Life's Common Challenges

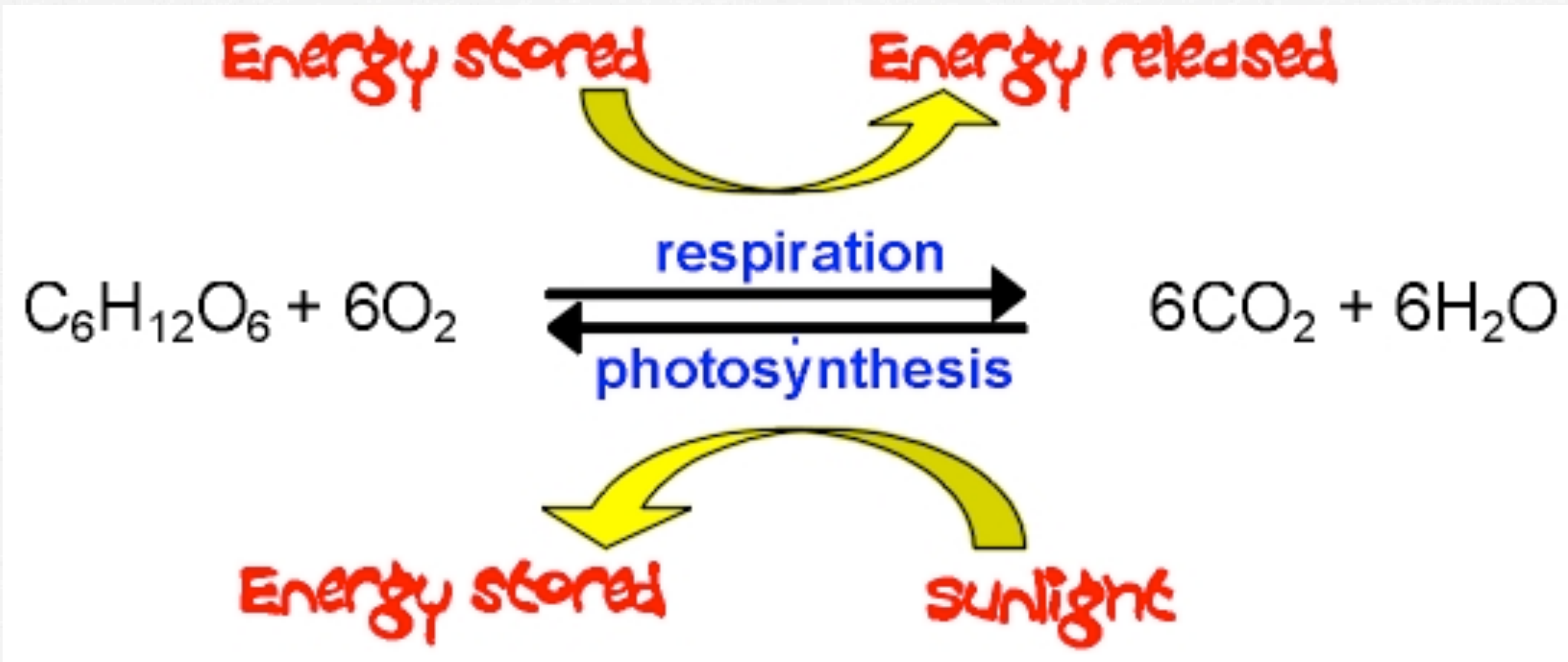
Gas Exchange

Life's Common Challenges

Introduction

- Every cell exchanges “gases” with its environment.
- Every cell uses ATP as its energy currency or cellular fuel.
- Autotrophs utilizes solar energy to build organic molecules out of carbon dioxide
    - Photosynthesis
- Heterotrophs and autotrophs utilize the chemical energy in organic molecules to produce ATP
    - Cell respiration
- Most eukaryotic cells and some prokaryotic carry out aerobic respiration
    - It is likely that even anaerobic cells exchange some gases
- Both photosynthesis and aerobic cell respiration require the exchange of carbon dioxide and oxygen.

Review: Write down the equations for photosynthesis and cell respiration.



Introduction

- **Ultimately all life exchanges gas with its environment at the cellular level...the plasma membrane.**
  - **In unicellular organisms, exchange occurs directly with the external environment.**
  - **In multicellular organisms this direct transfer of materials (gas) is not possible.**
  - **Instead multicellular organisms require special systems:**

Introduction

- Instead multicellular organisms require special systems:
  - One for gas exchange between the environment and the other for gas transport to each and every cell
  - There is remarkable variation in form and organization between species each of these systems.
  - Regardless of the variation, their goals are the same make gas transport as short a distance as possible
  - Gas exchange relies on diffusion on diffusion is slow over long distances!
    - ex. to diffuse 1cm it would take 3hrs

Introduction

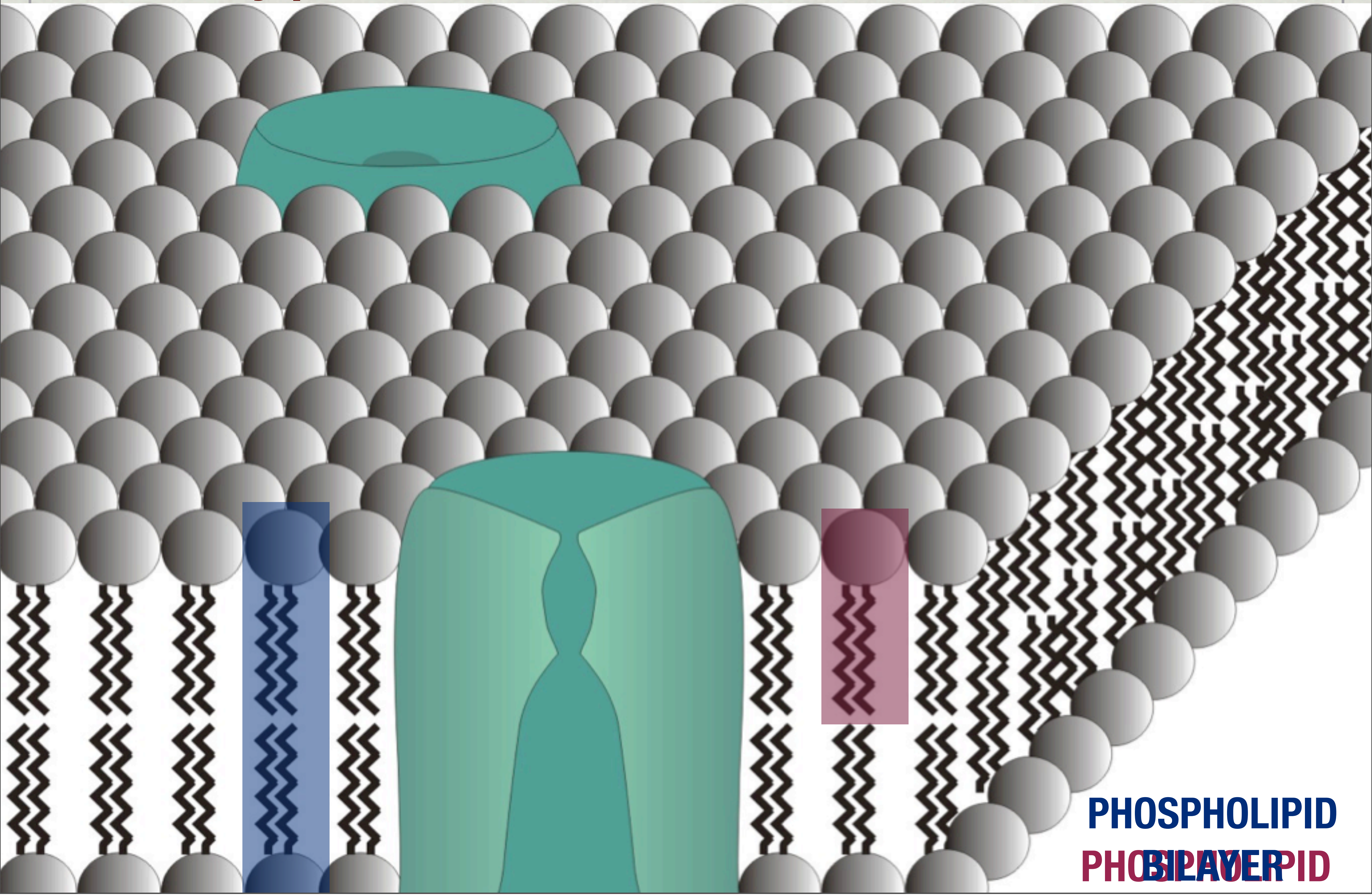
Ultimately all life exchanges gas with its environment at the cellular level...the plasma membrane.

So lets begin by reviewing membrane transport concepts!

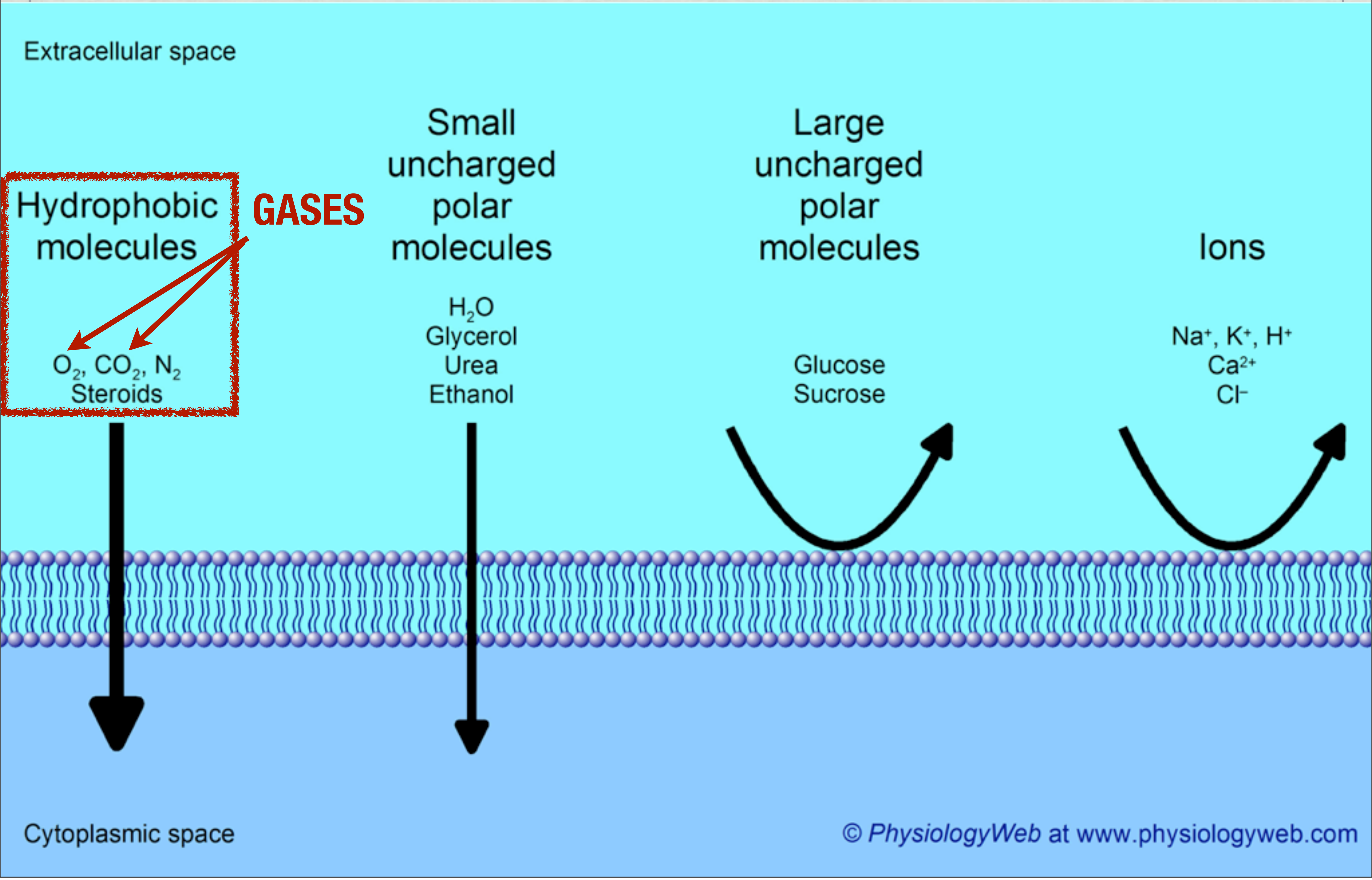
Life's Common Challenges

Membrane Transport ...a review

Remember ALL cells no matter the shape or size have a selectively permeable membrane!



Selective Permeability



Regulate the movement of materials into and out of the cell

However

If cell permits

Small Molecules

Fat Soluble Molecules

Molecules with no electrical charge

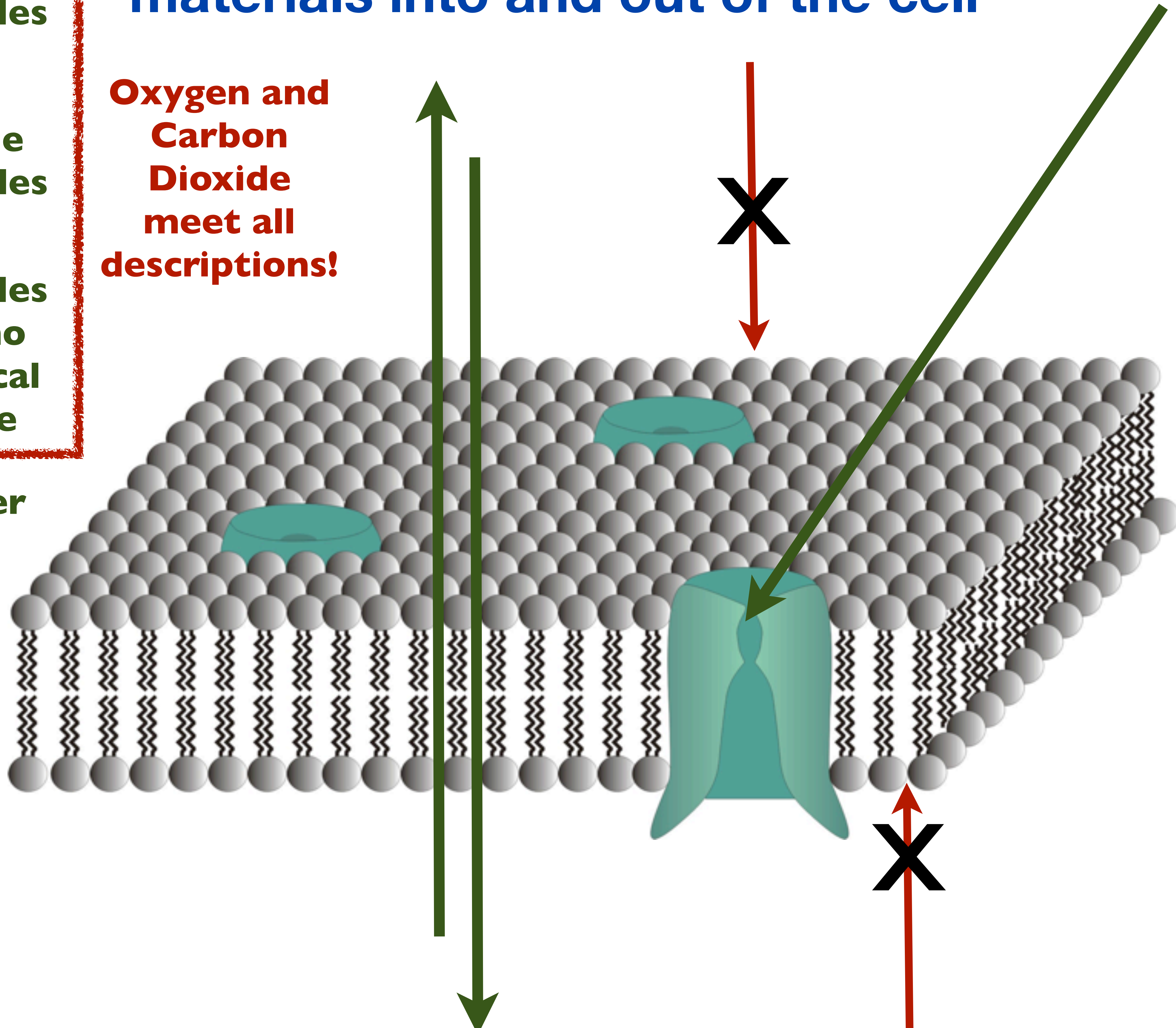
*Water

Oxygen and Carbon Dioxide meet all descriptions!

