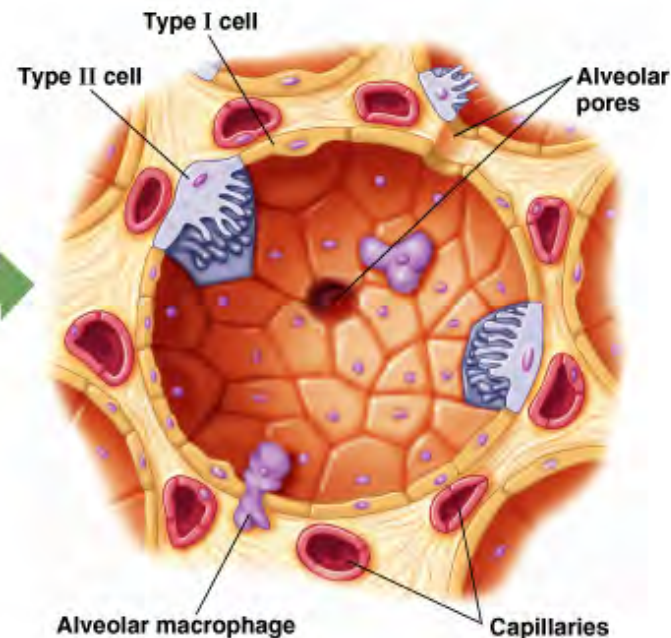
## \*Alveoli are the site of gas exchange

Both lungs are surrounded by a \* pleural sac



*\*Type I = squamous alveolar cells = wall of alveoli*

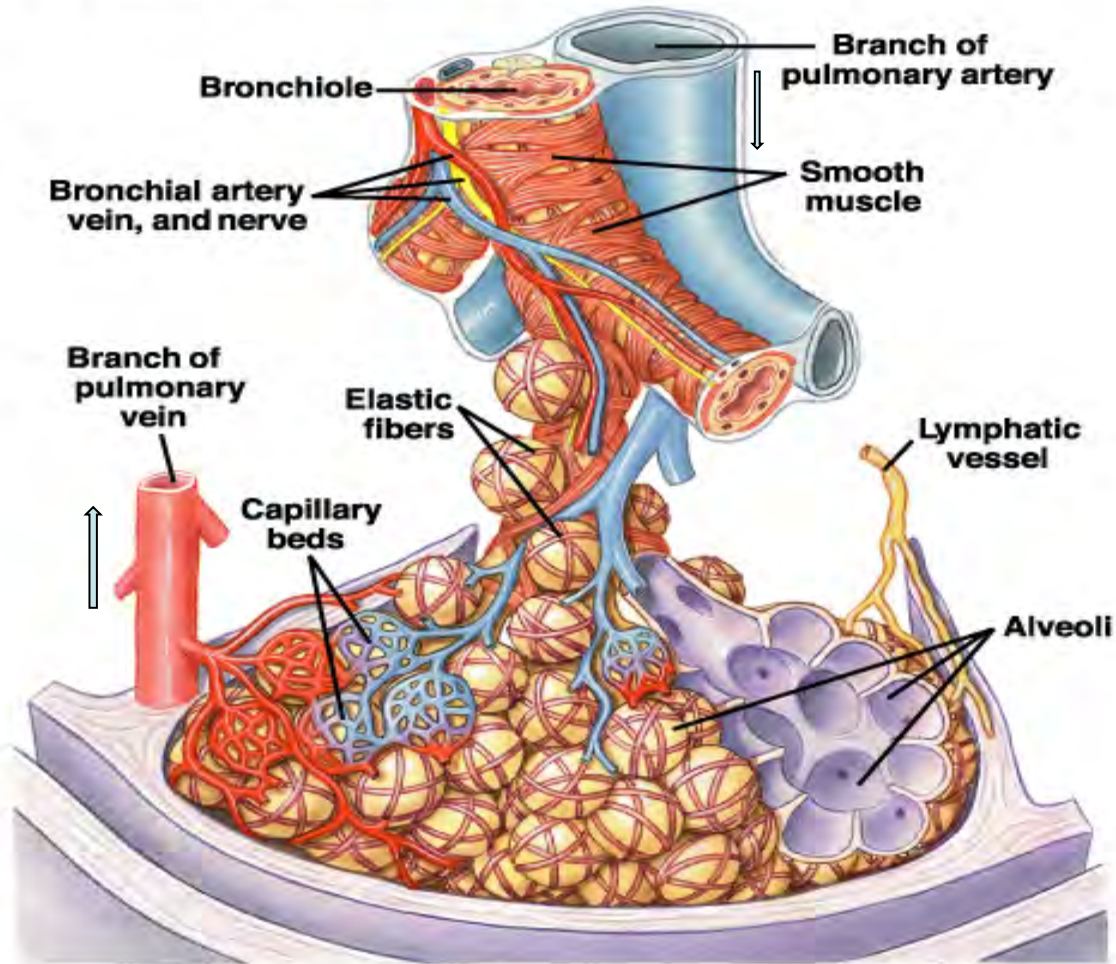
*Type II = secrete pulmonary surfactant = reduces surface tension*



# \*Mammalian lungs

## Structure of lung lobule

Each cluster of alveoli surrounded by elastic fibers and a network of capillaries.





# *\*Physical Properties of the Lungs*

**\*Compliance** = Distensibility (stretchability) = Ease with which the lungs can expand. Affected by surfactant. Inhalation = to increase volume which decreases pressure and so air can flow into lungs

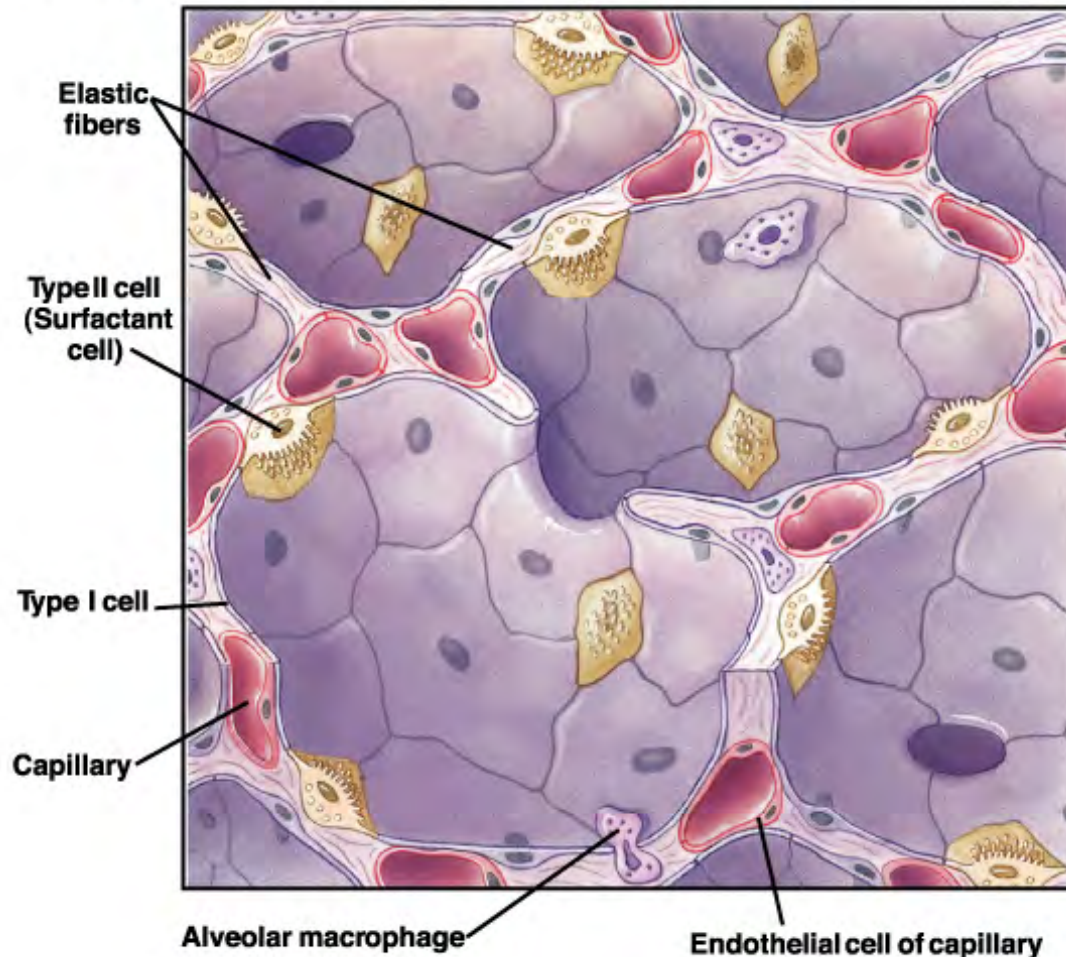
**\*Elasticity** = Tendency to return to initial size after distension.

- High content of elastin proteins.
- Very elastic and resist distension.
- **\*Recoil ability**. Affects exhalation. Exhalation at rest is passive due to elastic recoil
  
- **\*Inhalation is active = use external intercostal and diaphragm muscles**
- Exhalation at rest is passive = use elastic recoil

# Mammalian lungs - alveoli

## Alveolar structure

The alveoli are composed of type I cells for gas exchange and type II cells that synthesize surfactant. Alveolar macrophages ingest foreign material that reaches the alveoli.



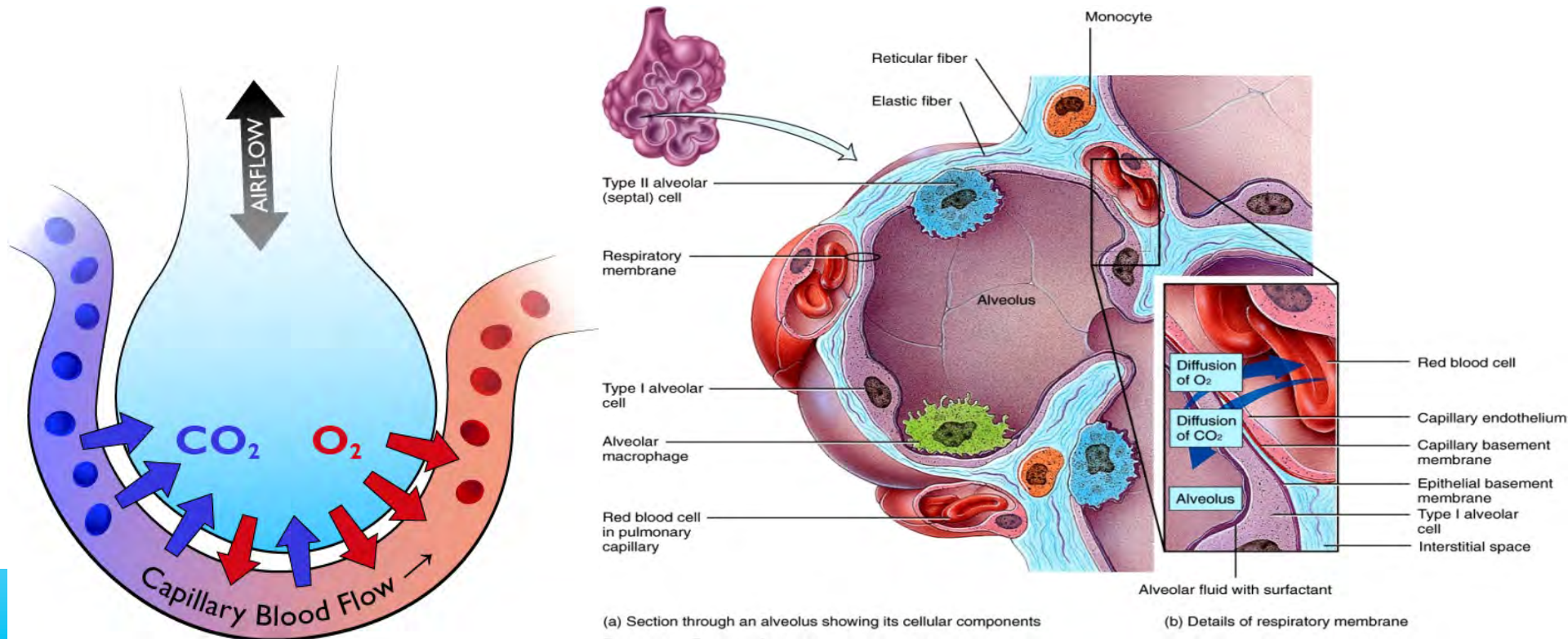
Type I cells  
gas exchange

Type II cells  
surfactant secretion

# The Lungs - Alveoli

## Alveolar Epithelium

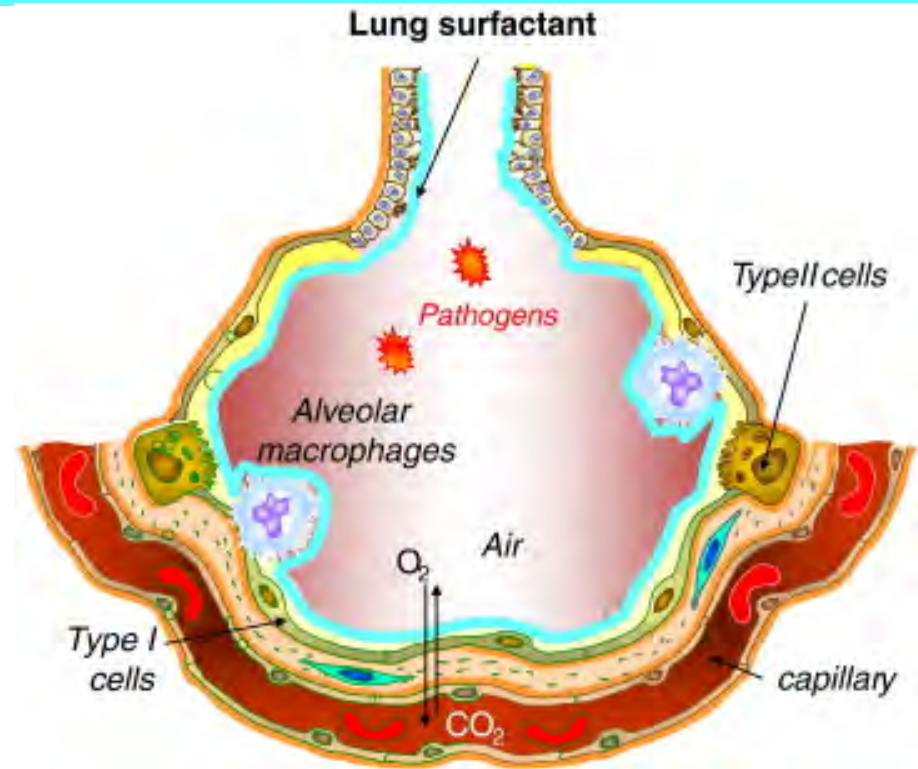
- Consists of **simple squamous epithelium** = one layer and **thin** = gas exchange
- **pneumocytes type I** = gas exchange
- Patrolled by **alveolar macrophages**, also called **dust cells**
- **pneumocytes type II** that produce **surfactant**. Surfactants = an oily secretion = Contains phospholipids and proteins =detergent, foaming



# \* Lung - surfactant

Surfactants = Decrease the Work of breathing

- Fluid is under tension = like thin membrane being stretched. Why do we need some fluid? Gases have to dissolve before they diffuse
- Surface tension is directed **toward the center of the alveoli** and this creates pressure → Surfactans decrease the surface tension = increases compliance → **easier to increase the volume of the lungs = less work is used.**



From: Role of lipid ordered/disordered phase coexistence in pulmonary surfactant function

Cristina Casals and Olga Cañadas.

*Biochimica et Biophysica Acta (BBA) – Biomembranes*;

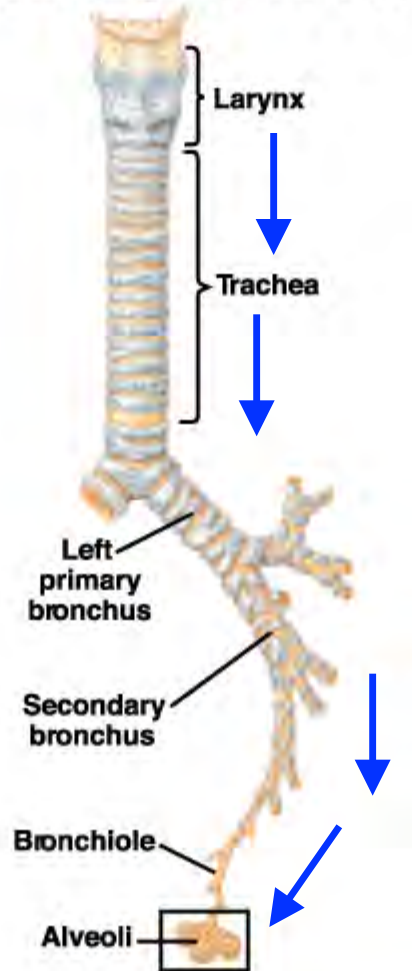
Volume 1818, Issue 11, November 2012, Pages 2550–2562

*Compliance = measure of how easy it is to inflate lungs*

# Mammalian lungs

## Branching of airways

The trachea branches in to two bronchi, one to each lung. Each bronchus branches 22 more times, finally terminating in a cluster of alveoli.



Airways:

Larynx

Trachea

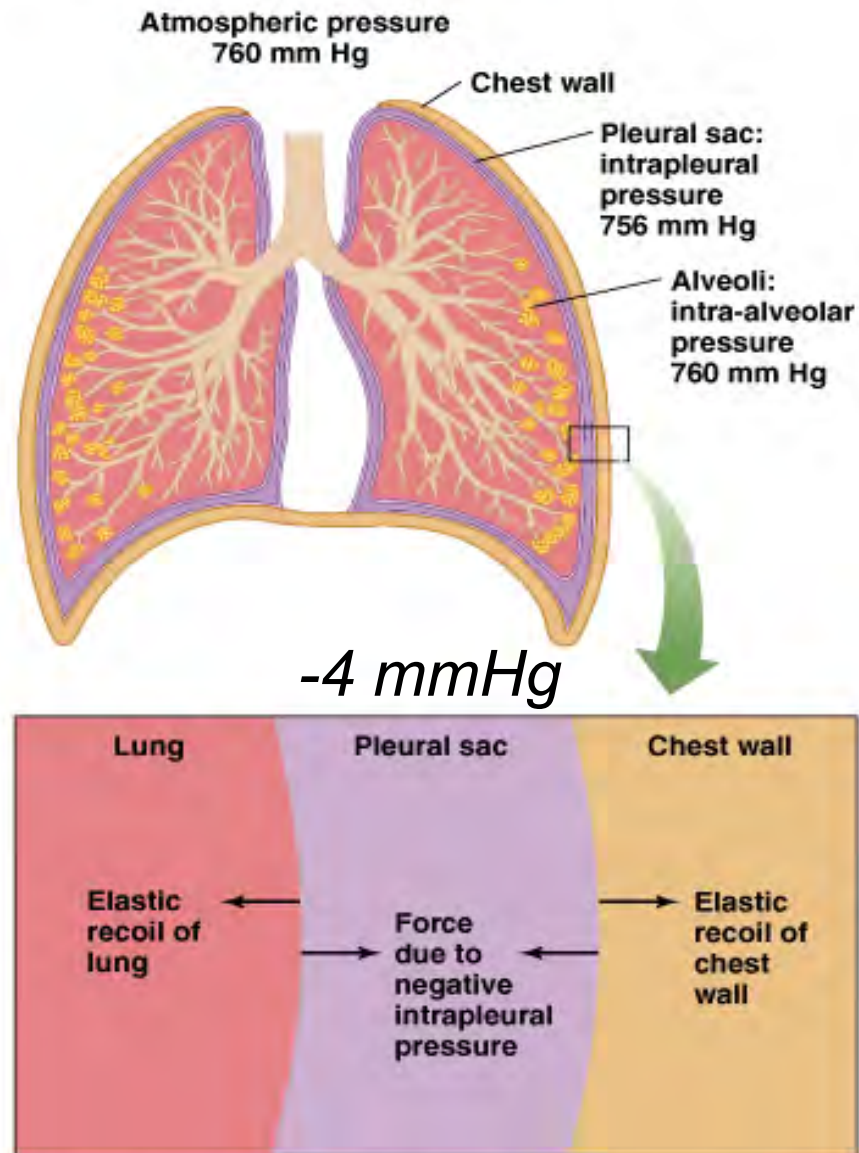
Bronchii

Bronchioles

Alveoli

# Ventilation and Pressures

- **Atmospheric pressure** is the pressure of the air **outside the body (1 atm)**. Has to be higher than inside the lungs to get air in
- **Intraalveolar pressure** is the pressure **inside the alveoli of the lungs (< atm during inhalation)**. Has to be less than atmospheric pressure for air to move into lungs/alveoli
- **Intrapleural pressure** is the pressure **within the pleural cavity (always negative (-4mmHg))**.



# \*\*Flow and airway resistance

- \*Flow =  $\Delta P/R$  ,  $\Delta P$  = pressure gradients; R = resistance to flow
- \*If resistance increases, a greater  $\Delta P$  is needed to maintain the same flow
- \*Airway resistance is inversely proportional to airway radius to the 4<sup>th</sup> power ( $1/r^4$ ). \* *What does this mean in terms of radius? Small changes in radius lead to big changes in flow*
- \***Bronchoconstriction** – reduction in airway radius. *Histamine* causes bronchoconstriction – think allergic reaction and antihistamine
- \***Bronchodilation** – increase in radius = sympathetic nervous system= A and NA= sympathomimetic = *Beta2 adrenoreceptors*

*Resistance (R) is directly proportional to the length (L) of the “tube” and the viscosity ( $\eta$ ), and inversely proportional to the radius to the fourth power ( $r^4$ ).*

$$R = \frac{\eta * L}{r^4}$$

# Mammals - \*\*Ventilation

\*Tidal ventilation= measure of tidal volume.

\*Steps. To know

- **Inhalation**

- motor neuron innervation from inspiratory center in medulla oblongata
- Contraction of the **external intercostals and the diaphragm**
- Ribs move outwards and the diaphragm moves down
- **Volume of thorax increases and .....**
- Air is pulled in

- **Exhalation**

- Inhibition of the inspiratory neurons by the expiratory center => electrical signal to inspiratory muscles stops
- Inspiratory muscles relax
- (Ribs and) diaphragm and lungs return to their original positions
- **Volume of the thorax decreases**
- Air is pushed out due to ***elastic recoil*** the alveoli of the lungs

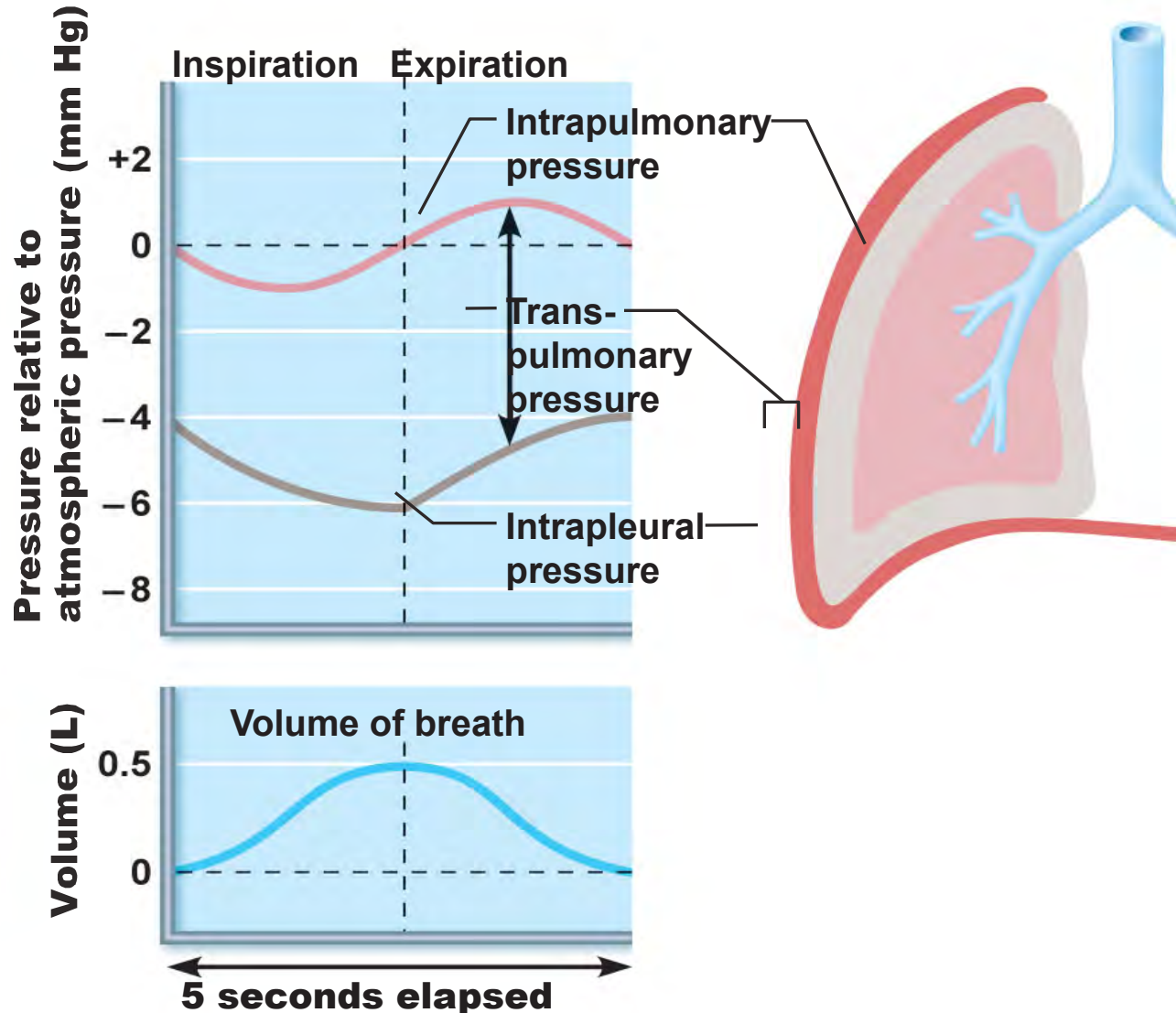


# Air moves into and out of the lungs along pressure gradients that are the result of volume changes

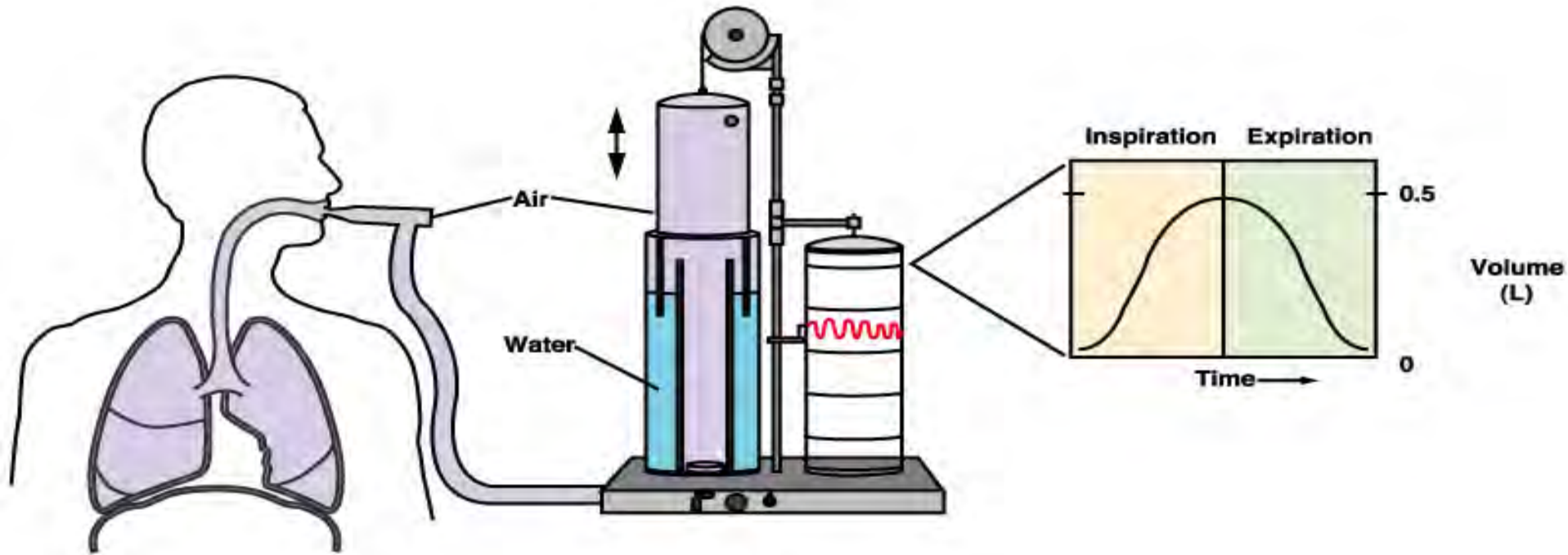
**Intrapulmonary pressure.** **Pressure inside lung decreases as lung volume increases** during inspiration; pressure increases during expiration.

**Intrapleural pressure.** Pleural cavity **pressure becomes more negative as chest wall expands** during inspiration. Returns to initial value as chest wall recoils.