Large Molecules

Water Soluble Molecules

Molecules with electrical charges



EXCHANGING WITH THE ENVIRONMENT

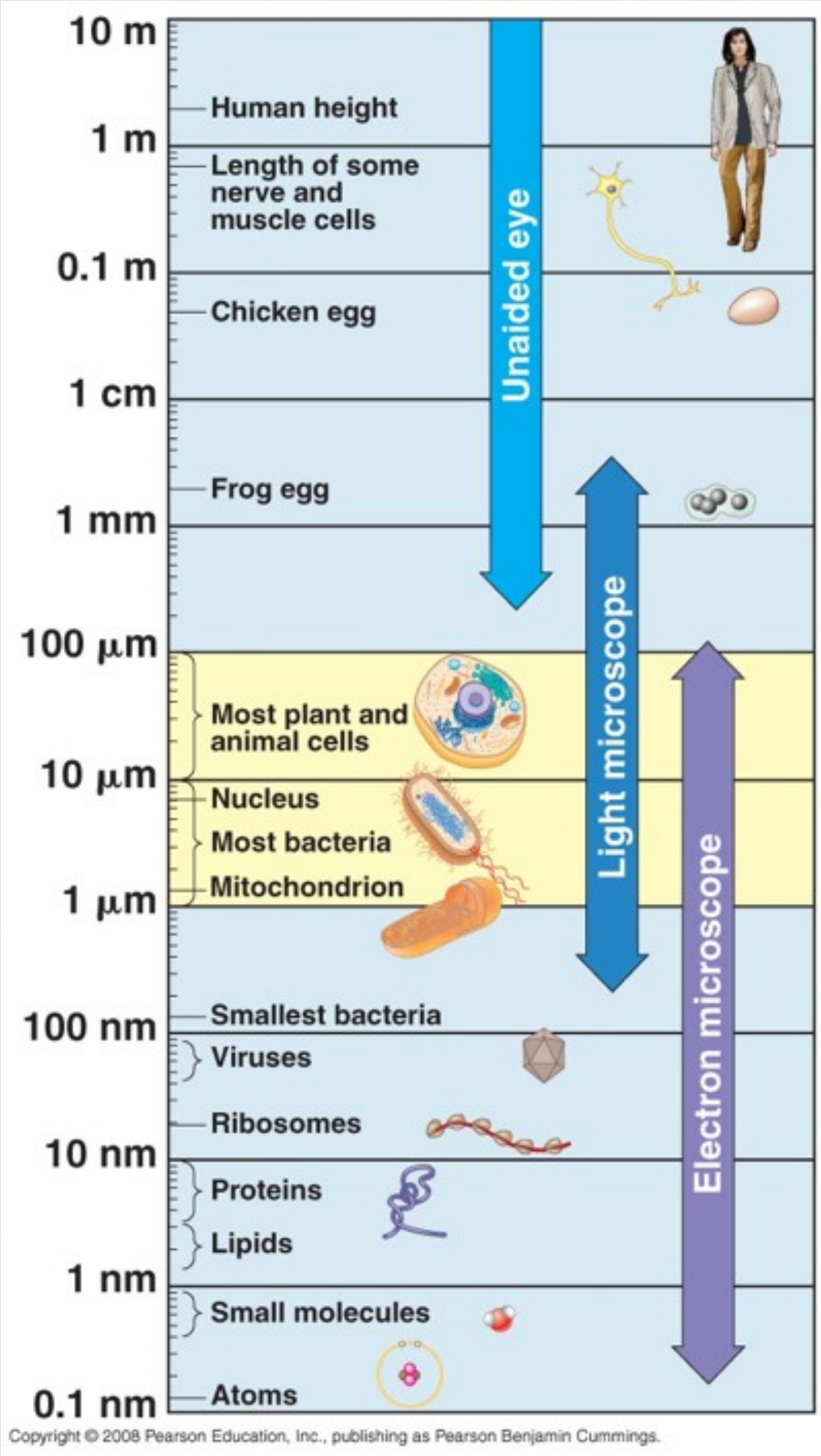
- Gases need to imported and exported across the membrane.
- Cells are filled with water and cells are surrounded by water.
  - Not pure water but rather a solution.
- Water is the medium that imports and exports gases across the membrane.
- Small cells can import and export gases more efficiently than larger cells. All cells are small.

Cells are filled with water and cells are surrounded by water.

- The inside of a cell is 70-95% water, more specifically called cytosol.
  - *The cytosol is a complex mixture of substances dissolved in water.*
- A unicellular organism is surrounded lives an aquatic environment.
- The cells of a multicellular organism are bathed in extracellular fluid.
  - *denotes all <u>body fluid</u> outside of cells*

Water is the medium that imports and exports molecules across the membrane.

- Life began in water.
- Life remains tied to water, organisms require water more than any other substance.
- Important cellular substances and molecules are dissolved in water.
- Water molecules participate in many chemical reactions necessary to sustain life.



Small cells can import and export molecules more efficiently than larger cells. All cells are small.

SIZE MATTERS

The logistics to carry out metabolism sets the lower limit on cell size

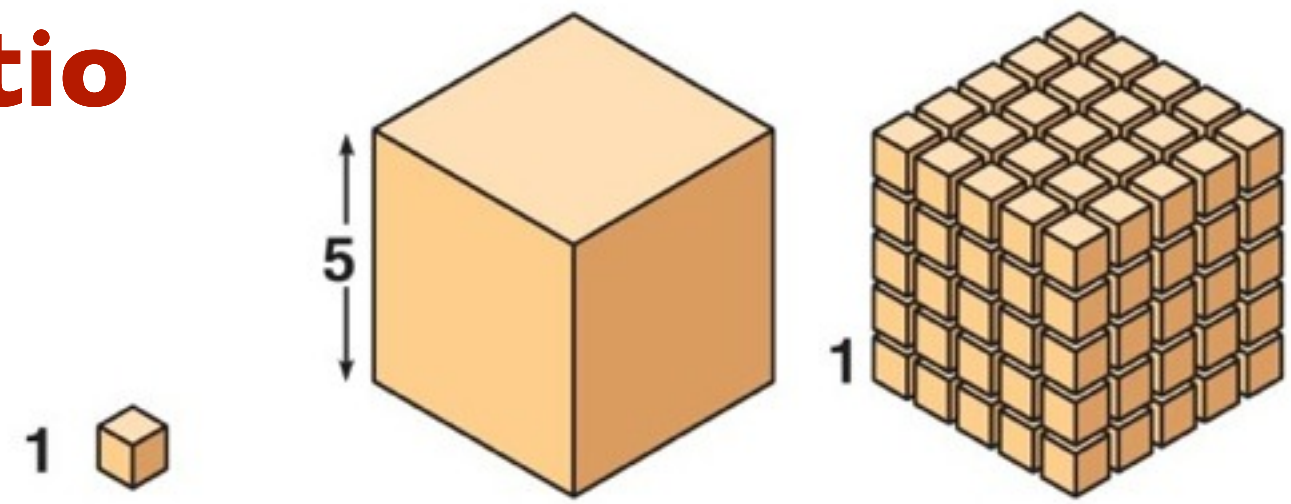
The requirements for metabolism set the upper limit on cell size

The ratio of surface area to volume is critical

Volume (cubed function) grows proportionately more than its surface area (squared function)

Thus a smaller object has a greater SA:V ratio

Surface area increases while total volume remains constant



Total surface area [Sum of the surface areas (height × width) of all box sides × number of boxes]	6		
Total volume [height × width × length × number of boxes]	1		
Surface-to-volume (S-to-V) ratio [surface area ÷ volume]	6		

Bigger is Better!

A. Unicellular & Multicellular Organisms

- Single celled organisms exchange material with its environment in the same ways that individual cells of a multicellular organism exchange with its environment.
- The difference often lies with the external environment itself.
  - Single cells interact with the “outside” environment as we think of “outside”.
  - For many cells in a multicellular organism their outside environment is extracellular fluid which lies inside of the organism as a whole.
  - **Here in lies the crux; single celled organisms have to adapt as the outside world changes but multicellular organisms work as a whole to maintain/regulate an outside environment that is conducive for life**

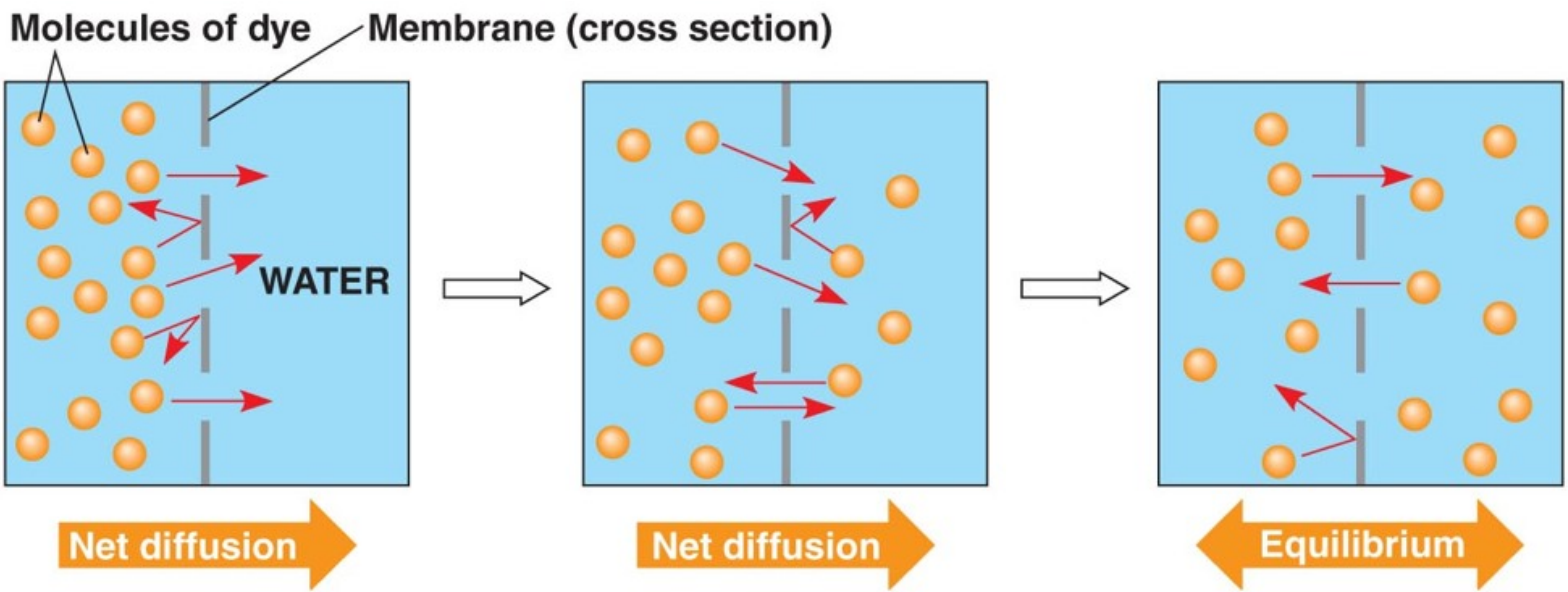
B. Cells Exchanging with Environment

- Cells can transport “relatively” anything across their plasma membrane.
- Cells have different mechanisms for transport depending on the nature of that which is being transported.
  - *Some substances move freely, with no input of energy.*
  - *Others require energy source to bring them across.*
  - *Some substances can travel through the lipid bilayer.*
  - *Yet others can only travel through protein channels located in the membrane.*
  - ***Fortunately our attention will focus on gases that move freely through membranes. We will review only the passive transport concept and the mechanism of diffusion.***

Some substances move freely, with no input of energy.

- **Passive transport** moves substances across membranes with no energy investment from the cell itself.
  - However energy is still required for any movement, where does it come from?
- The *Kinetic Molecular Theory* states that molecules are in constant random motion, these molecules therefore have their own energy.
- This motion results in **diffusion,** the movement of molecules from an area of high concentration to an area of low concentration. They "spread out"!