**Volume of breath.** During each breath, the pressure gradients move 0.5 liter of air into and out of the lungs.



# Spirometry



Method for measuring pulmonary function

# \*Lung pathologies

**Pneumonia** = acute infection or inflammation of the alveoli = Causes fluid to leak into alveoli and will compromise respiration

**Emphysema** = destruction of the walls of the alveoli = due to loss of elastic fibers (smoking, pollution, dust) = creates less surface area for gas exchange

**Pulmonary edema** = fluid accumulation in interstitial spaces and alveoli = could be due to high capillary pressures or increased fluid loss of capillaries

**SIDS** = sudden infant death syndrome = more common in infants of drug abuse, smokers, premature babies, etc.

**Chronic bronchitis** = excessive secretion of bronchial mucous = leading cause is smoking = cilia are compromised

**Air breathers:**

**Summarize respiratory strategies**

**Structures involved ie muscles.**

**Types ie unidirectional, tidal**

You have learned how water/air enters the respiratory structure

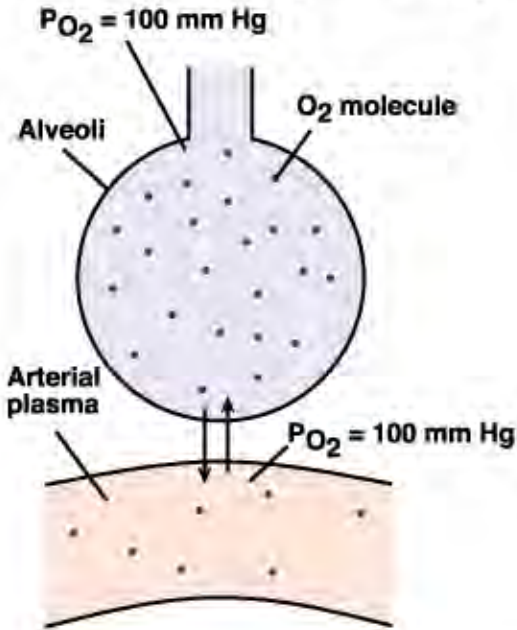
**Next step: Gas exchange**

# Oxygen Transport

- Solubility of oxygen in aqueous fluids is low
- But Respiratory pigments help to **increase the amount of O<sub>2</sub>** in blood
- By binding oxygen to carriers, **PO<sub>2</sub> in the blood remains low** and results in improved oxygen extraction
- Contain metal ions
- Gives them a strong colour (e.g. hemoglobin – red)
- Oxygen binds reversibly to the metal ion
- Bind to the pigment **at the lungs**
- Releases from the pigment at the **tissues**

# Oxygen carrying capacity of blood

Oxygen transport in blood without hemoglobin. Alveolar  $P_{O_2}$  = arterial  $P_{O_2}$



- Because of the low solubility of oxygen in aqueous solutions, **only a small amount of oxygen can dissolve in blood**
- $P_{O_2}$  is equal in plasma and lungs, but **oxygen content of plasma is much lower**

*Amount of oxygen that can dissolve in plasma is limited at physiological  $P_{O_2}$*

*Henry's Law:  $[O_2] = P_{O_2} * S_{O_2}$*

O<sub>2</sub> content of plasma = 3 mL O<sub>2</sub>/L blood

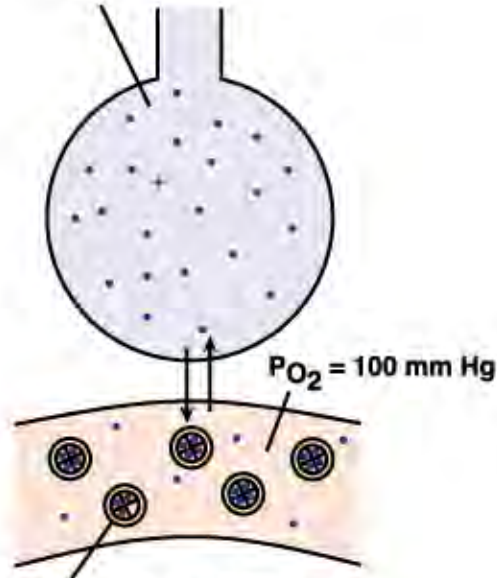
O<sub>2</sub> content of red blood cells = 0

Total O<sub>2</sub> carrying capacity = 3 mL O<sub>2</sub>/L blood

# Oxygen carrying capacity of blood

Oxygen transport at normal  
 $PO_2$  in blood with hemoglobin

$PO_2 = 100$  mm Hg



Red blood cells with hemoglobin  
are carrying 98% of their maximum  
load of oxygen

$O_2$  content of plasma = 3 mL  $O_2$ /L blood

$O_2$  content of red  
blood cells = 197 mL  $O_2$ /L blood

Total  $O_2$  carrying  
capacity = 200 mL  $O_2$ /L blood

- If an oxygen carrier such as hemoglobin is present, some of the oxygen will bind to the pigment
- This oxygen no longer contributes to  $PO_2$
- $PO_2$  is the same as in the previous example, but oxygen content is higher. The oxygen carrying capacity is much higher with metalloproteins.
- $PO_2$  = partial pressure of  $O_2$

$$\text{Henry's Law: } [O_2] = PO_2 * S_{O_2}$$



# Respiratory Pigments

## Three major types

- *Hemoglobins*
  - Vertebrates, nematodes, some annelids, crustaceans, and insects
  - Consist of a protein *globin* bound to a *heme* molecule containing *iron*
  - Usually located within blood cells
  - **Appears red when oxygenated**
  - Myoglobin is found in muscles = holds on very tightly to O<sub>2</sub>
- *Hemocyanins*
  - Arthropods and molluscs
  - Contain *copper*
  - Usually dissolved in the *hemolymph*
  - **Appears blue when oxygenated**
- *Hemerythrins*
  - Sipunculids, priapulids, some annelids = Worms
  - Contains *iron* directly bound to the protein
  - Usually found inside *coelomic cells*
  - **Appears violet-pink when oxygenated**

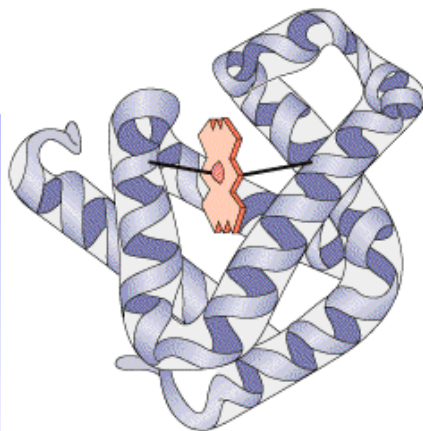
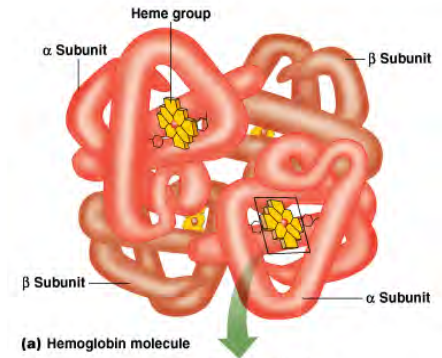
# Hemoglobin and Myoglobin

## Hemoglobin = protein = will be affected by pH, Temperature, Pressure

- Each contains a heme group
- Each heme group can bind 1 molecule of oxygen
- Therefore 1 Hb molecule can bind 4 oxygen molecules

## Myoglobin

- Type of hemoglobin found in vertebrate muscle
- Each Mb molecule binds one molecule of oxygen
- “stores” O<sub>2</sub> in skeletal muscle
- Holds onto the O<sub>2</sub> strongly



Myoglobin, a globular protein

# Gas Transport - O<sub>2</sub>

Carrying capacity = the maximum amount of oxygen that can be carried in blood

- **Total O<sub>2</sub> in blood = dissolved O<sub>2</sub> + O<sub>2</sub> bound to respiratory pigment**

## Oxygen–Hemoglobin Saturation Curve:

- shows the relationship between partial pressure of oxygen in the plasma and the percentage of oxygenated respiratory pigment in a volume of blood
- **P<sub>50</sub>** – oxygen partial pressure at which the pigment is 50% saturated. **Used as an indicator of affinity. In the figure the P50 is about 28 mmHg. This means that for this protein (Hb), at 28 mmHg 50% are saturated with O<sub>2</sub>**

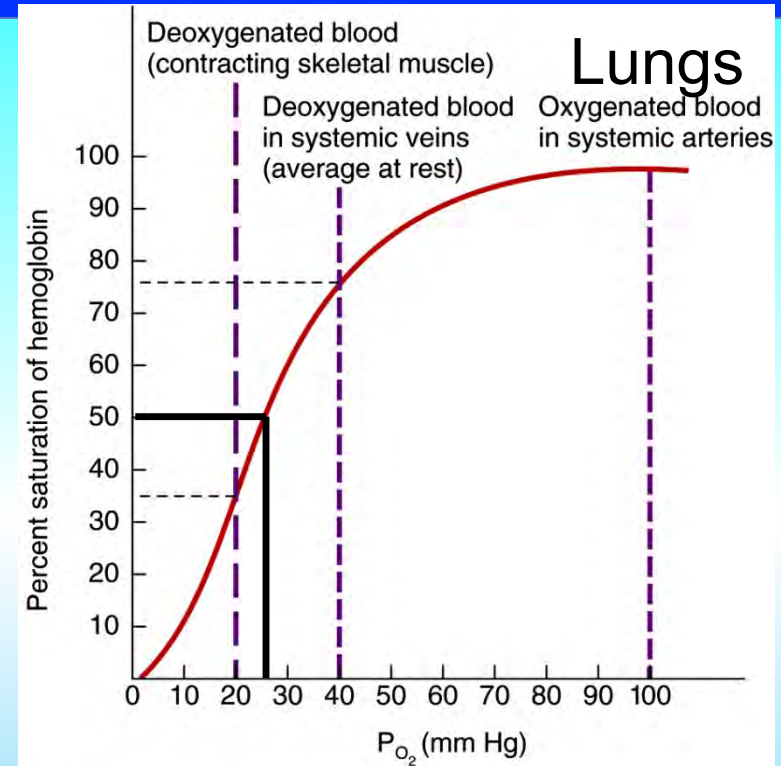


Figure 23.19 Tortora - PAP 12/e  
Copyright © John Wiley and Sons, Inc. All rights reserved.

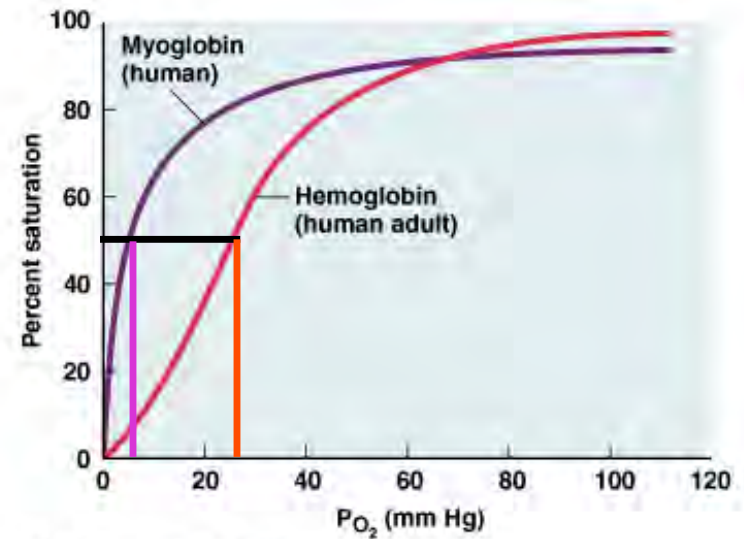
# Gas Transport - $O_2$

## Myoglobin

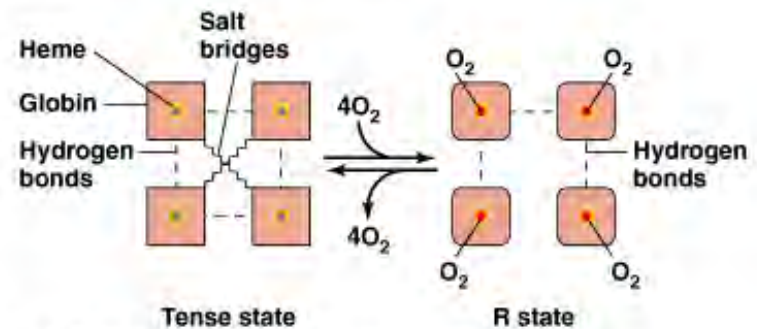
- has a lower  $P_{50}$  than Hemoglobin
- Myoglobin has **higher oxygen affinity**
- $PO_2$  for Myoglobin has to be very low for it to let go of  $O_2$  😊. Helps while exercising

Also note the difference in the shapes of the curve

- The **hemoglobin curve is sigmoidal**
- **Myoglobin curve is hyperbolic**
  
- **Hb** changes shape each time a molecule of  $O_2$  is bound
- Each  $O_2$  bound makes next  $O_2$  binding easier
- **Allows Hb to bind  $O_2$  when  $O_2$  levels are low**
  
- **Myoglobin only binds one  $O_2$**



(a) Oxygen equilibrium curves



(b) A model for hemoglobin cooperativity

# Gas Transport - $O_2$

The Bohr Effect = the effect of pH on hemoglobin-saturation curve = the effect of  $CO_2$ /pH on the behaviour of hemoglobin. Don't forget proteins are affected by their environment

- Caused by  $CO_2$ 
  - $CO_2$  diffuses into RBC
  - An enzyme, called **carbonic anhydrase**, catalyzes reaction with  $H_2O$
  - Produces carbonic acid ( $H_2CO_3$ ) which dissociates into **hydrogen ion ( $H^+$ )** and bicarbonate ion ( $HCO_3^-$ )
  - An increase in  $CO_2$  can cause a decrease in pH
- When **pH drops** more oxygen is released → **Curve shifts to right**
- When **pH rises** less oxygen is released → **Curve shifts to left**

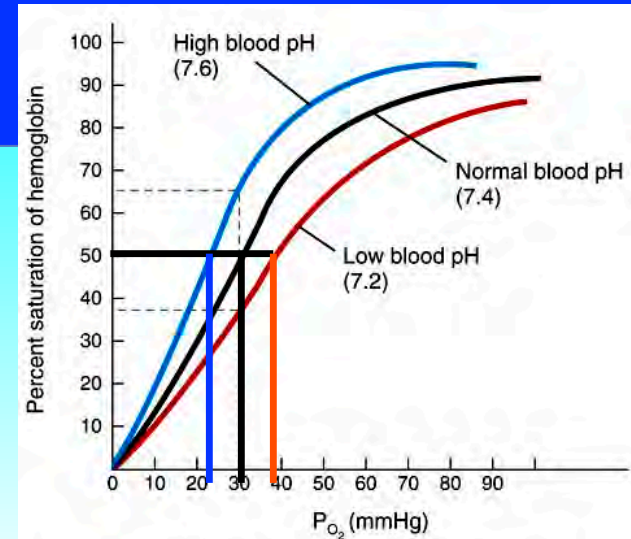
# Bohr effect

## pH

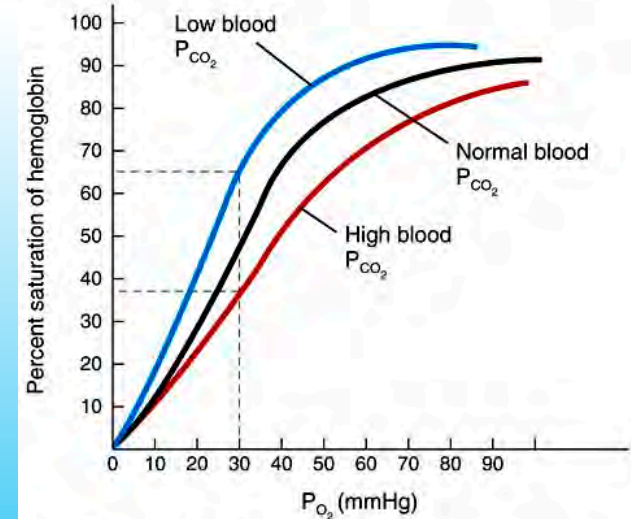
- As pH decreases, affinity of Hb for O<sub>2</sub> decreases = enhances unloading == Shifts curve to right
- Hemoglobin is a protein that will change shape in response to its environment. At low pH, will change shape and let go sooner of O<sub>2</sub>. At high pH, will change shape and let go later of O<sub>2</sub>
- The more active you are, the more CO<sub>2</sub> you will produce, also the H<sup>+</sup> will be produced. The more active, the more O<sub>2</sub> you need. SO the the Hb will sense change in activity and the Hb will let go sooner of O<sub>2</sub> = right shift = lower affinity 😊

## P<sub>CO2</sub>

- Also shifts curve to right
- As P<sub>CO2</sub> rises, Hb unloads oxygen more easily
- Low blood pH can result from high P<sub>CO2</sub>



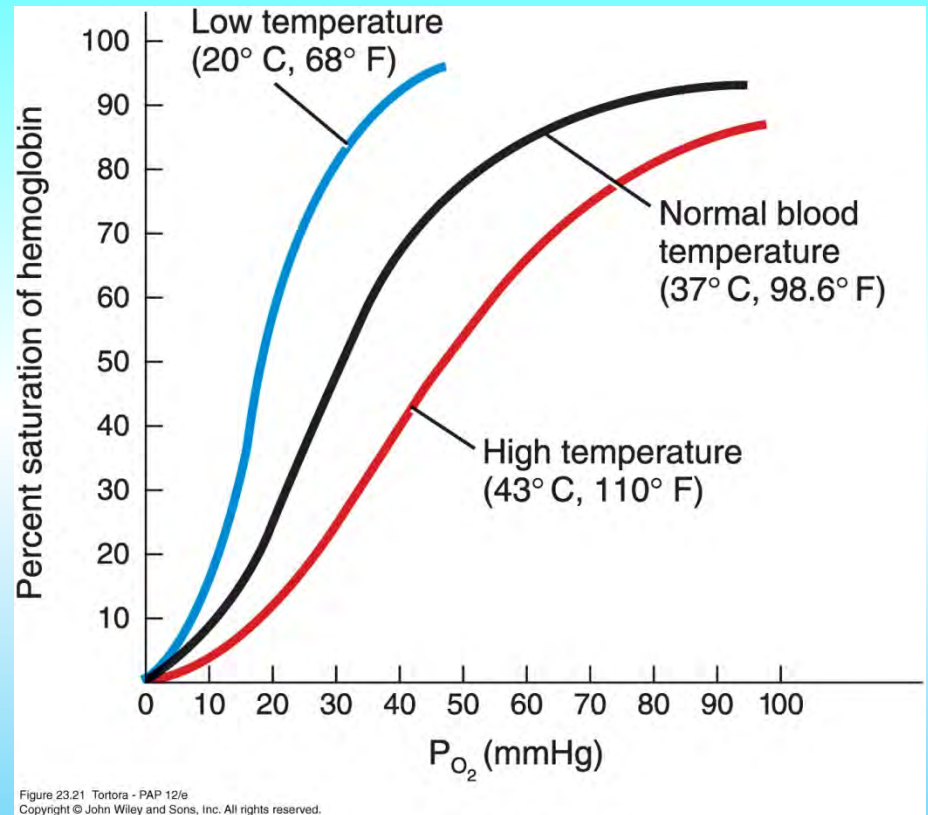
(a) Effect of pH on affinity of hemoglobin for oxygen



(b) Effect of P<sub>CO2</sub> on affinity of hemoglobin for oxygen

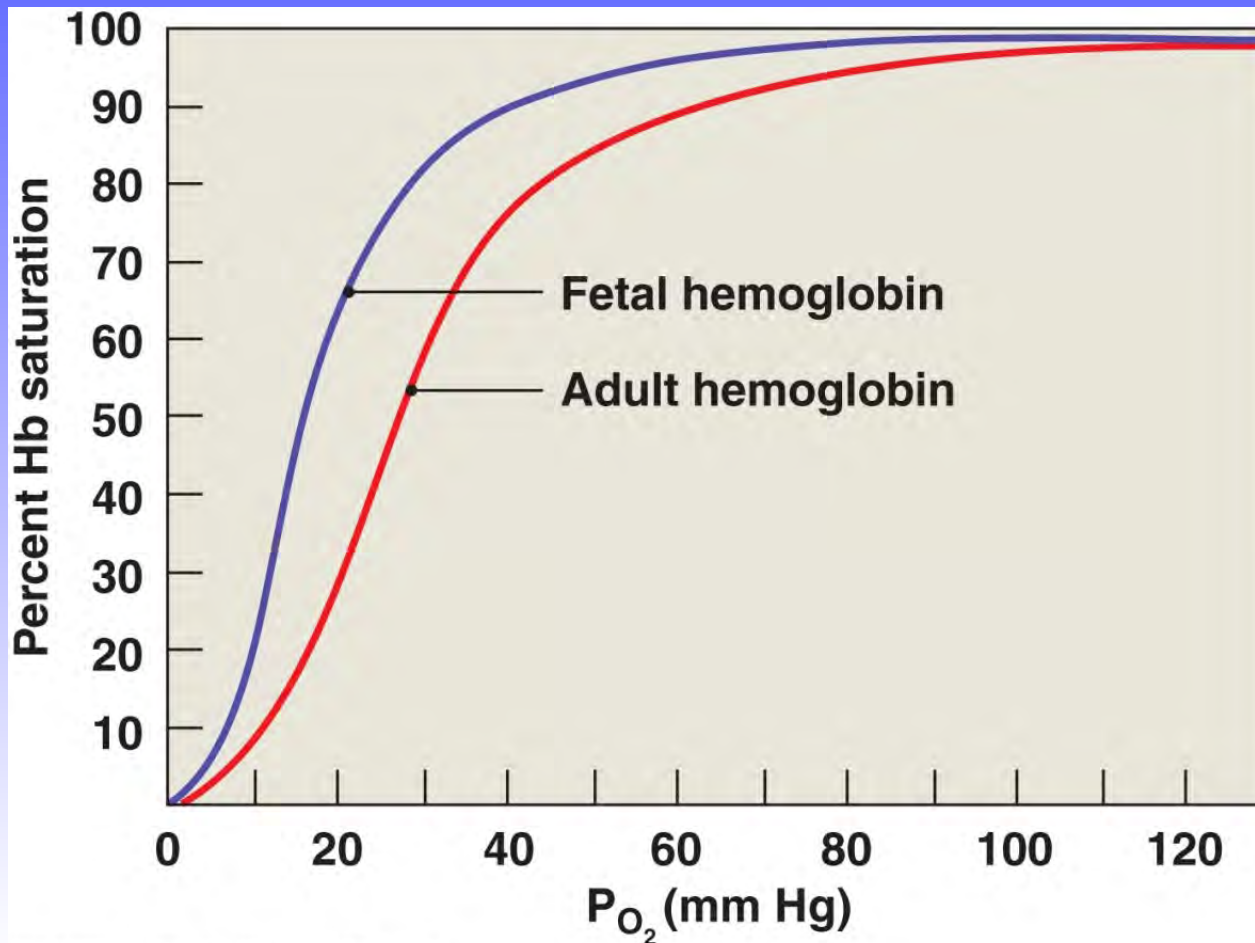
# Temperature and Bohr

- As temperature increases, more oxygen is released from Hb. Why? When Temperature increases, more activity, and so let go sooner of O<sub>2</sub>
- During hypothermia, more oxygen remains bound. Why? Allows to bring O<sub>2</sub> to tissues that are farther from heart because blood flow has decreased = at cooler temperatures, holding onto O<sub>2</sub> helps to get it to little toe



# Structure of the pigment

Fetal hemoglobin has a **lower**  $P_{50}$  than maternal hemoglobin.  
Fetus gets O<sub>2</sub> from mom

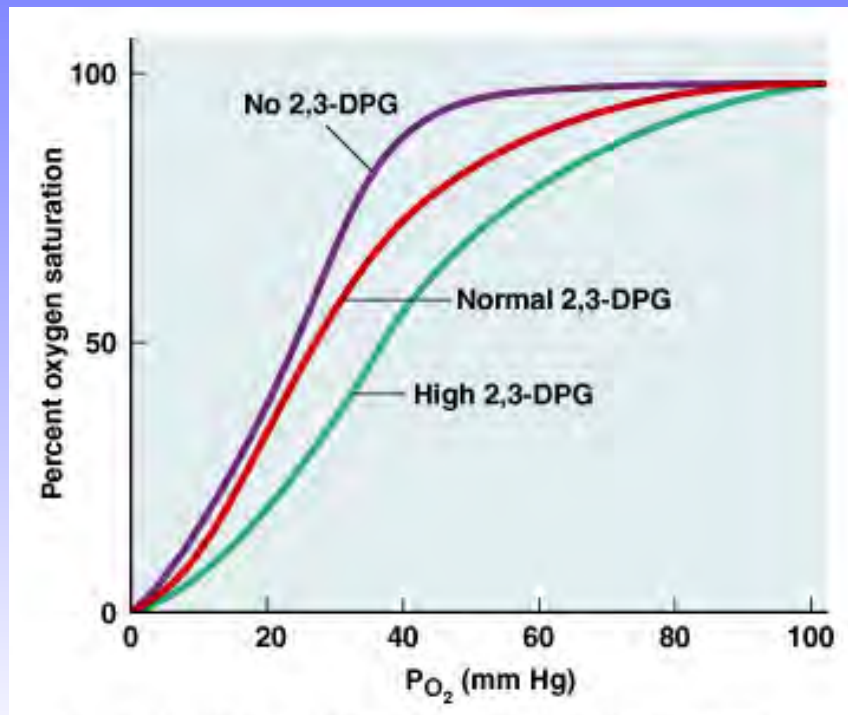




# Conditions That Affect Oxygen Affinity

**Organic modulators** (e.g., 2,3-DPG, ATP, GTP); **DPG = Diphosphoglycerate**  
= byproduct of RBC activity = always have some

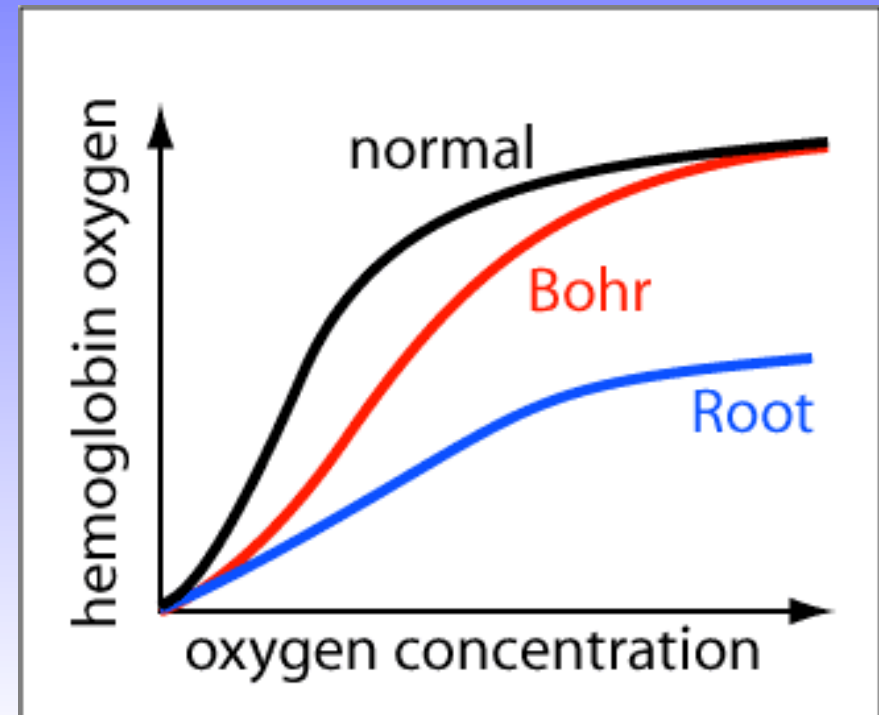
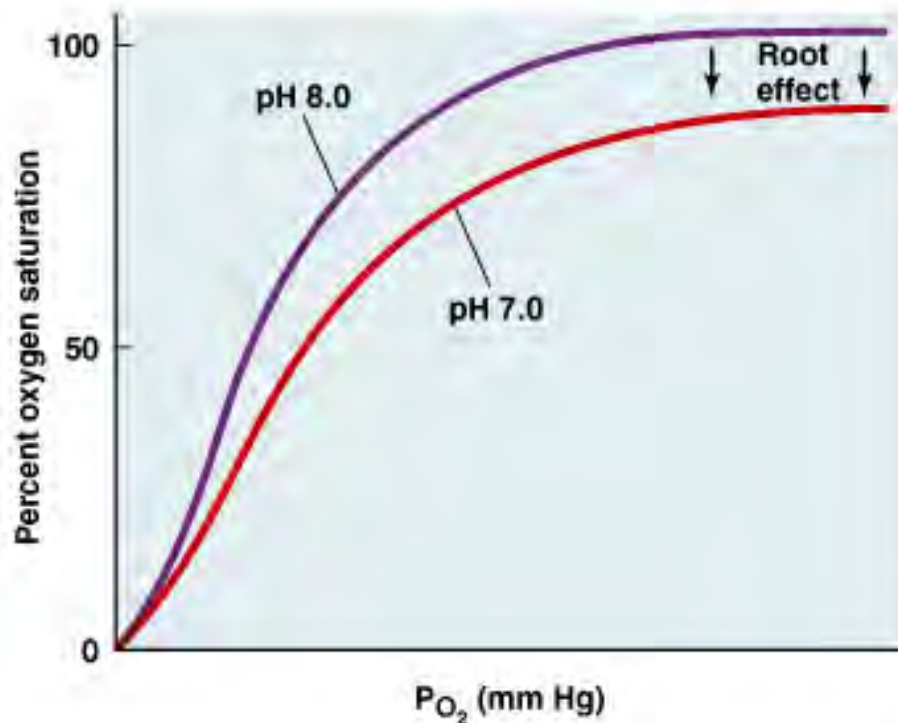
- Increases in these modulators **decrease** oxygen affinity; **right shift**
  - Helps oxygen unloading at tissues
  - High DPG = just means you are running amok = let go of O<sub>2</sub> sooner