Diffusion



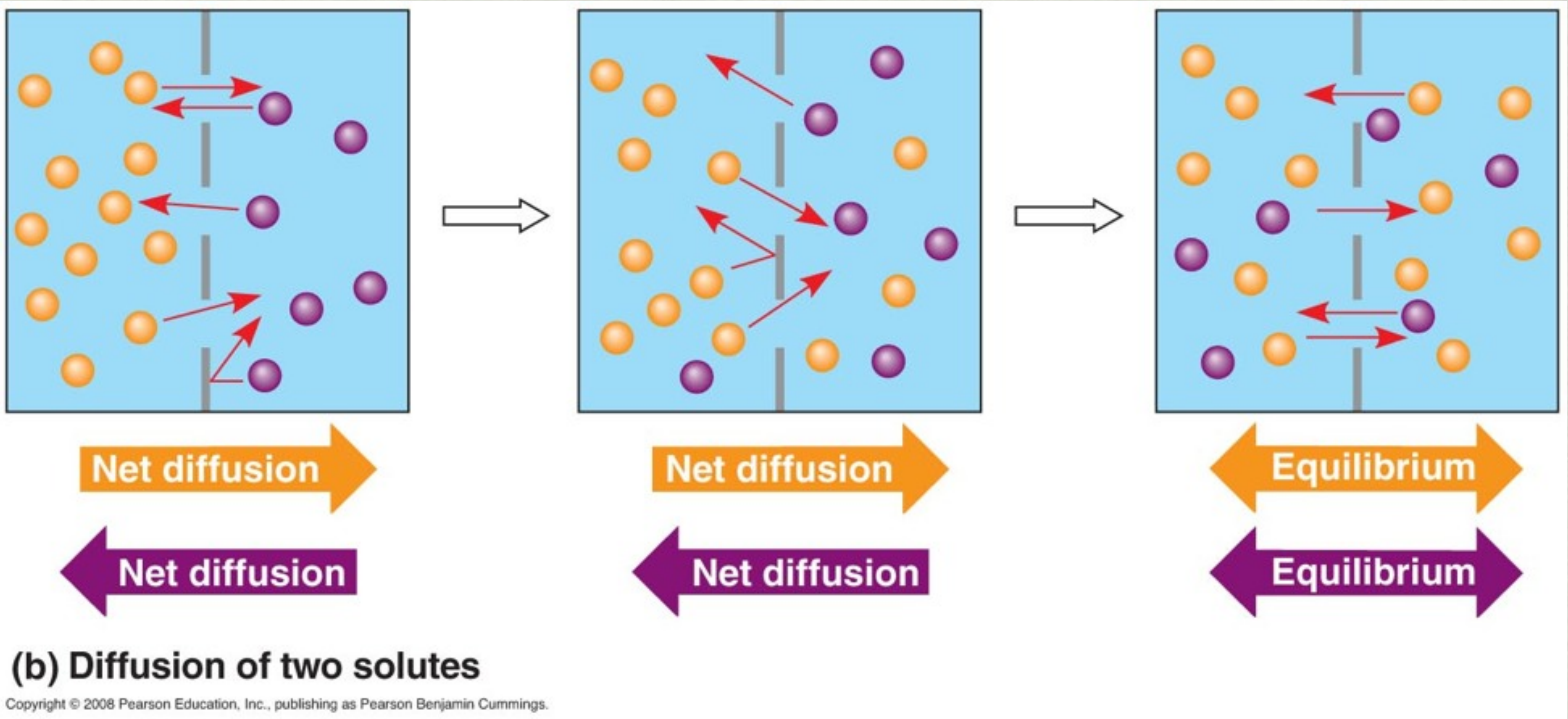
(a) Diffusion of one solute

Fick's law *considers the way these three factors relate to the rate of diffusion. This law states that:*

*the **rate of diffusion** is proportional to*

$$\frac{\text{surface area} \times \text{difference in concentration}}{\text{length of diffusion path}}$$

Diffusion



DIFFUSION OF SOLUTES IS INDEPENDENT OF OTHER SOLUTES

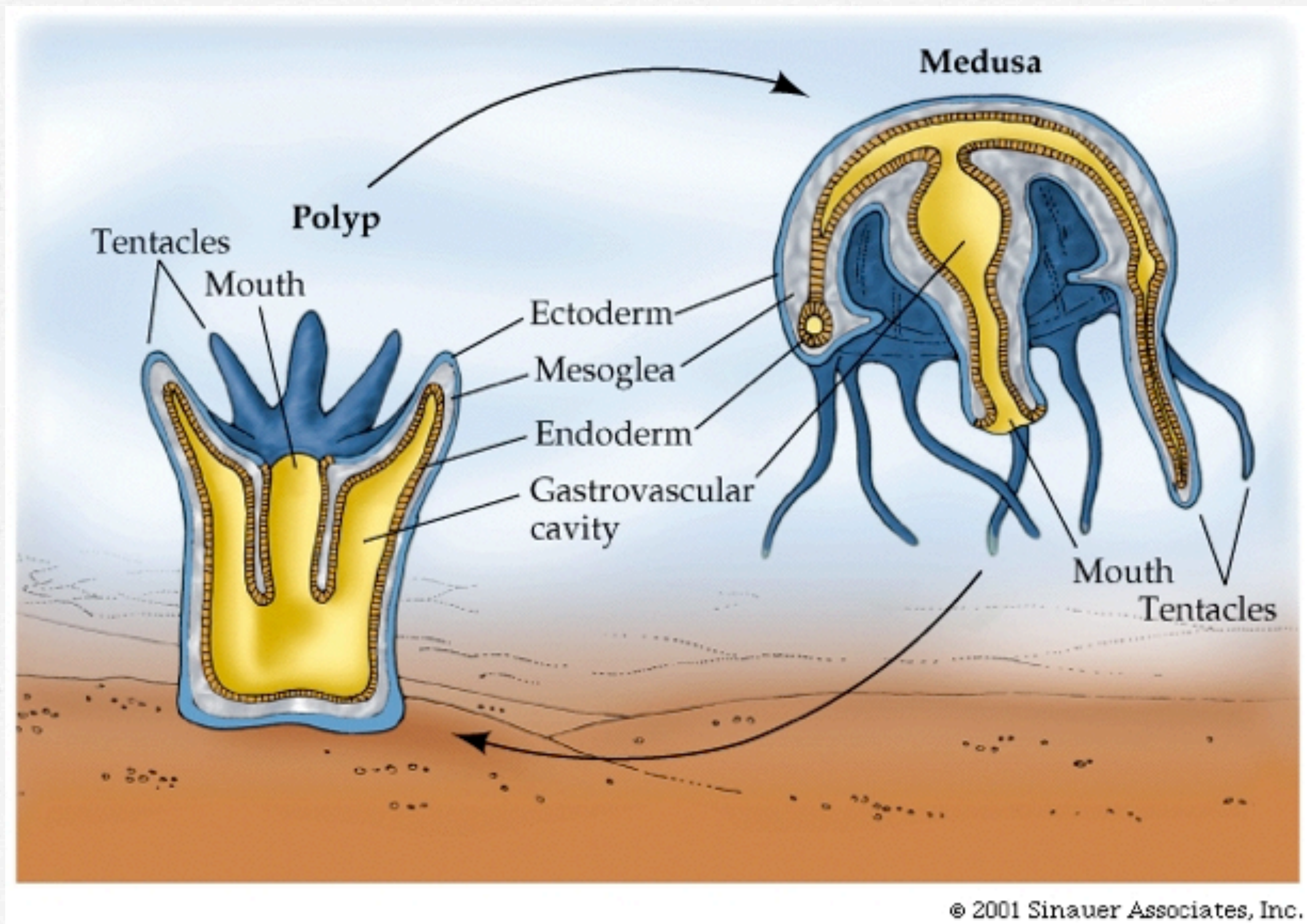
Animals

Gas Exchange

Circulatory Systems-
Link Exchange Surfaces

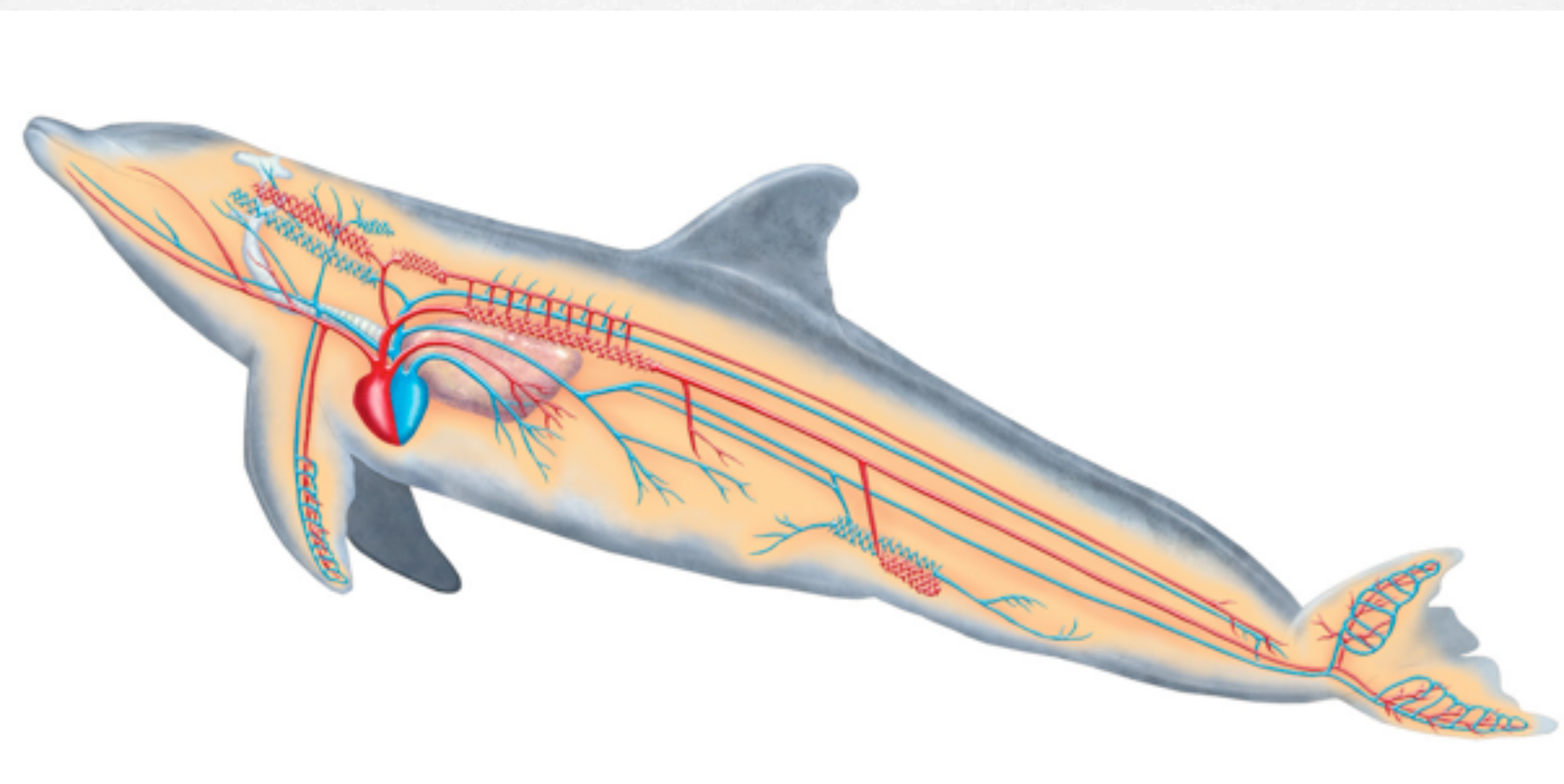
- Recall: Diffusion is slow!
    - (ex. 100 seconds to go 1mm)
- Since gases diffuse, this puts a significant constraint on the body plan of any animal.
- Natural selection has resulted in TWO general solutions.

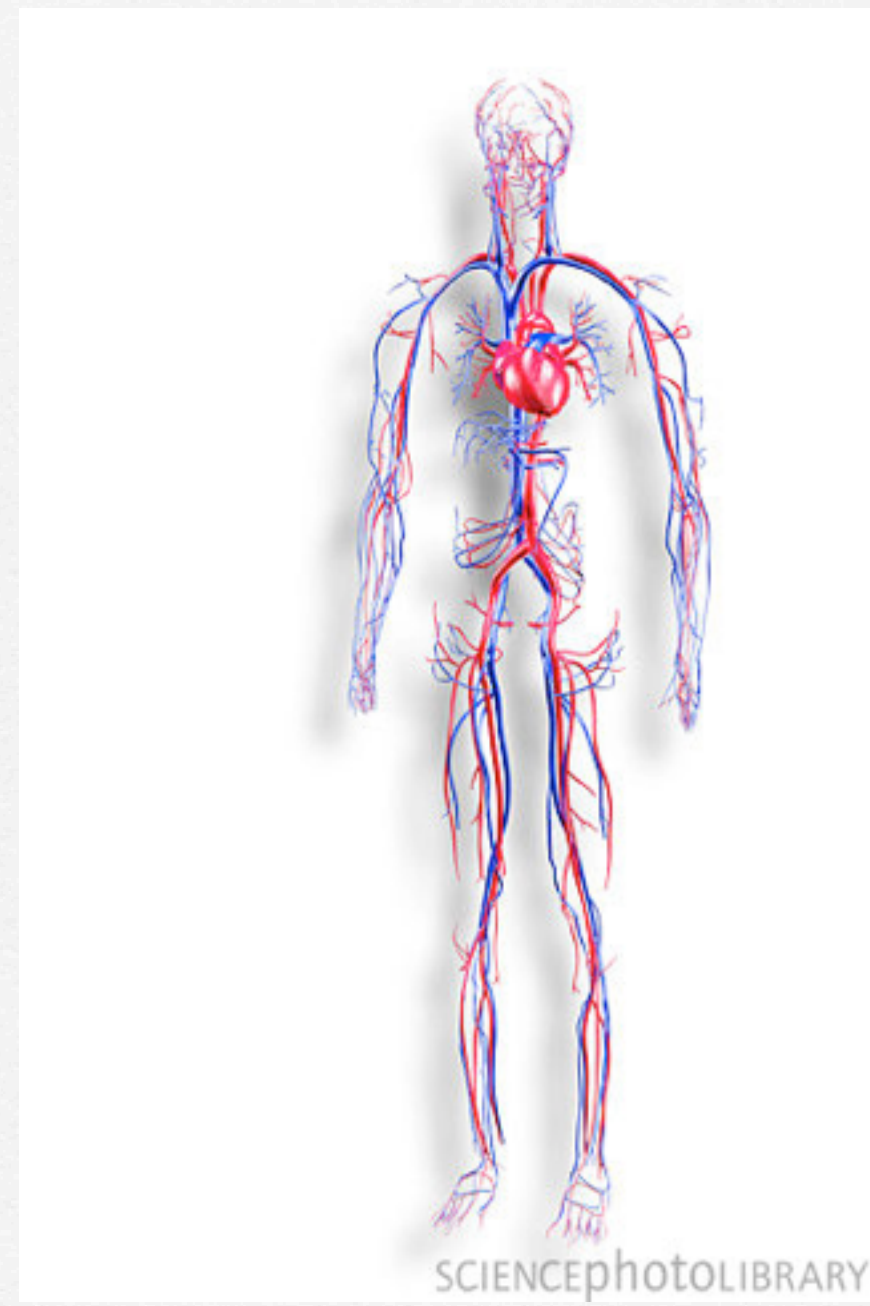
- **Solution One:** A body size and shape that keeps all or most cells in direct contact with the environment.
  - seen only in certain invertebrates and flatworms



- **Solution Two:** A circulatory system that moves fluid between each cell's immediate surroundings and the tissues where exchange with the environment occur.

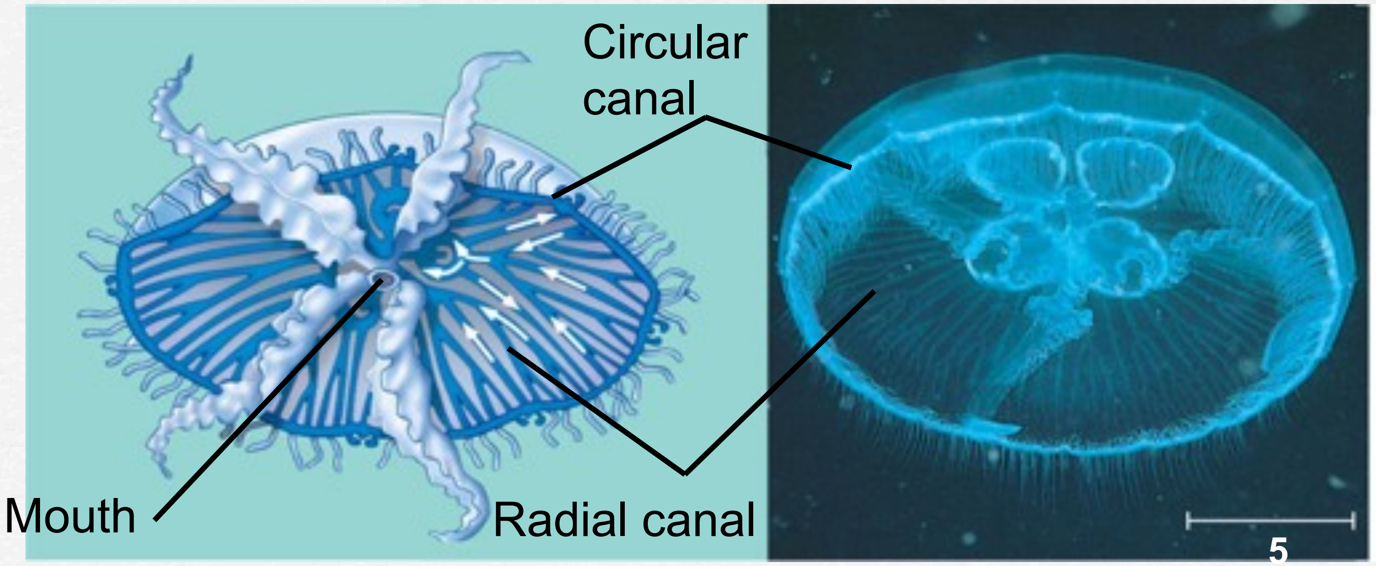
- found in all other animals





Gastrovascular Cavities

- Animals that lack circulatory systems.
  - hydras, jellies, flatworms
- An opening at one end connects the cavity to the surrounding water.
- The outside environment (fluid) bathes both inner and outer tissue layers, facilitating the exchange of gases
- The flat body of a flatworm optimizes surface area and minimizes diffusional distances



Evolutionary Variation in Circulatory Systems

- A gastrovascular cavity is not efficient enough when animals have many cell layers.
- Circulatory systems evolved and became a lasting adaptation because they were able to minimize the distances that substances (gases) must diffuse to enter or leave a cell.

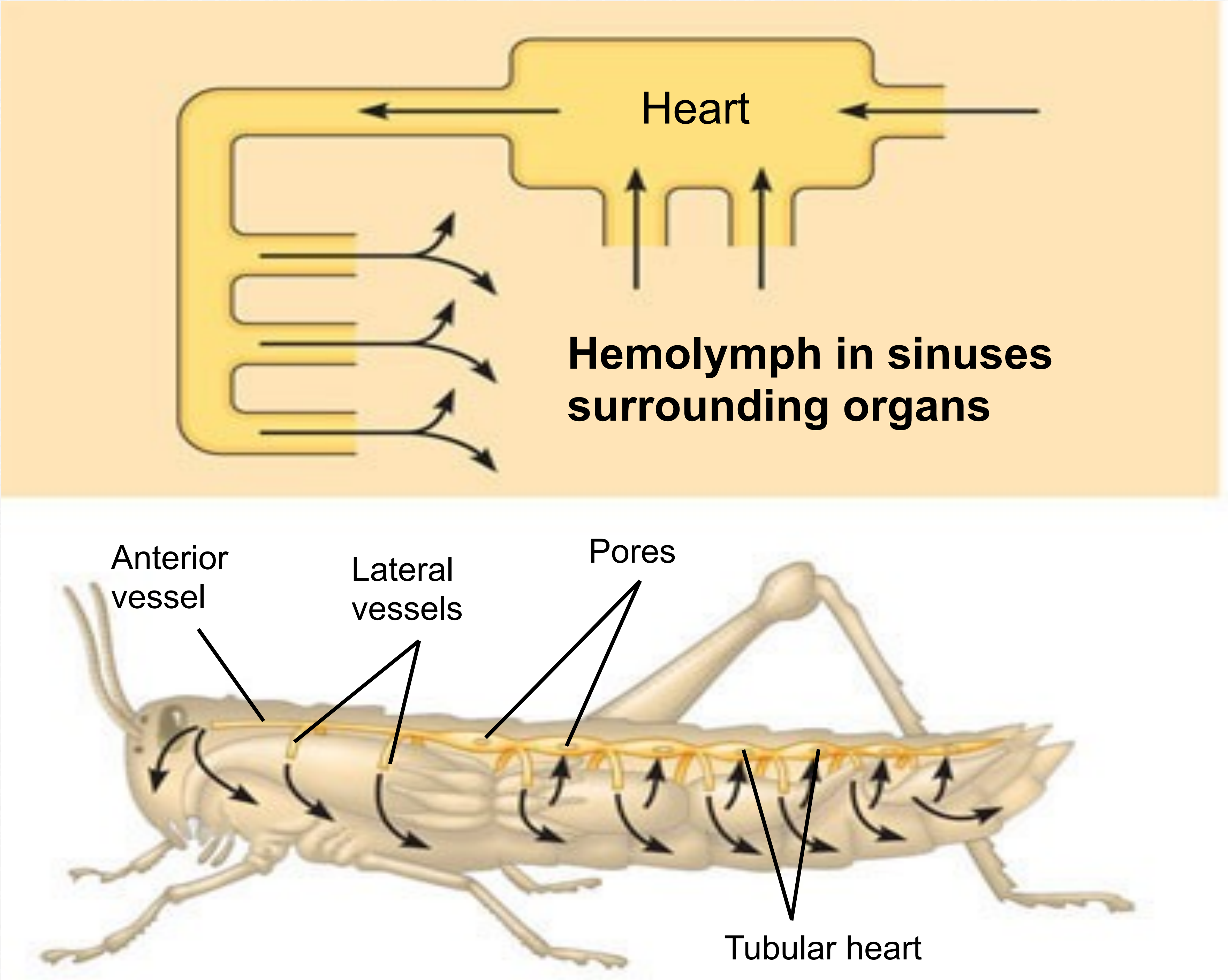
General Properties of Circulatory Systems

- **A circulatory system has three basic components:**
  - **a fluid, vessels, a pump(s)**
- By moving fluid through the body the circulatory system connects the aqueous surroundings of the cells to the organs that exchange gases (or absorb nutrients, or eliminate waste)
- Several basic types of systems have evolved, each adapted to the constraints imposed by anatomy and environment...
  - open or closed systems
  - number of circuits
  - number of pumps ,organization of pump(s), structure of pump(s)

Open & Closed Circulatory Systems

- **Open circulatory systems,** a circulatory fluid bathes the organs directly
  - arthropods and mollusks
- The circulatory fluid is called **hemolymph** or *interstitial fluid.*
  - Heart(s) pump hemolymph, hemolymph moves through vessels, empties into spaces surrounding organs, exchange occurs between hemolymph and cells, heart(s) relaxes, fluid is drawn back into vessels

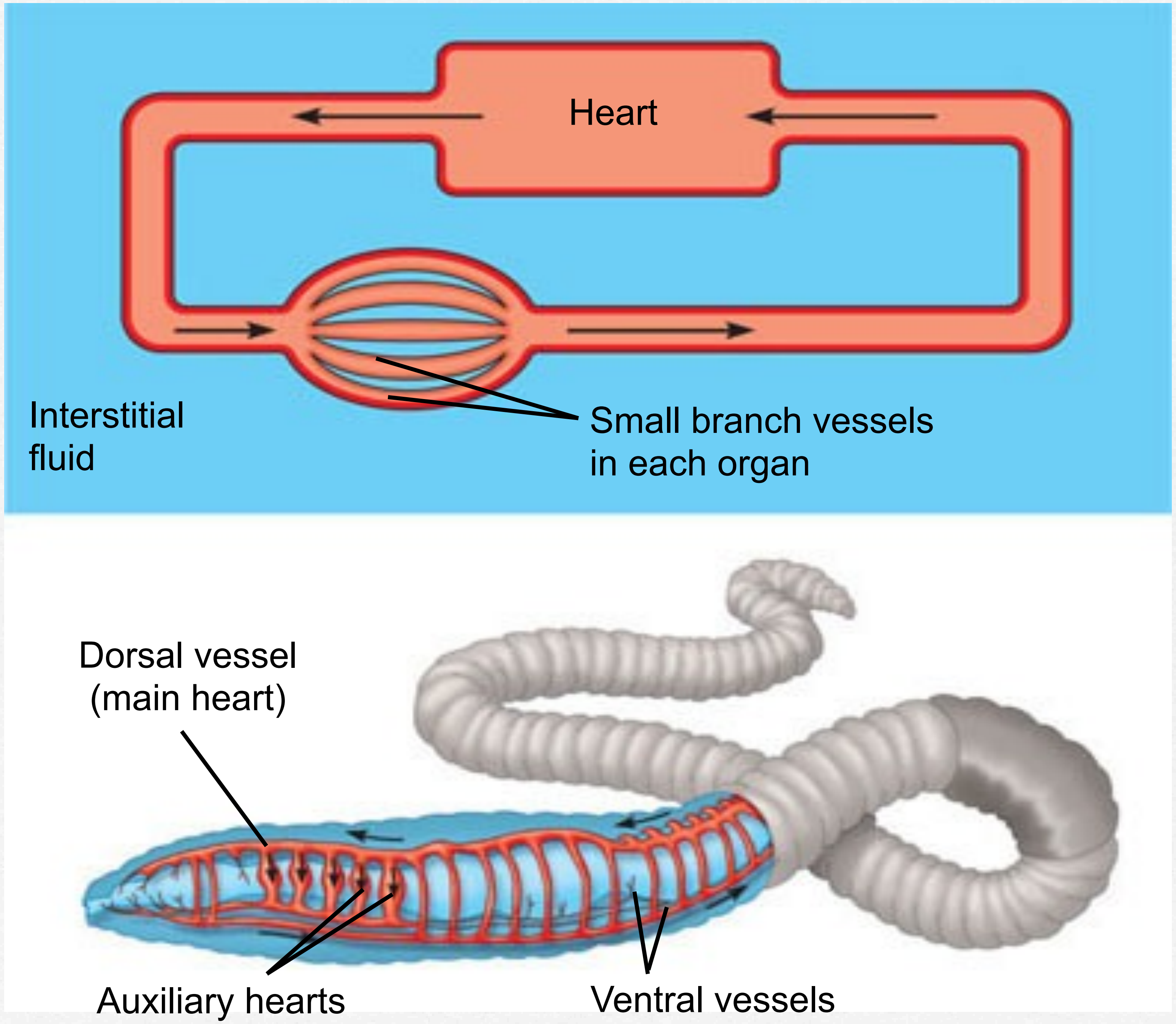
Open Circulatory Systems



Open & Closed Circulatory Systems

- **Closed circulatory systems,** a circulatory fluid called *blood* is confined to vessels and is separate from interstitial fluid
  - annelids, cephalopods, all vertebrates
  - Heart(s) pumps blood, blood moves through large vessels which continuously branch into more numerous smaller ones, the very smallest infiltrate organs and tissues, exchange occurs between blood and interstitial fluid and cells, blood returns to the heart.

Closed Circulatory Systems



"Trade Offs"

- Both open and closed systems are common in nature, this suggests that each may have its own advantages and disadvantages.
  - Open circulatory systems generate low hydrostatic pressures as a result they do not require much energy but they are unable regulate their distribution of blood flow.
  - Closed circulatory systems require much more energy but they can regulate the deliver of blood to different organs at different times.

Organization of Vertebrate Circulatory Systems

- **Recall a circulatory system has three basic components:**
  - **a fluid, vessels, a pump(s)**
- **The fluid-blood-**fluid component and a cellular component. Although many substances are found within the blood for this unit you only need to remember that oxygen and carbon dioxide are transported carried around the body in this fluid called blood.
- **The pump(s)-heart-**regardless whether an animal has one or more hearts every heart has at least two chambers. Chambers that receive blood are called *atria*. Chambers that pump blood out of the heart are called *ventricles*.

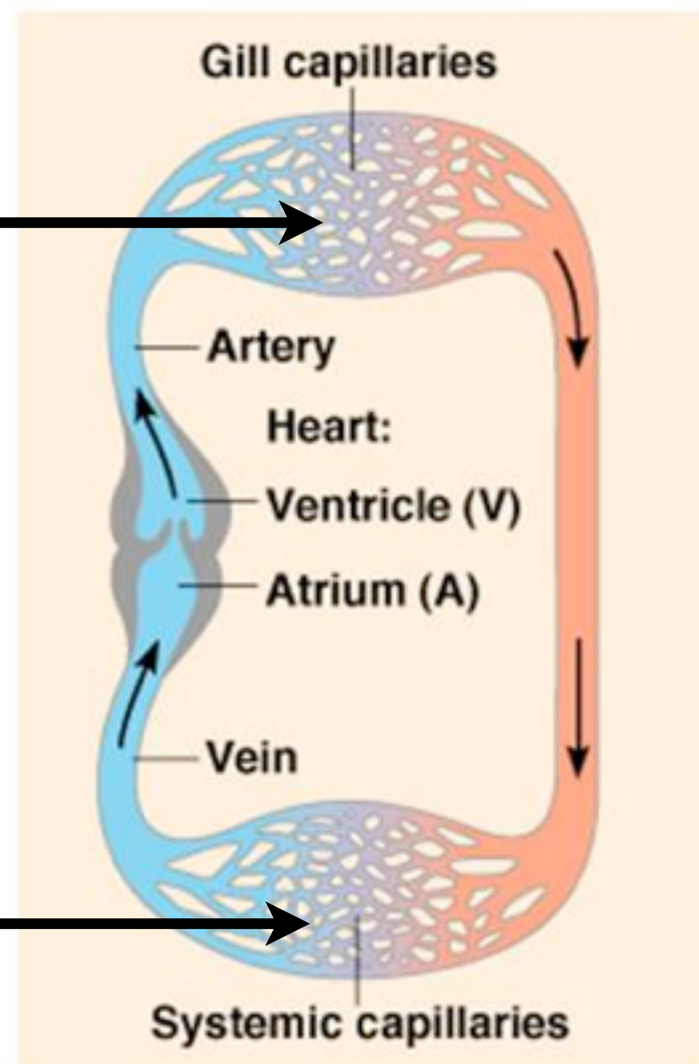
- **The vessels-**form an extensive network that carry blood to and from the heart.
  - The total length of vessels in an adult human is twice the circumference of the earth at the equator! WOW
- **The vessels-**are distinguished by the direction in which they carry blood, not their oxygen content or some other characteristic.
  - *Arteries* carry blood away from the heart and towards capillary beds.
  - *Veins* carry blood away from capillary beds and back to the heart.
  - *Capillaries* are microscopic vessels with very thin (one cell thick) porous walls. *Capillaries* infiltrate every tissue of the body and comes within a few cell diameters of every cell in the body. Gases are exchanged through cell walls of capillaries, into interstitial fluid and finally into each cell and vice versa.