# Root effect - something fishy

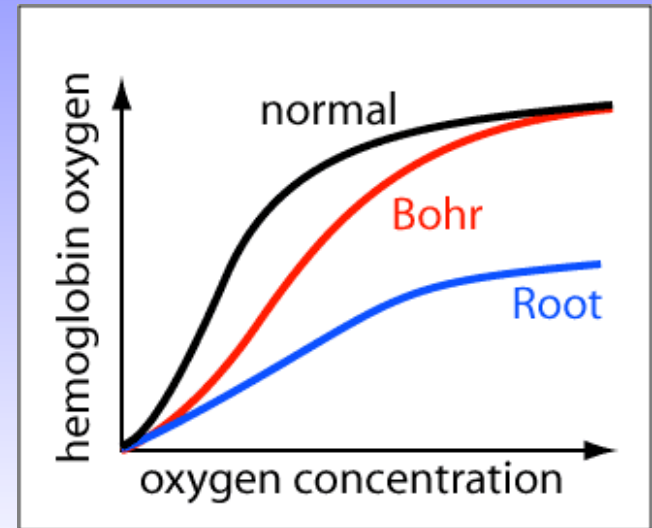
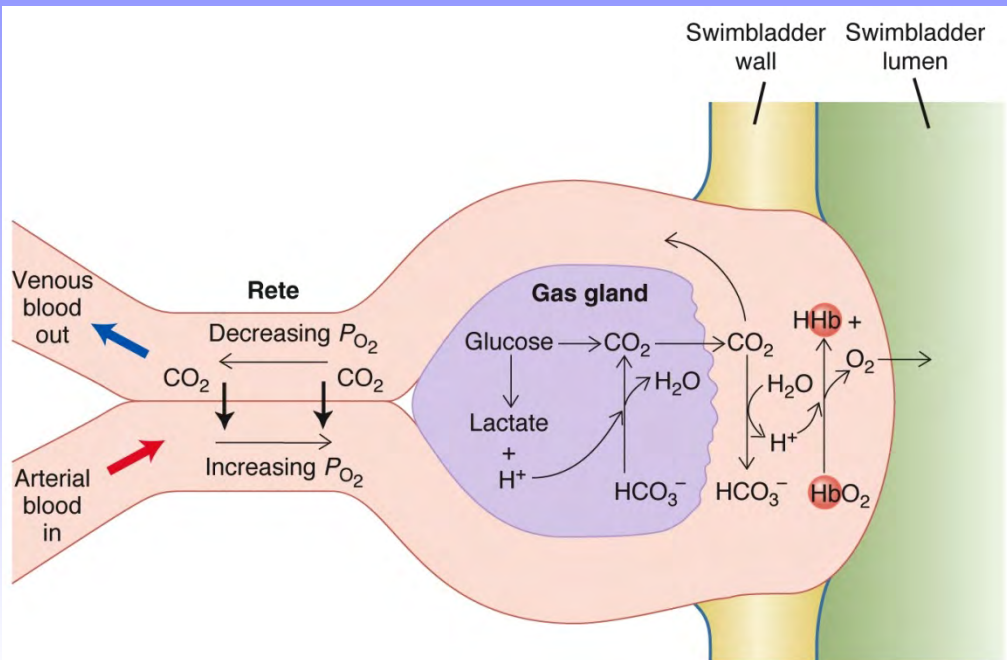
**Root effect** – a Bohr effect with a reduction in the oxygen carrying capacity

- Seen in hemoglobin of many teleost fishes
- Helps in oxygen delivery to eye and swim bladder = affects buoyancy
- Root effect is a right shift with a reduction in carrying capacity = O<sub>2</sub> will diffuse into the swim bladder = increase buoyancy



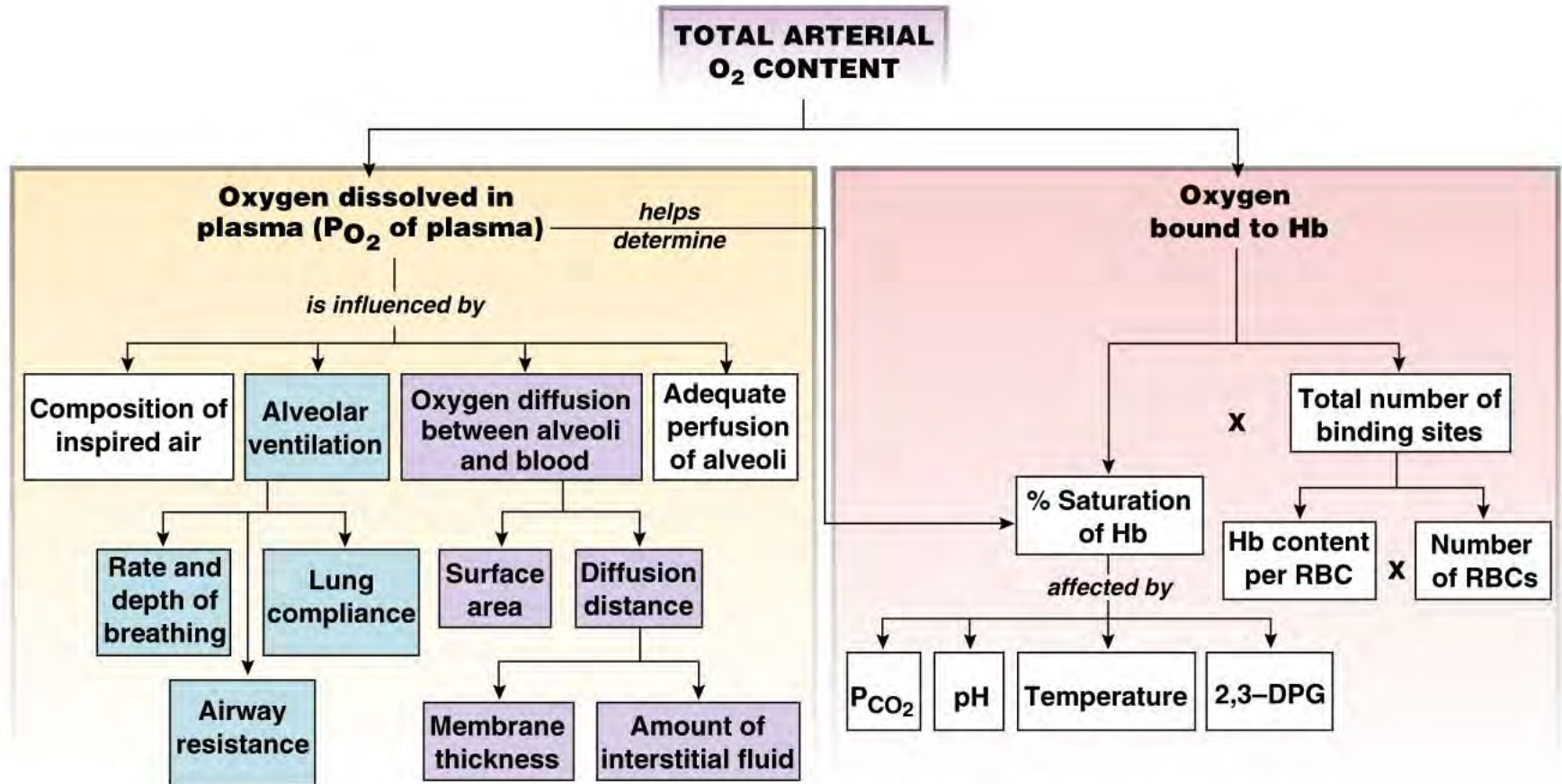
# Swim bladder and Oxygen

- Many bony fish have a swimbladder that helps to maintain neutral buoyancy
  - Gas-filled sac
  - Fill with gas to **increase buoyancy**
  - Remove gas to **reduce buoyancy**
  - In most species this gas is **oxygen**
- 
- *Gas gland excretes **lactic acid***
  - *Acidity causes hemoglobin of the blood to **lose its oxygen***
  - *Oxygen **diffuses into the bladder** while flowing through a complex structure known as the **rete mirabile***



# Summary of oxygen transport

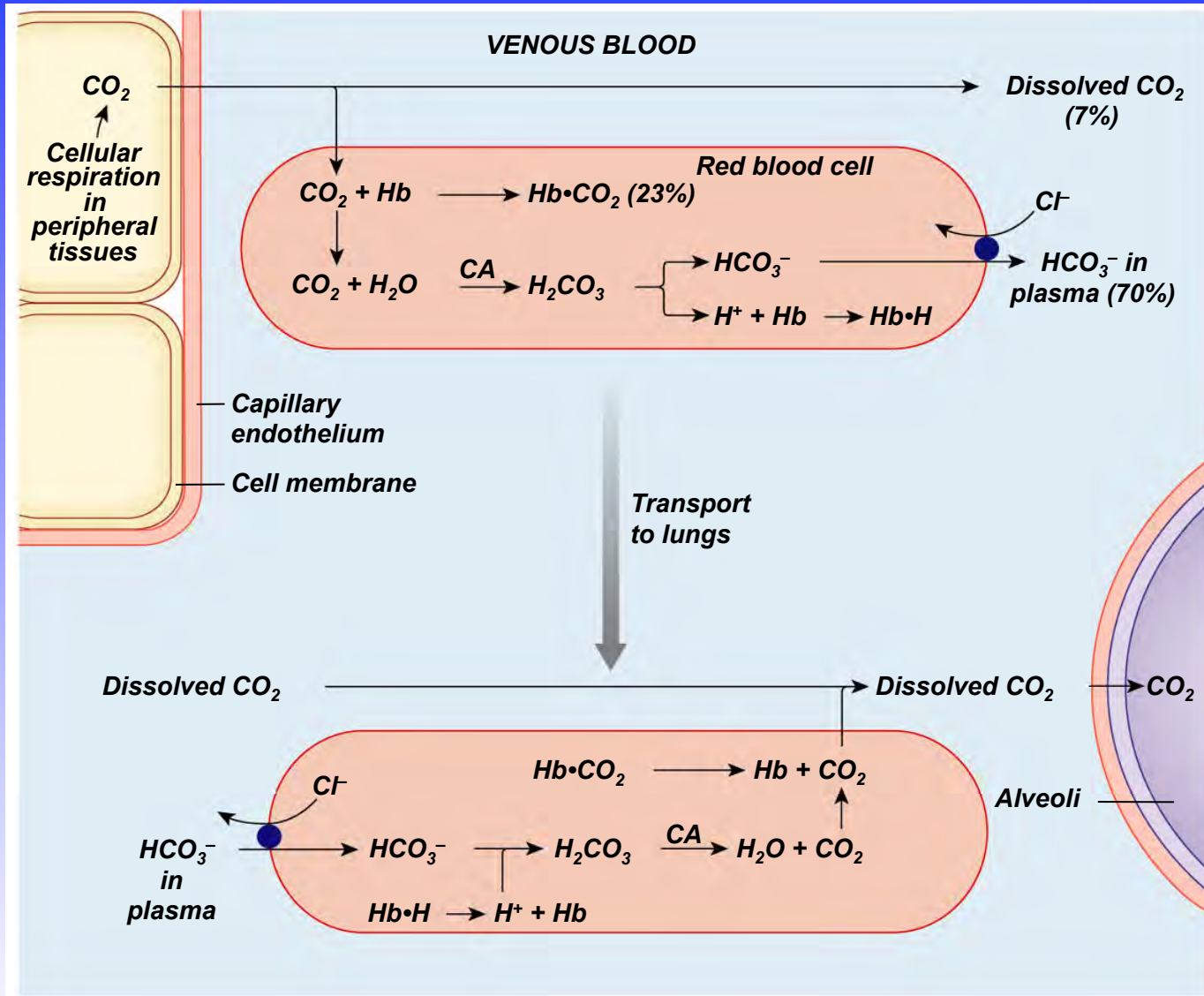
## Factors contributing to the total oxygen content of arterial blood



# Carbon Dioxide Transport

- **Carbon dioxide is more soluble in body fluids than oxygen**
- Little CO<sub>2</sub> is transported in the plasma
- Some CO<sub>2</sub> binds to proteins = *carbaminohemoglobin*
- Most CO<sub>2</sub> is transported as **bicarbonate**
  - $\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3$  (carbonic acid)  $\rightleftharpoons \text{HCO}_3^-$  (bicarbonate) + H<sup>+</sup>
- **Carbonic anhydrase** catalyzes the formation of HCO<sub>3</sub><sup>-</sup>

# Carbon Dioxide Transport



# CO<sub>2</sub> transport

At tissues:

CO<sub>2</sub> is produced during cellular respiration = Krebs cycle

CO<sub>2</sub> diffuses out into plasma

1. Some will stay in plasma dissolved

2. Most will enter RBC:

1. Some will bind directly to Hb, after Hb has let go of O<sub>2</sub>: Hb-O

2. Most of it will combine with H<sub>2</sub>O in presence of carbonic anhydrase

1.  $\text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}^+ + \text{HCO}_3^-$

1. H<sup>+</sup> will bind to Hb after Hb let go of O<sub>2</sub>: Hb-H<sup>+</sup>

2. HCO<sub>3</sub><sup>-</sup> is removed to the plasma for exchange of Cl<sup>-</sup>  
= chloride shift. Most CO<sub>2</sub> carried back to lungs as HCO<sub>3</sub><sup>-</sup>

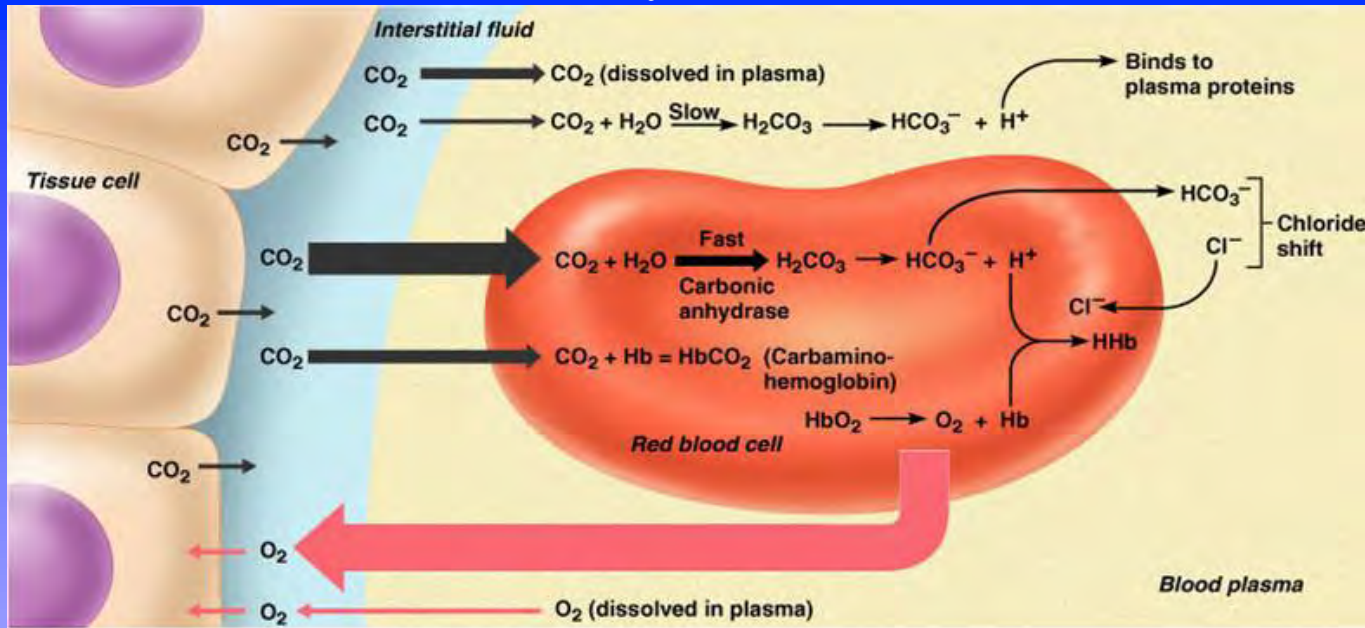
# CO<sub>2</sub> transport

At lungs:

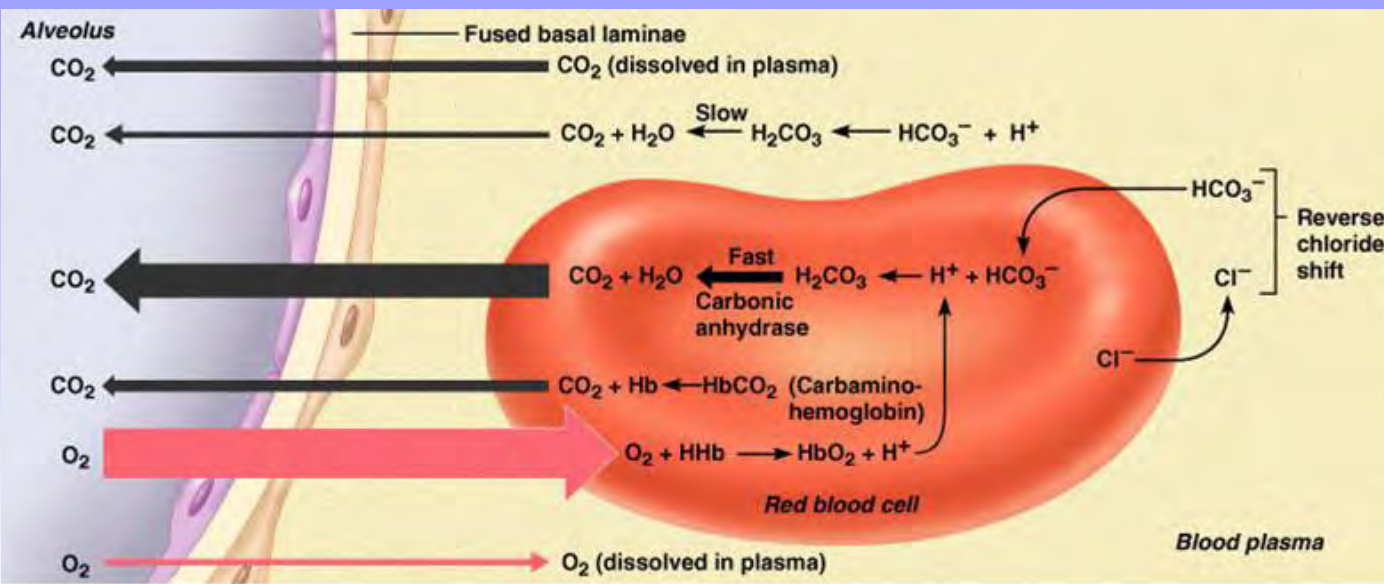
1. The dissolved CO<sub>2</sub> will diffuse out = exhale
2. Within the RBC the Hb will let go of the CO<sub>2</sub> and then can bind O<sub>2</sub>. The CO<sub>2</sub> will diffuse out = exhale
3. HCO<sub>3</sub><sup>-</sup> is brought back into RBC via reverse chloride shift = Cl<sup>-</sup> out and HCO<sub>3</sub><sup>-</sup> in. Hb-H<sup>+</sup> = will let go of H<sup>+</sup> and so Hb can bind O<sub>2</sub>  
Then :  $\text{HCO}_3^- + \text{H}^+ \leftrightarrow \text{CO}_2 + \text{H}_2\text{O}$



# Carbon Dioxide Transport



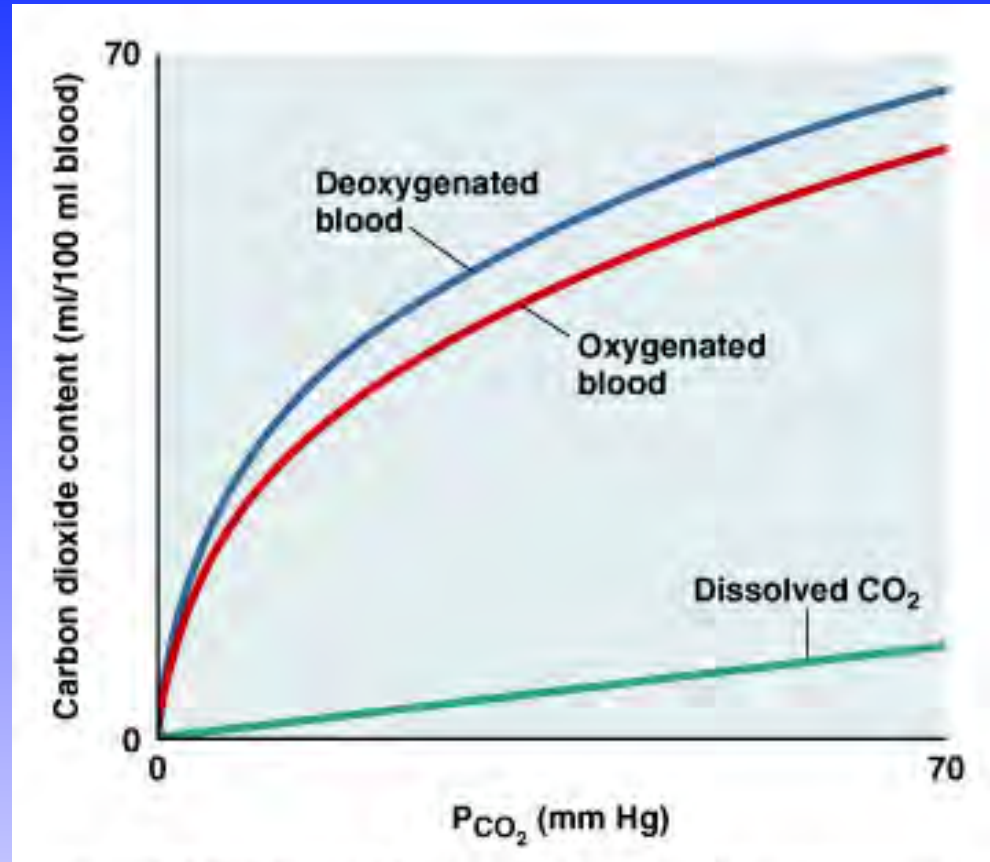
**(a) Oxygen release and carbon dioxide pickup at the tissues**



**(b) Oxygen pickup and carbon dioxide release in the lungs**

# Carbon Dioxide Equilibrium Curve

- Shows the relationship between  $P_{\text{CO}_2}$  and the total  $\text{CO}_2$  content of the blood
- The shape of the curve depends on the kinetics of  $\text{HCO}_3^-$  formation
- Deoxygenated blood can carry more  $\text{CO}_2$  than oxygenated blood = *Haldane effect*
  - Removal of oxygen from hemoglobin increases hemoglobin's affinity for carbon dioxide



# Regulation of Respiratory Systems

- Respiratory systems are **closely regulated**
- Respond to changes in **external and internal environment**
- Must be able to supply sufficient oxygen to meet metabolic demands
- Must be able to **remove carbon dioxide** to prevent pH disturbance

Vertebrate **respiratory and circulatory systems work together** to regulate gas delivery by

- Regulating ventilation
- Altering oxygen carrying capacity and affinity
- Altering perfusion

# Definitions

**Hypoventilation** = Abnormally low respiration rate = like holding your breath  
→ results in  $\text{CO}_2$  buildup in blood (high  $P_{\text{CO}_2}$ ) = **hypercapnia**

**Hyperventilation** = Abnormally high respiration rate. Not exercise = exercise is good 😊. Panic attack is an example  
→ results in abnormally low  $P_{\text{CO}_2}$  = **hypocapnia**

- **Acidosis:** ↓ plasma pH = due to increase in  $\text{H}^+$ . Increase in  $\text{CO}_2$  leads to increase in  $\text{H}^+$
- **Alkalosis:** ↑ plasma pH = due to decrease in  $\text{H}^+$ . A decrease in  $\text{CO}_2$  leads to a decrease in  $\text{H}^+$



The effects of  $\text{CO}_2$  on acid-base homeostasis...

# Law of mass action



## Law of mass action:

when a reaction is at equilibrium, the ratio of the products and substrates will remain constant.

### (a) Reaction at equilibrium

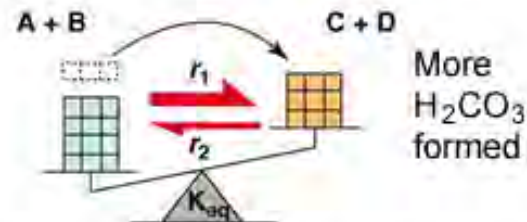


Rate of reaction in forward direction ( $r_1$ ) = rate of reaction in reverse direction ( $r_2$ )

## Law of mass action:

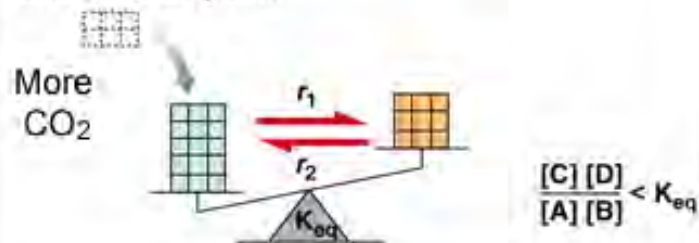
when a reaction is at equilibrium, the ratio of the products and substrates will remain constant.

### (c) Reaction rate $r_1$ increases to convert some of added A + B into product C + D.



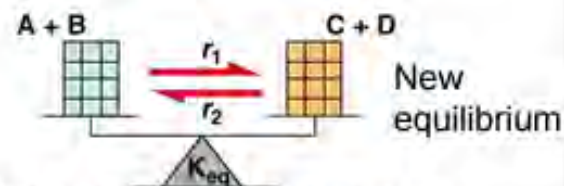
### (b) Equilibrium disturbed.

Add A + B to system



### (d) Equilibrium restored when

$\frac{[\text{C}][\text{D}]}{[\text{A}][\text{B}]} = K_{\text{eq}}$  once more.



The ratio of products to substrates is always the same at equilibrium.

# CO<sub>2</sub> and acid-base disturbances

1. **Metabolic acidosis = too much acid**; pH is decreased = due to too many H<sup>+</sup>. Your lungs are working fine. When you exercise H<sup>+</sup> increase due to ATP hydrolysis = will hyperventilate = blow off CO<sub>2</sub>

- **What causes metabolic acidosis?**

**Proton accumulation**, ketoacids (from breakdown of fats or amino acids ), kidney disease = pee out H<sup>+</sup> but kidneys are not peeing out H<sup>+</sup>



- **How can we fix it?**

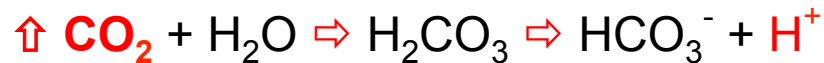
- **Hyperventilate** ie CO<sub>2</sub> can be blown off at the lungs
- **Renal (kidneys) compensation** - Secretion of H<sup>+</sup> and reabsorption of bicarbonate. Only if kidneys are functioning properly

# *CO<sub>2</sub> and acid-base disturbances*

**2. Respiratory acidosis** = lungs cannot remove all of the carbon dioxide the body produces; **ph is decreased due to increase in H<sup>+</sup>. Now lungs are messed and so cant use lungs to fix problems**

- **What causes respiratory acidosis?**

Hypoventilation which could be due to a wet lung, some obstruction in respiratory system. Anything that prevents CO<sub>2</sub> exhalation such as fluid



- **How can we fix it?**

- **Renal (kidneys) compensation only** - Secretion of H<sup>+</sup> and reabsorption of bicarbonate.
- **Cant use lungs to fix it because the lungs are mucked up**

# CO<sub>2</sub> and acid-base disturbances

## 3. Metabolic Alkalosis = Loss of protons; pH is elevated above normal

- **What causes metabolic alkalosis?**

Loss of protons due to vomiting, etc. Puke = puke up HCl-. Diarrhea = loss of ions, including H+



- **How do we fix it?**

- **Must make more H+ as we are losing H+**

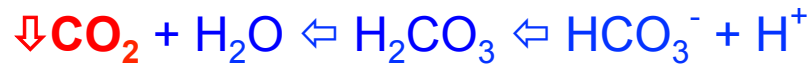
- **Hypoventilate** - keep CO<sub>2</sub> ie PCO<sub>2</sub> increases. By holding your breath, you will: Keep CO<sub>2</sub> in and CO<sub>2</sub> + H<sub>2</sub>O ↔ HCO<sub>3</sub><sup>-</sup> + H<sup>+</sup> and now we have more H<sup>+</sup>
- **Renal (kidneys) compensation** - bicarbonate excreted and H<sup>+</sup> reabsorbed



# *CO<sub>2</sub> and acid-base disturbances*

## 4. Respiratory Alkalosis = removing too much CO<sub>2</sub> across lungs.

- What is the cause? Due to hyperventilation = panic attack. Cant use lungs to fix it cause lungs are messed up



- How do we fix it?

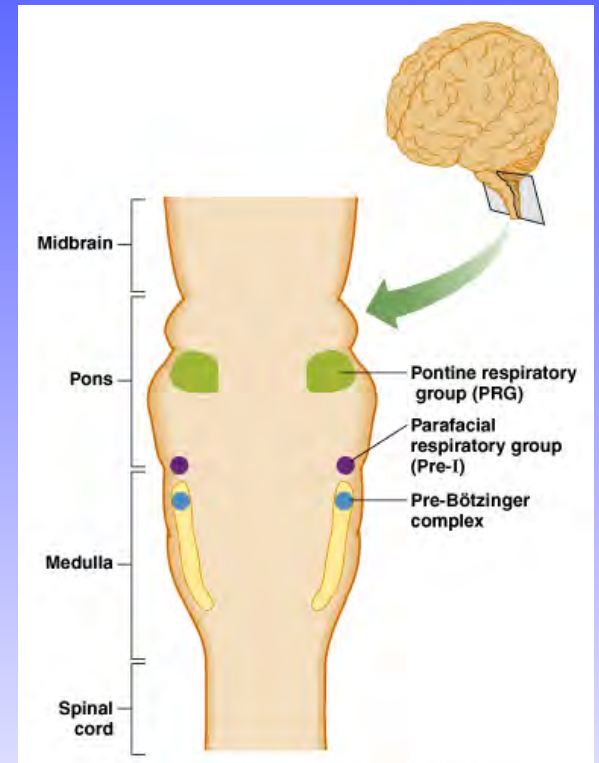
**Renal (kidneys) compensation only** - bicarbonate excreted and H<sup>+</sup> reabsorbed