Single Circulation

- The heart consists of two chambers an atria and a ventricle. Blood passes through the heart once in one complete circuit.
  - bony fish, rays and sharks

Carbon dioxide diffuses out of blood, oxygen diffuses into blood

Carbon dioxide diffuses into blood, oxygen diffuses out of blood



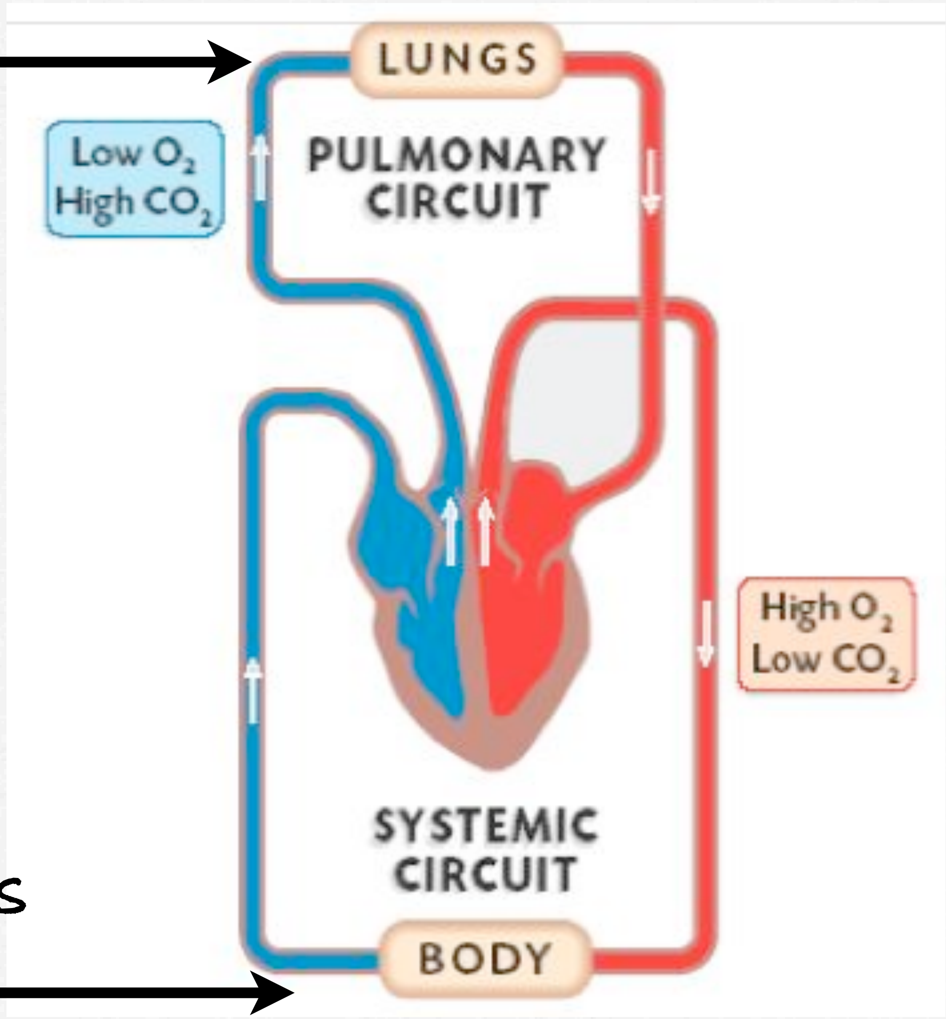
(a) Fish

Pressure drops when blood flows through capillary beds as a result blood flow to the rest of the body is sluggish. Fortunately as fish swim their contracting muscles help move blood along.

Double Circulation

- The heart consists of two pumps one for each circuit.
    - amphibians, reptiles, mammals

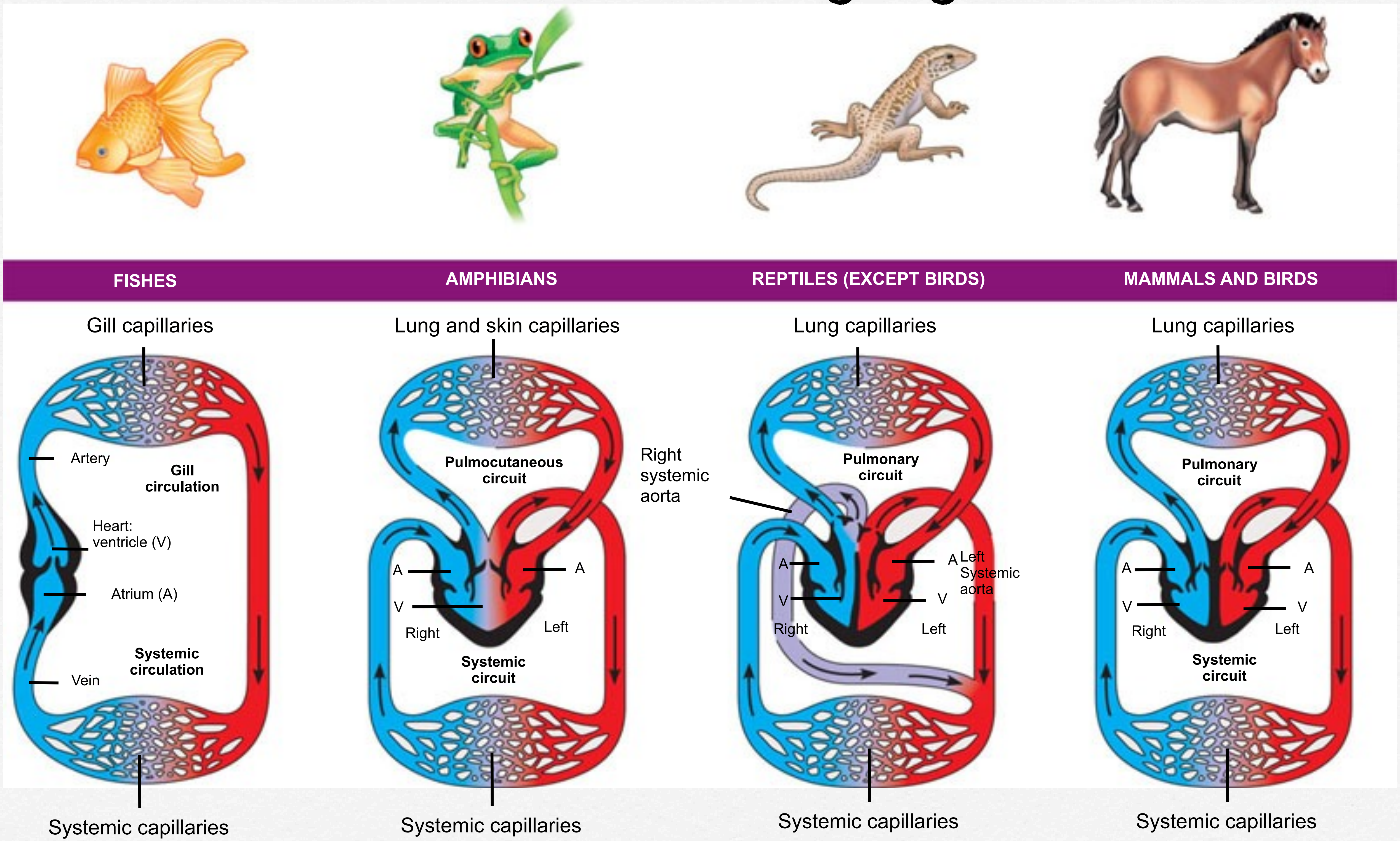
Carbon dioxide diffuses out of blood, oxygen diffuses into blood



The two pumps provide vigorous flow throughout the body. When blood moves through the capillary beds of lungs it loses much pressure however blood returns to the heart's second pump which reestablishes a hydrostatic pressure

Carbon dioxide diffuses into blood, oxygen diffuses out of blood

Vertebrate Circulatory Systems



“In Summary”

- Animals can either have a body plan that puts every cell in contact with its environment so that gas exchange occurs a rate to sustain life OR...
- Animals can use a circulatory system to deliver oxygen to every cell and remove carbon dioxide waste from every cell.
- BUT How does the organism as a whole get oxygen and get rid of carbon dioxide?
    - Answer...Respiratory Systems exchange gas between the outside environment and the circulatory system.

Gas Exchange Occurs Across Specialized Respiratory Surfaces

- **Gas Exchange or Respiration** (not to be confused with cellular respiration) is the uptake of molecular oxygen from the environment and the discharge of carbon dioxide to the environment.

Partial Pressure Gradients in Gas Exchange

- To understand gas exchange we must understand partial pressures.
- **Partial Pressure** is simply the pressure exerted by a particular gas in a mixture of gases.
  - Ex. the atmosphere at sea level exerts a force equal to 760mm Hg, oxygen makes up 21% of the atmosphere thus (760mm Hg)(0.21)= 160 mm Hg, the partial pressure oxygen!

Calculate the partial pressure of nitrogen which makes up 78% of the atmosphere.

What percent of the atmosphere does carbon dioxide account for if its partial pressure is 0.29mm Hg?

- Partial pressures also apply to gases dissolved in liquids, like water.
- Water exposed to air will have gases with the same partial pressures as the air.
  - Ex. 160 mm Hg is the partial pressure of oxygen in water and in the atmosphere.
  - HOWEVER concentration of oxygen is much less (40x lower) in water because it is less soluble in water.
- Once we know the partial pressures of the gas at the exchange surface we can easily predict its net diffusion.
- **Gases always diffuse from a region of higher partial pressure to a region with lower partial pressure!**

Respiratory Media

- Gas exchange varies considerably depending on the respiratory media...air or water.
- Air is less dense, less viscous and easy to move as a result breathing is relatively easy and does not need to be very efficient.
- Water is dense, more viscous and demands much more energy. In addition much less oxygen is dissolved in an equivalent volume of water.
    - Keep in mind that as water warms and/or salt concentrations increase the water holds even less oxygen!
- **As a result aquatic animals MUST be very efficient in their gas exchange. Fortunately aquatic organisms have evolved adaptations that increase this efficiency.**

Respiratory Surfaces

- Cells that carry out gas exchange must be in contact with aqueous solution, respiratory surfaces are therefore always moist.
- Movement of O_2 and CO_2 across respiratory surfaces takes place entirely by diffusion.
- Rate of diffusion is proportional to the surface area and inversely proportional to the square of the distance through which the gas must diffuse
    - **In other words diffusion is fast when area for diffusion is large and path for diffusion is short!**

Remember* - *Fick's law *considers the way these three factors relate to the rate of diffusion. This law states that:*

the ***rate of diffusion*** *is proportional to*

$$\frac{\textit{surface area} \times \textit{difference in concentration}}{\textit{length of diffusion path}}$$

- Some simple animals like sponges and flatworms have every cell close enough to the external environment for gases to diffuse efficiently.
- Other animals are able to use their skin as a respiratory surface.
  - Earthworms and amphibians have a dense network of capillaries just below the surface of their skin that facilitates gas exchange.
- In most animals the body surface lacks sufficient surface area for gas exchange instead they have evolved special respiratory organs that extensively folded and branched thereby providing sufficient surface area for gas exchange.
  - **Gills, Trachea and Lungs are three such organs!**

Gills in Aquatic Animals

- Gills are outfoldings of the body surfaces that are suspended in the water.
    - they vary considerably, but have far more surface area than the body exterior.
- **Ventilation-** the movement of the respiratory medium over the respiratory surface.
    - To promote ventilation animals either move water over the gills or move gills through the water.

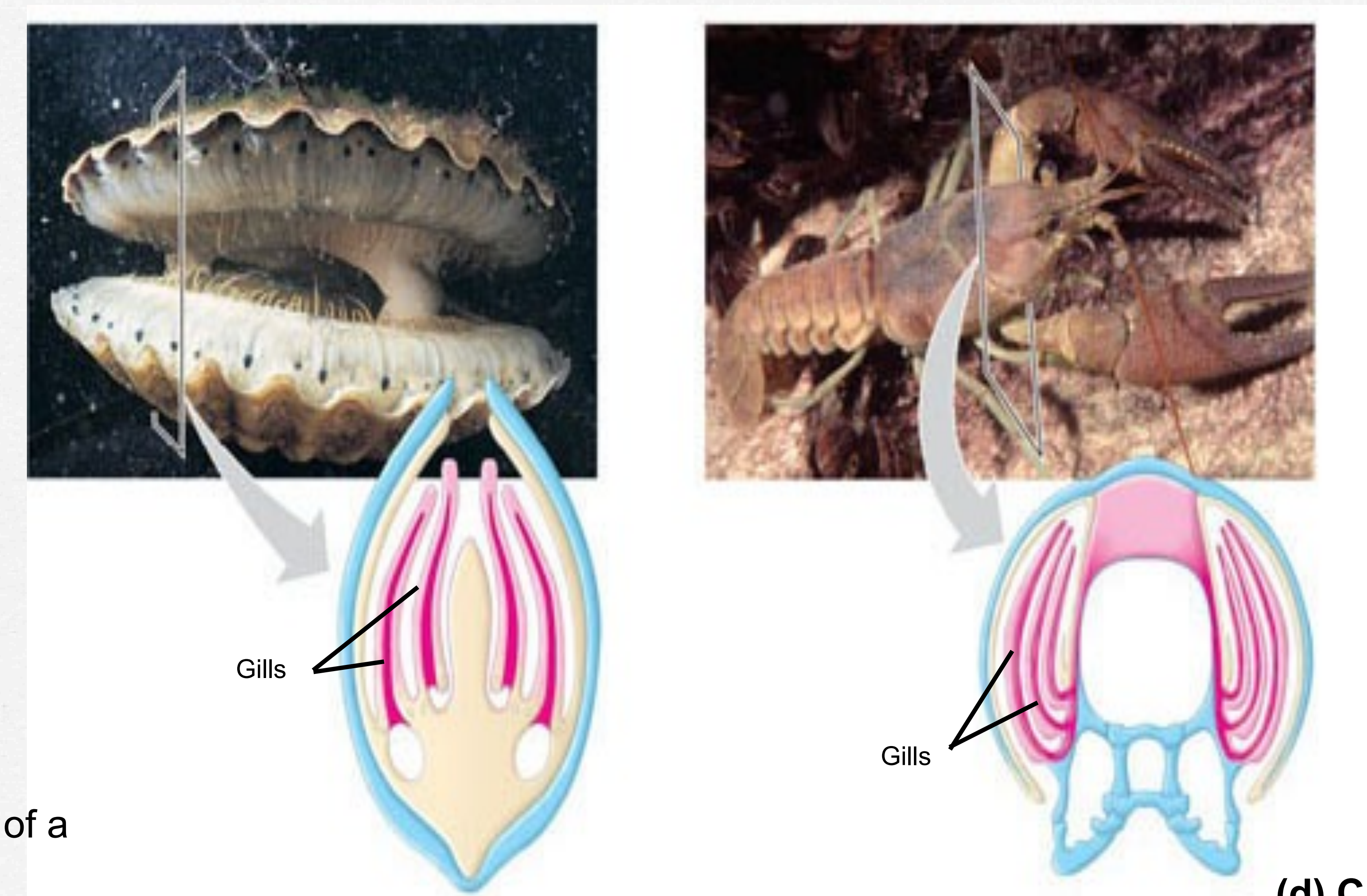
Gills in Aquatic Animals

(a) Sea star. The gills of a sea star are simple tubular projections of the skin. The hollow core of each gill is an extension of the coelom (body cavity). Gas exchange occurs by diffusion across the gill surfaces, and fluid in the coelom circulates in and out of the gills, aiding gas transport. The surfaces of a sea star's tube feet also function in gas exchange.

Gills in Aquatic Animals

(b) Marine worm. Many polychaetes (marine worms of the phylum Annelida) have a pair of flattened appendages called parapodia on each body segment. The parapodia serve as gills and also function in crawling and swimming.