**Breathing into a bag will allow you to rebreathe CO<sub>2</sub> and thus not lose it**

# Regulation of Ventilation

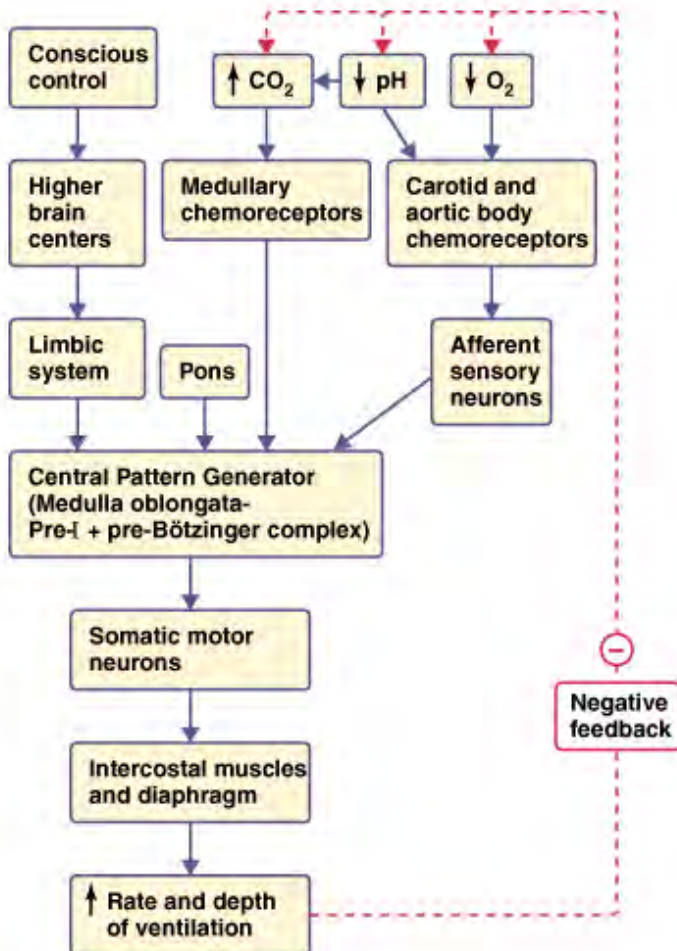
- Ventilation is an **automatic process**
- Continues even when we are unconscious
- Central pattern generator in medulla

- Rhythmic firing of *central pattern generators* within the medulla **initiate ventilatory movements**
- **Pre-Botzinger complex** is an important respiratory rhythm generator in mammals



# Regulation of Ventilation

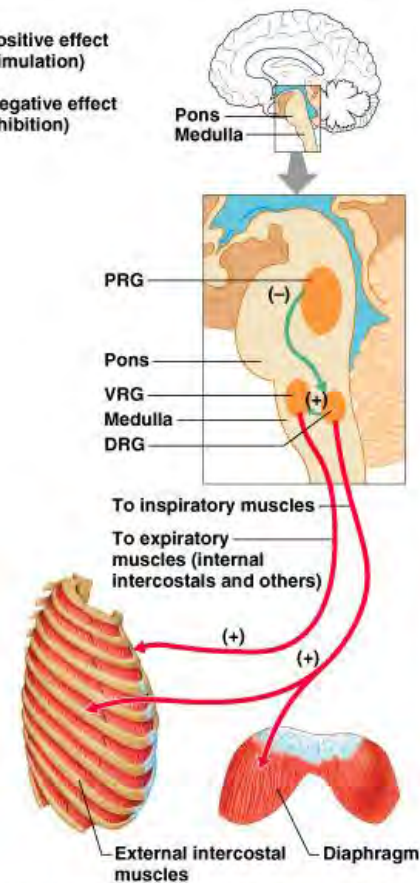
- Chemosensory input helps **modulate** the output of the central pattern generators
- Chemoreceptors detect **changes in CO<sub>2</sub>, H<sup>+</sup>, and O<sub>2</sub>**
- Oxygen is the primary regulator in **water-breathers** while CO<sub>2</sub> is the primary regulator in **air-breathers**



**Key:**

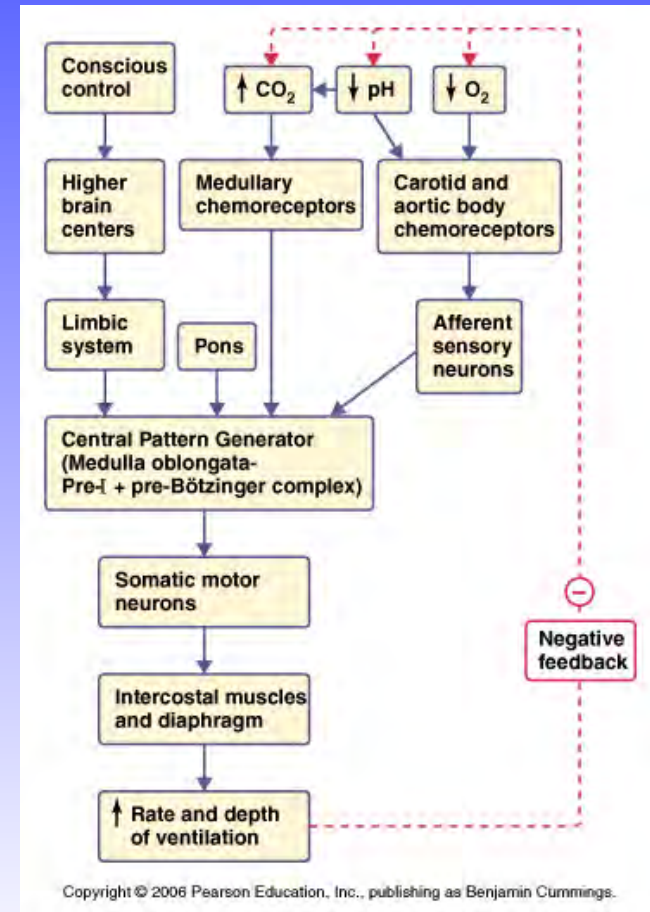
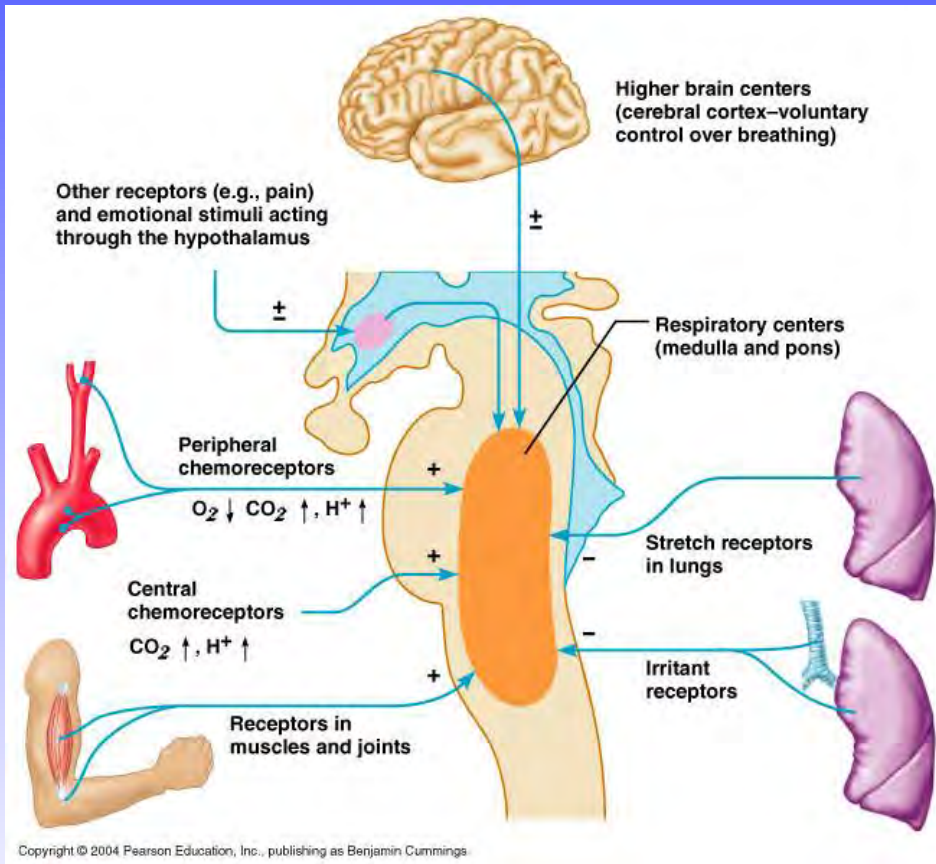
(+) = Positive effect (stimulation)

(-) = Negative effect (inhibition)



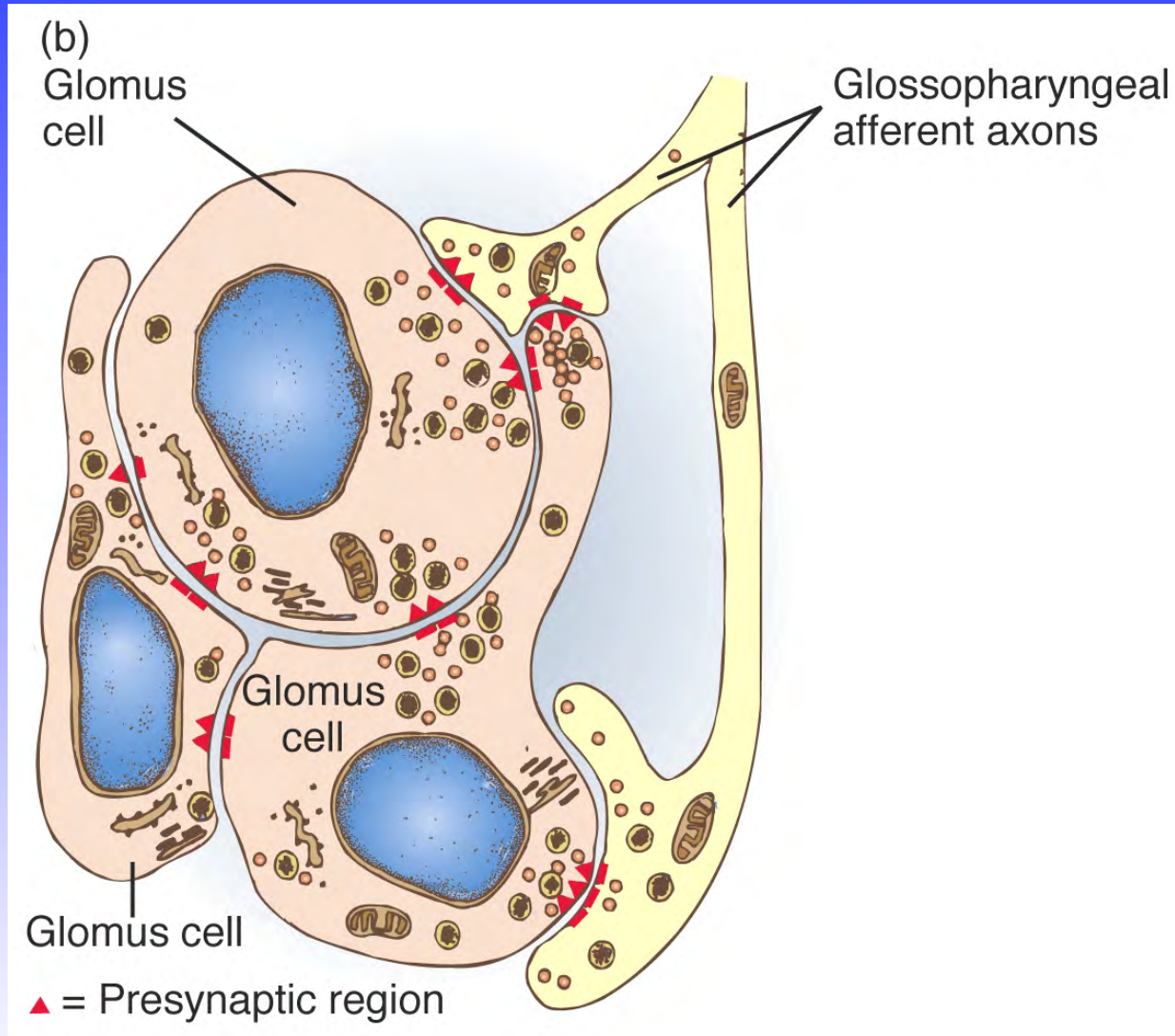
# Regulation of ventilation

- Ascending sensory input comes from chemosensory neurons in carotid and aortic bodies, in vasculature of lungs, and chemoreceptors in the medulla
- Modulates the rate and depth of breathing
- Negative feedback loop to maintain blood  $PO_2$  and  $PCO_2$  within a narrow range