Gills in Aquatic Animals



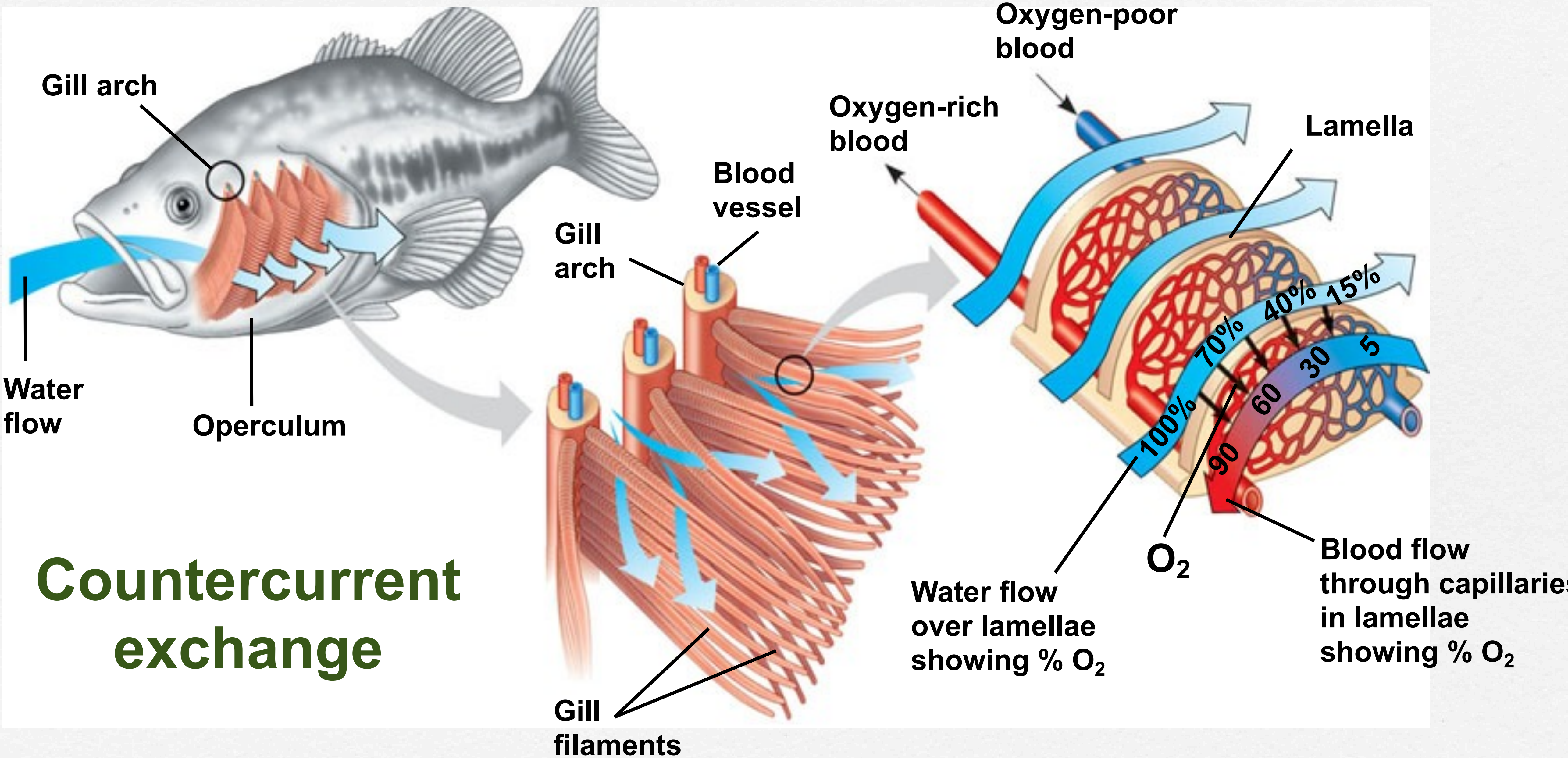
(c) Scallop. The gills of a scallop are long, flattened plates that project from the main body mass inside the hard shell. Cilia on the gills circulate water around the gill surfaces.

(d) Crayfish. Crayfish, other crustaceans have long, feathery gills covered by the exoskeleton. Specialized body appendages drive water over the gill surfaces.

Gills in Aquatic Animals (cont.)

- The arrangement of capillaries in a fish gill allows for counter current exchange.
- **Counter Current Exchange-** the exchange of a substance or heat between two fluids moving in opposite directions. This process maximizes gas exchange efficiency.
  - Over 80% of the oxygen is removed from the water! (human lungs only remove about 25%)
  - Gills are unsuitable for animals living on land, the wet surface would lose far to much water by evaporation

Gills in Aquatic Animals (cont.)



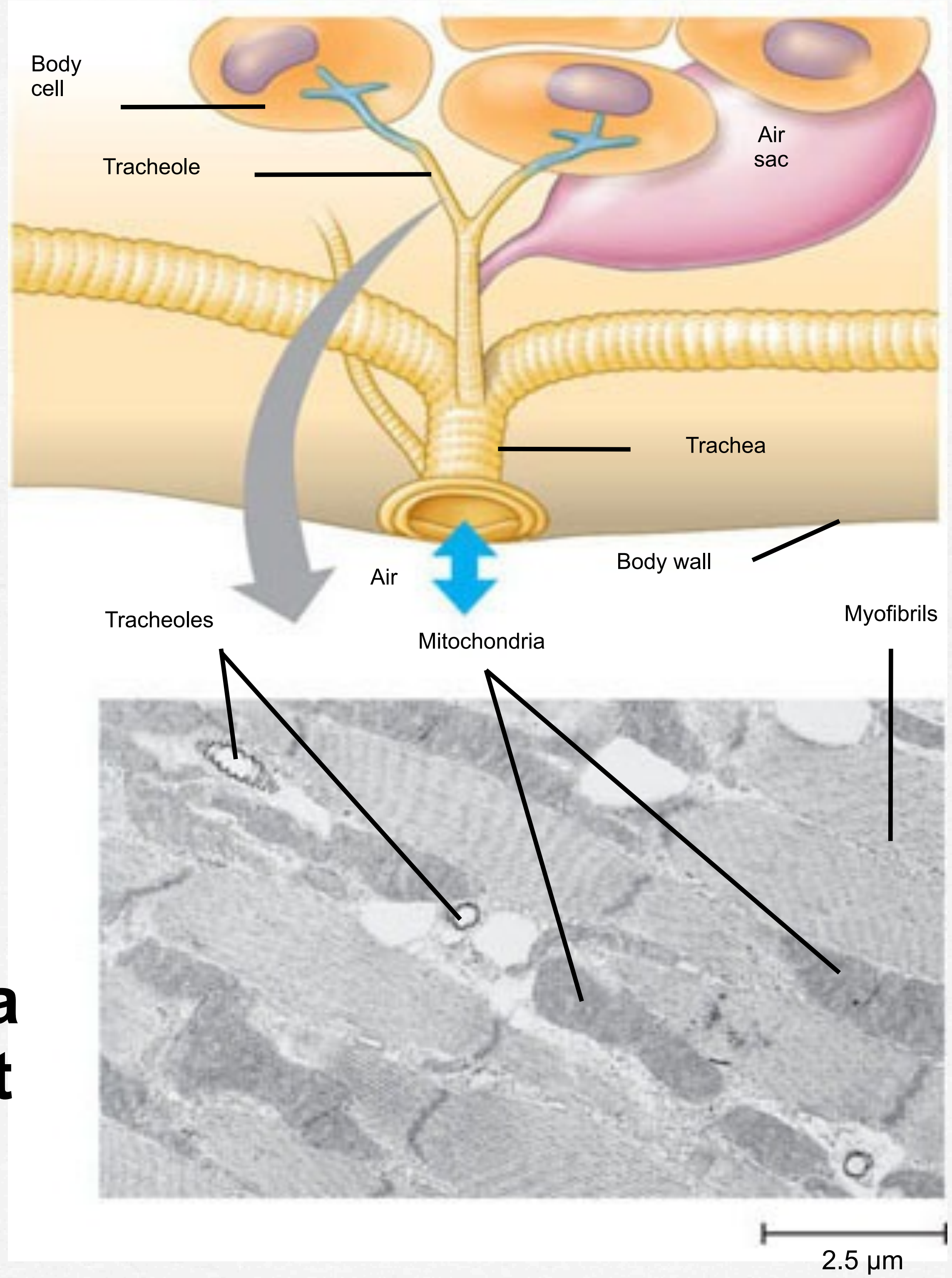
Countercurrent exchange

Higher oxygen gradient is maintained along entire length of capillary

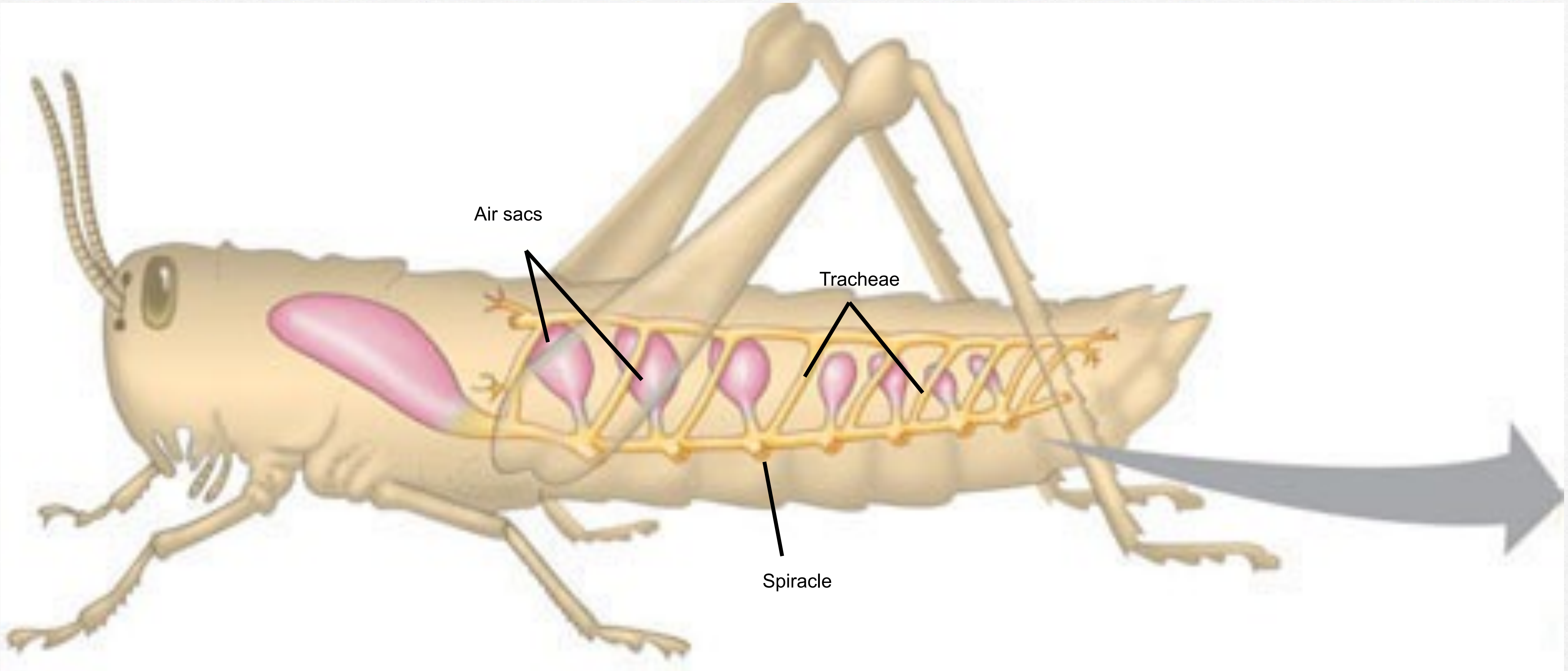
Tracheal Systems in Insects

- The most common respiratory structure is the *tracheal system* found in insects.
- The tracheal system consists of air tubes that branch throughout the body.
- The largest tubes open to the outside environment.
- The smallest tubes extend inward and come in close proximity to every cell of the organism where gas exchange by diffusion occurs.
  - because theses tubes bridge the gap between the outside world and each cell...no circulatory system is required
  - larger insects do however need to use body movements to ventilate these tubes

Tracheal Systems in Insects



This micrograph shows cross sections of tracheoles in a tiny piece of insect flight muscle (TEM). Each of the numerous mitochondria in the muscle cells lies within about 5 µm of a tracheole.

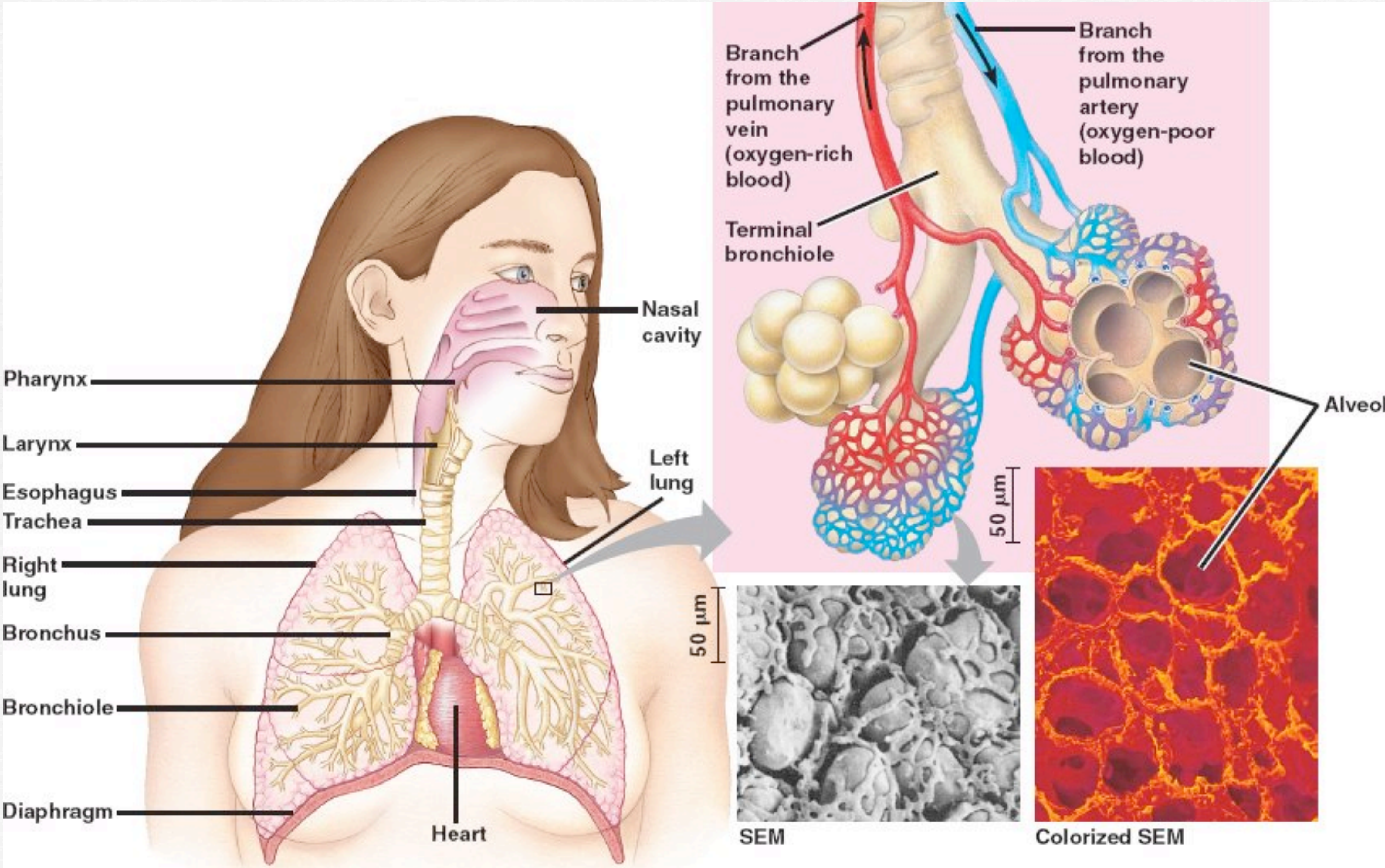


(a) The respiratory system of an insect consists of branched internal tubes that deliver air directly to body cells. Rings of chitin reinforce the largest tubes, called tracheae, keeping them from collapsing. Enlarged portions of tracheae form air sacs near organs that require a large supply of oxygen. Air enters the tracheae through openings called spiracles on the insect's body surface and passes into smaller tubes called tracheoles. The tracheoles are closed and contain fluid (blue-gray). When the animal is active and is using more O_2, most of the fluid is withdrawn into the body. This increases the surface area of air in contact with cells.