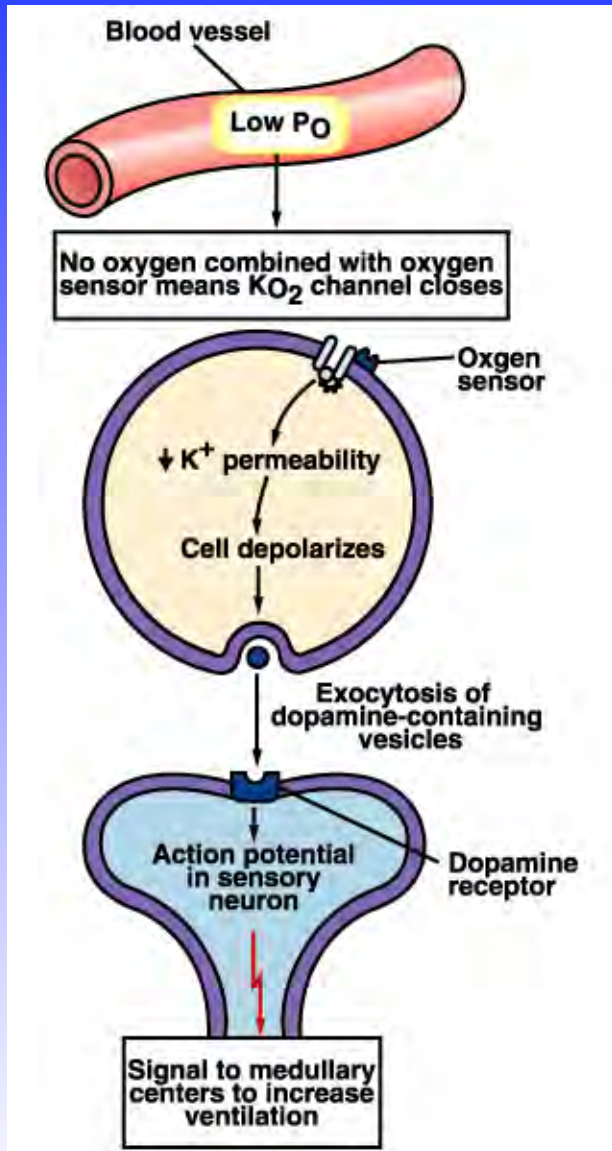


# Carotid and aortic chemoreceptors

Glomus cells = chemosensory cells



# Low $PO_2$ and mechanism in carotid body

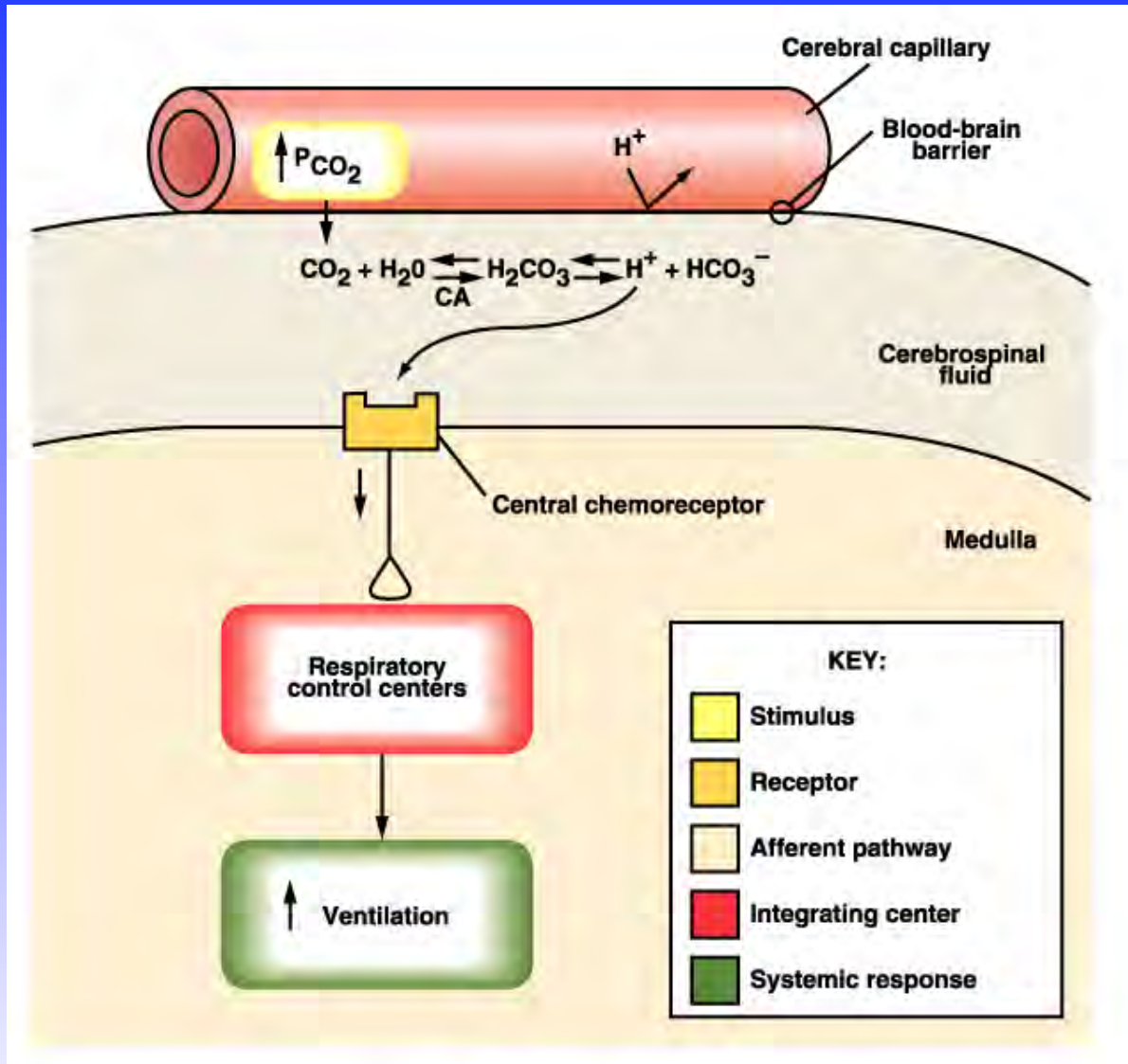


Glomus cells contain oxygen-gated  $K^+$  channels

1. Oxygen sensor detects low  $PO_2$
2. Closes  $K^+$  channels = keep  $K^+$  inside cells
3. Cell depolarizes = makes cells more positive
4. Causes release of dopamine = electrical signal will result in release of chemical messenger = dopamine
5. Stimulates sensory neuron
6. Send signal to CNS = start breathing more

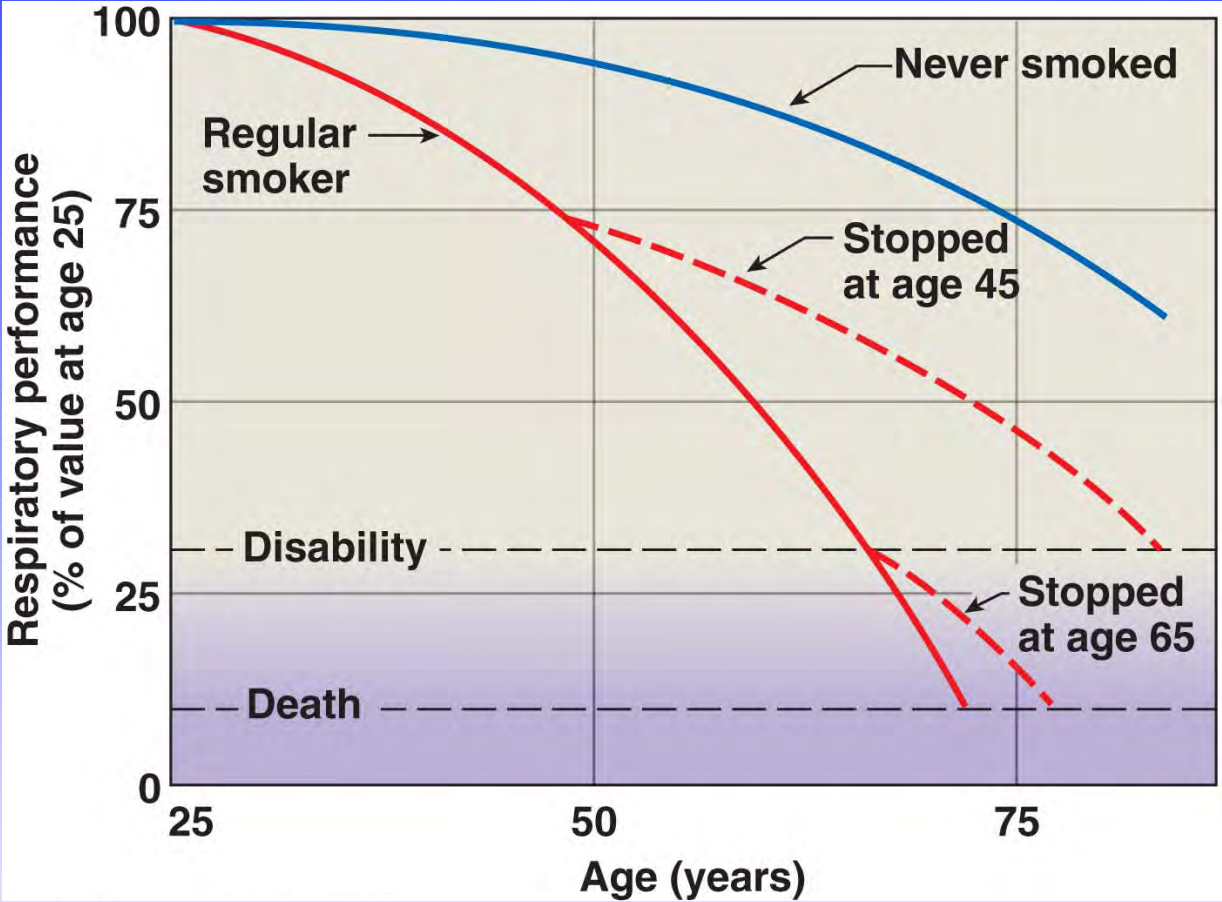
High altitude = get less  $O_2$  per breath. Still 21%  $O_2$  but  $PO_2$  lower

# High PCO<sub>2</sub> and mechanisms in central chemoreceptors



- Most important controllers in mammals
- Sensitive to changes in PCO<sub>2</sub> and pH
- CO<sub>2</sub> crosses blood/brain barrier
- Carbonic anhydrase converts CO<sub>2</sub> to HCO<sub>3</sub><sup>-</sup> and H<sup>+</sup>
- H<sup>+</sup> stimulates receptor
- Stimulates ventilation = exhale CO<sub>2</sub>

# Respiratory Performance and smoking





# Oxygen at Altitude – a special case

- *Pressure declines as altitude increases*
- *Oxygen delivery to body dependent on partial pressure of oxygen*
- *Concentration of oxygen doesn't change but you get less oxygen per breath*
- *At 12,000ft you get ~40% less oxygen per breath*

## *Moderate Altitude – initial symptoms*

- *Headache*
- *Nausea*
- *Fatigue*
- *Loss of appetite*
- *Difficulty sleeping*
- *Frequent Urination*

## *High Altitude – symptoms*

- *Confusion*
- *Reduced mental acuity*
- *Loss of coordination*
- *Cerebral edema*
- *Pulmonary edema*
- *Death*

# Oxygen at Altitude - a special case

## **Sleeping patterns**

1. Low inspired oxygen ( $PaO_2$  low)
2.  $CO_2$  production normal
3. Arterial/Carotid chemoreceptors sense low  $O_2$
4. Increase rate and depth of breathing to bring in  $O_2$  even at rest
5. = Hyperventilate = blow off more  $CO_2$  than produced
6. Leads to Hypocapnia = low  $CO_2$  in blood due to **Respiratory Alkalosis**. Also pee more to keep  $H^+$  due to kidneys being more active = pee more
7. Intermittent breathing (especially at night)
8. Causes difficulty sleeping

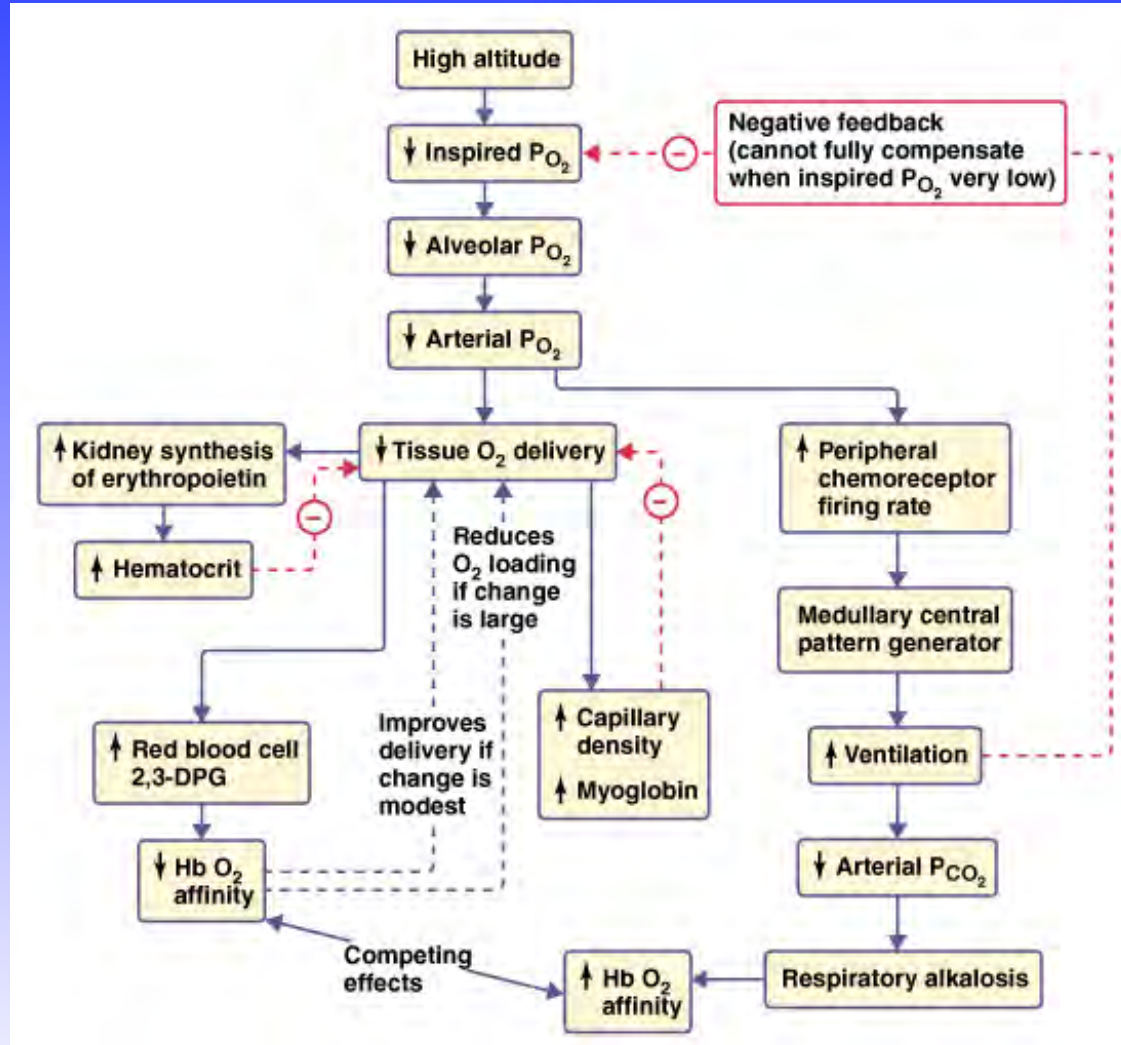
## **Lungs = later**

1. Inspired air low  $PO_2$
2. Sensors in lung detect low oxygen
3. Causes vasoconstriction in lung
4. Reduces blood flow
5. Increases blood pressure
6. Can lead to pulmonary edema

## **Solution = later**

- Increased EPO = RBC increase
- Increased hematocrit
- Peripheral vasodilation

# Oxygen at Altitude - a special case



How do **diving mammals** deal with the lack of oxygen ie  
cant breathe under water

# Dive response

## Dive Response

- Apnea = breath hold
- Bradycardia = decrease of Heart rate from resting/baseline = conserve O<sub>2</sub>.
- Peripheral Vasoconstriction = reduce blood flow to non-essential tissues = helps to conserve O<sub>2</sub>
- Cooling of tissues to conserve energy

## Oxygen Stores

- Lungs but many collapse lungs
- Blood = higher carrying capacities of O<sub>2</sub>
- Muscle = higher Myoglobin

## Respiratory mechanics

High flow rates minimize the time for exhalation/inhalation cycle = rapid breaths allow animals to spend most of their travel time below the surface where drag is less

## Hb and Mb

- Marine mammals have exceptionally high [Hb] values compared to terrestrial mammals.
- [Mb] in diving mammals are 10 to 30 times that found in terrestrial mammals.

# O<sub>2</sub> stores in different species

<b>Species</b>	<b>mL O<sub>2</sub> kg<sup>-1</sup></b>	<b>Lung %</b>	<b>Blood %</b>	<b>Muscle %</b>
Human	20	24	57	15
Odontocetes	35	22	30	48
Otariids	40	13	54	33
Phocids	60	7	65	28
Sea Otter	55	55	29	16
Manatee	21	33	60	7

# Some questions

- The common passageway shared by the respiratory and digestive systems is the \_\_\_\_\_
- The sites of gas exchange within the lungs are \_\_\_\_\_
- **Most** of the oxygen transported by the blood is \_\_\_\_\_
- In humans the **most** important chemical regulator of respiration is \_\_\_\_\_
- Define hypercapnia. \_\_\_\_\_
- Air moves out of the lungs when the pressure inside the lungs is \_\_\_\_\_
- Carbon dioxide is more soluble in water than oxygen. To get the same amount of oxygen to dissolve in plasma as carbon dioxide, you would have to \_\_\_\_\_
- Define affinity. How is Hemoglobin's affinity for O<sub>2</sub> affected? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_
- Hyperventilation will \_\_\_\_\_ CO<sub>2</sub> exhaled and thus \_\_\_\_\_ pH. Use increase and/or decrease.

# Some questions

- What is the function of surfactants? \_\_\_\_\_
- How does your body fix a respiratory acidosis? \_\_\_\_\_
- What is the significance (why do they matter) of Henry's law, Boyle's law and Dalton's law to the process of respiration? Explain why these laws matter in relation to the respiratory system.  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_
- Diffusion rate increases with a decrease in molecular weight. True or False

Last slide for Test 1