Lungs

- **Lungs** do not branch throughout the entire body, instead they are localized infoldings of the body surface
- **Lungs-** are respiratory organs where gas exchange between the outside world and the circulatory system take place.
  - because lungs do not bring gas to every cell the circulatory is required to connect the lungs with all cells of the organism.
  - lungs are found in open circulatory systems such as spiders and snails
  - lungs are found in closed systems as well, all vertebrates that lack gills use lungs instead
    - Variation does exist among lungs!

Mammalian Respiratory System



Breathing Ventilates the Lungs

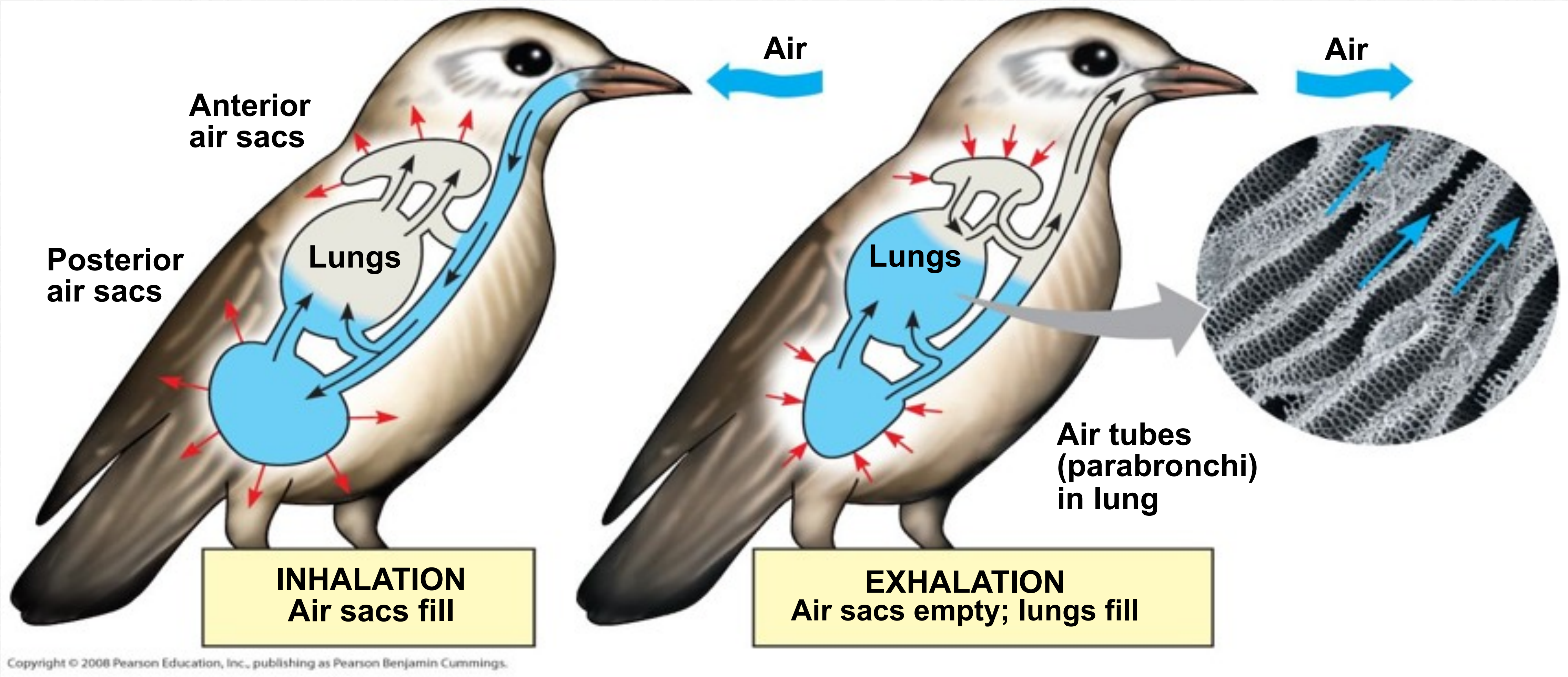
- **Breathing,** the alternating inhalation and exhalation of air, ventilates the lungs.
- *Ventilation* maintains high O_2 and CO_2 concentrations at the gas exchange surface.
    - A variety of breathing mechanisms have evolved!
    - We will explore, amphibian, bird and mammal adaptations

Amphibian Breathing

- Amphibians use **Positive Pressure Breathing,** they inflate their lungs with forced air flow.
  - *1. muscles lower floor of oral cavity*
  - *2. air is drawn in through nostrils*
  - *3. nostrils and mouth close*
  - *4. oral cavity rises*
  - *5. forcing air down trachea*
  - *6. lungs fill with air*
  - *7. elastic lungs recoil forcing air back out*

Bird Breathing

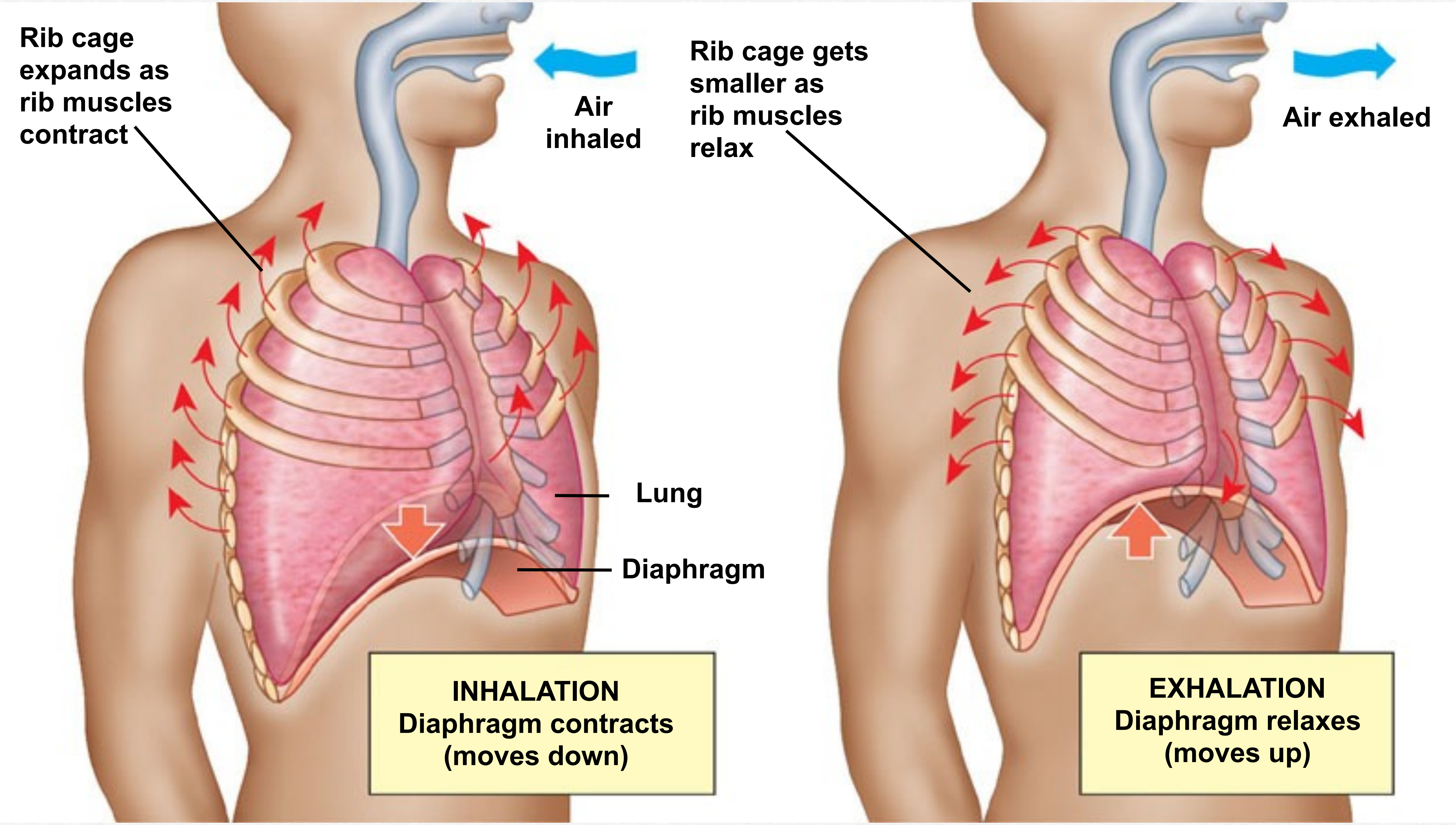
- Bird ventilation is highly efficient.
  - Birds only pass air over the exchange surface in one direction.
  - Incoming fresh air does not mix with outgoing air.



Mammal Breathing

- Mammals use **Negative Pressure Breathing,** they pull rather than push air into their lungs.
    - *1. muscles contract and increase volume of thoracic cavity*
    - *2. as volume increases, pressure drops lower than outside air*
    - *3. air rushes from higher outside pressure to lower inside pressure*
    - *4. air moves through nostrils and mouth, down trachea, to alveoli*
    - *5. muscles relax and decrease volume of thoracic cavity*
    - *6. as volume decreases, pressure rises higher than outside air*
    - *7. air moves out of lungs to outside*
        - **inhalation is active, exhalation is passive*

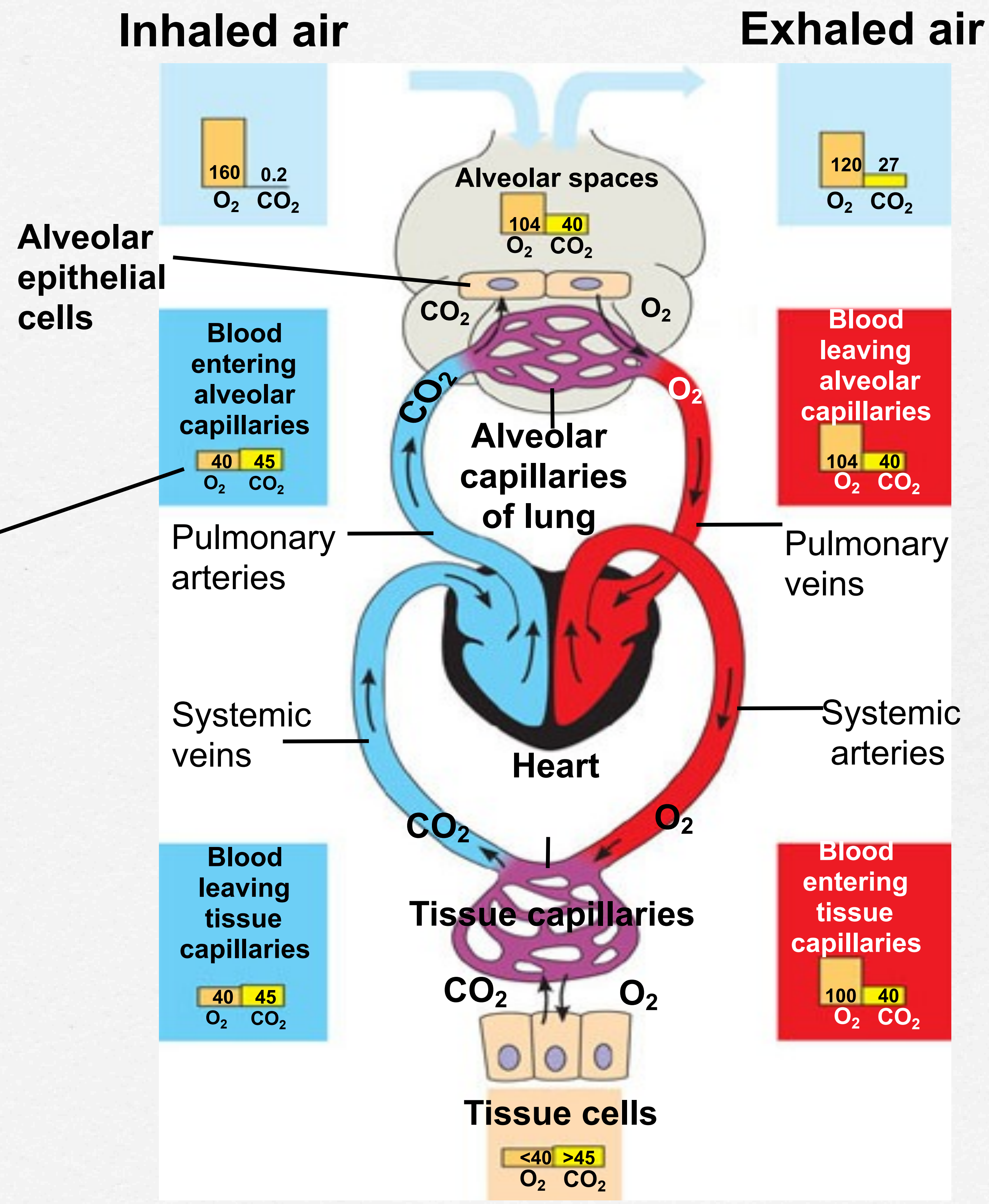
Mammal Breathing



Adaptations for Gas Exchange Include Pigments that Bind and Transport Gases

- High metabolic demands of many animals necessitate large quantities of O_2 and CO_2.
- Respiratory pigments facilitate this exchange through their interaction with O_2 and CO_2.

Coordination of Circulation and Gas Exchange



All numbers in orange and yellow boxes are partial pressures in mm/Hg

Respiratory Pigments

- The low solubility of O_2 in water poses a problem for animals that rely on a circulatory system to deliver oxygen.
  - Case in Point:
    - Human requires 2L of O_2 per minute of intense exercise
    - Only 4.5 ml of O_2 can dissolve into 1L of blood in the lungs (at standard temp and pressure)
    - Without the help of pigments the heart would need to pump 555L of blood per minute!
- **Most animals transport their O_2 bound to proteins called *respiratory pigments*.**

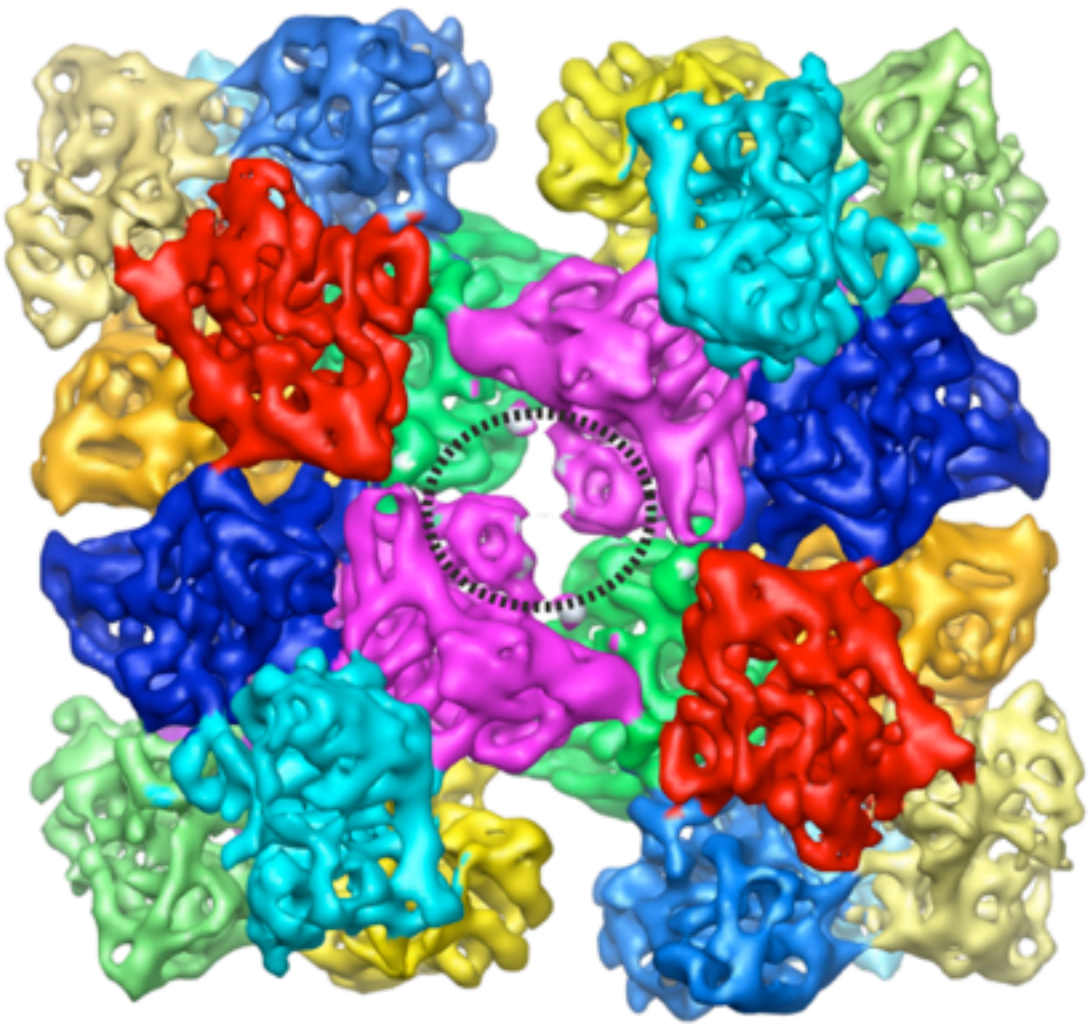
Respiratory Pigments

- ***Respiratory pigments*** greatly increase the amount of O_2 that the circulatory fluid can carry.
  - Same Case in Point: (with pigments)
    - Human requires 2L of O_2 per minute of intense exercise
    - Now 200 ml of O_2 can dissolve into 1L of blood in the lungs (at standard temp and pressure)
    - Without the help of pigments the heart would need to pump 12.5L of blood per minute!
- **A variety of *respiratory pigments* have evolved.**

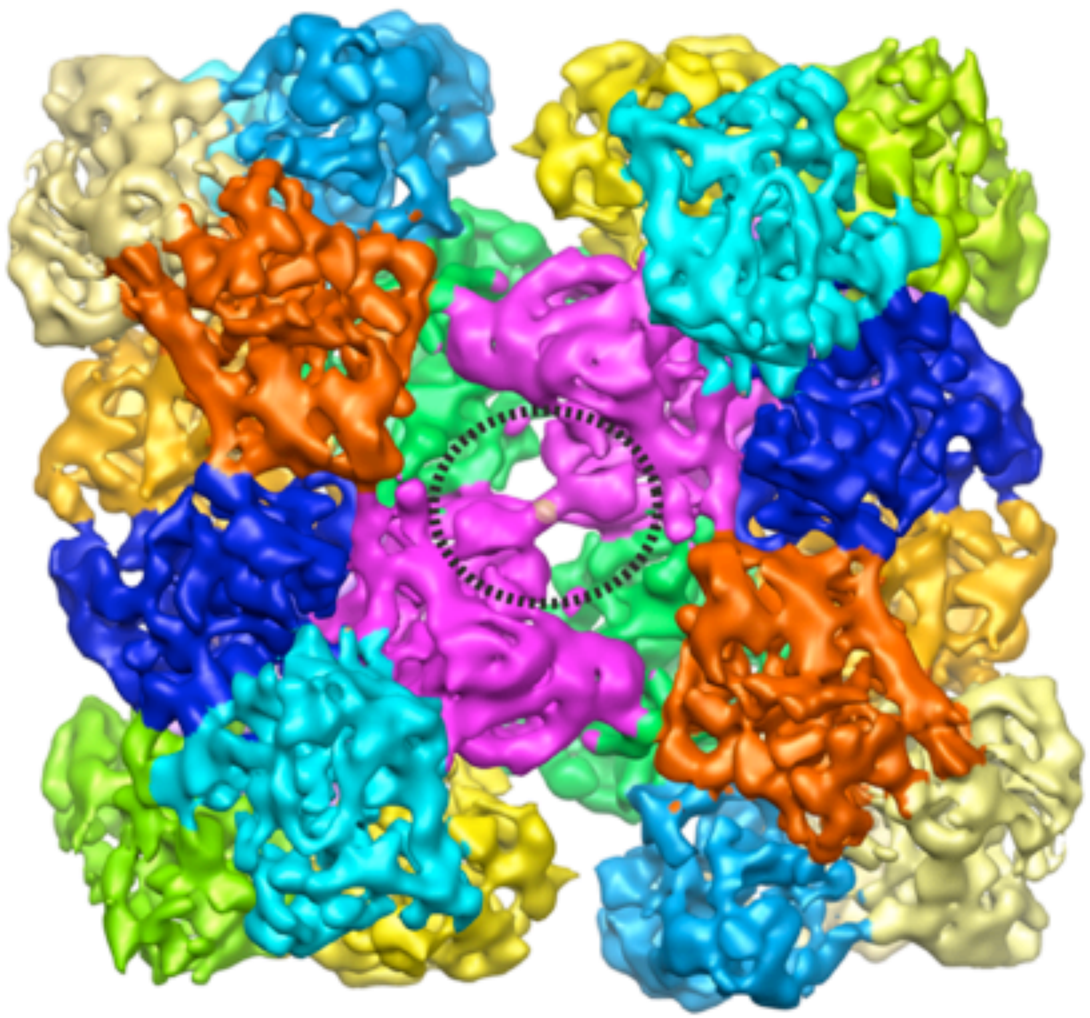
Respiratory Pigments

- ***Hemocyanin;*** a protein with copper molecules that bind oxygen.
  - found in arthropods and mollusks
  - has a distinct blue color
- ***Hemoglobin;*** a protein with 4 subunits with iron molecules that bind oxygen.
  - each subunit has 1 iron molecule that carries 1 oxygen molecule
  - thus 1 hemoglobin protein carries 4 oxygen molecules
  - found in almost all vertebrates and many invertebrates
  - has a red color

Hemocyanin

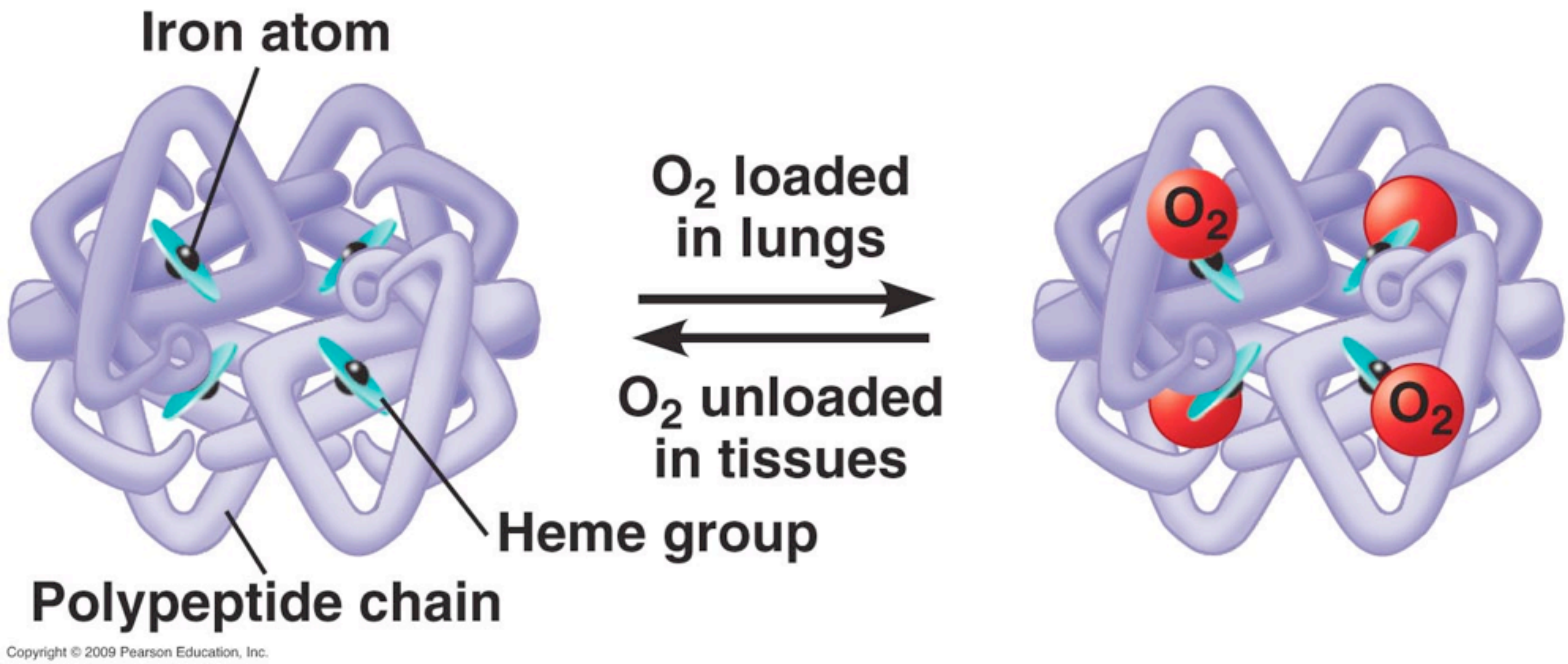


Resting state at 6.8 Å



Activated state at 8 Å

Hemoglobin



Iron atom
O_2 loaded
in lungs
O_2 unloaded
in tissues
Heme group
Polypeptide chain
O_2
O_2
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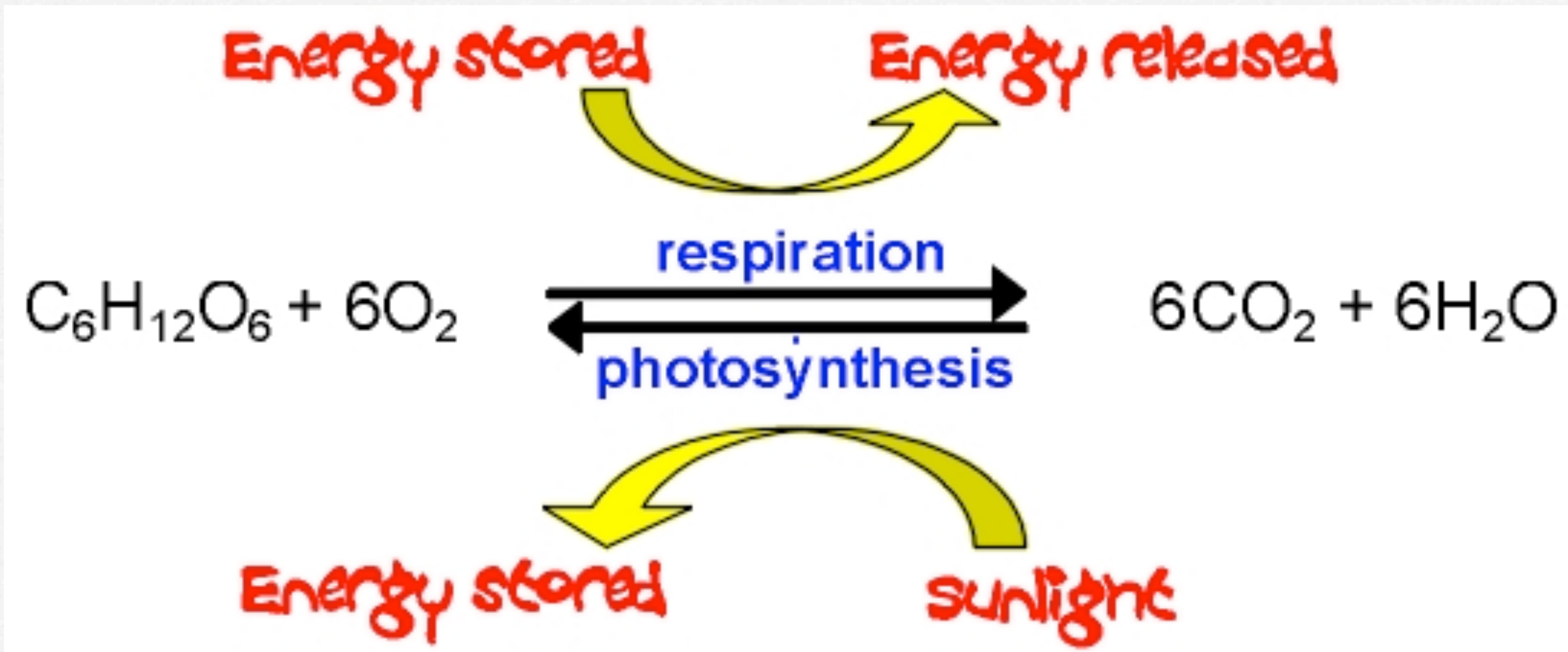
Plants

Gas Exchange

- Every cell exchanges “gases” with its environment.
- Every cell uses ATP as its energy currency or cellular fuel.
- Autotrophs utilizes solar energy to build organic molecules out of carbon dioxide
    - Photosynthesis
- Heterotrophs and autotrophs utilize the chemical energy in organic molecules to produce ATP
    - Cell respiration
- Most eukaryotic cells and some prokaryotic carry out aerobic respiration
    - It is likely that even anaerobic cells exchange some gases
- Both photosynthesis and aerobic cell respiration require the exchange of carbon dioxide and oxygen.

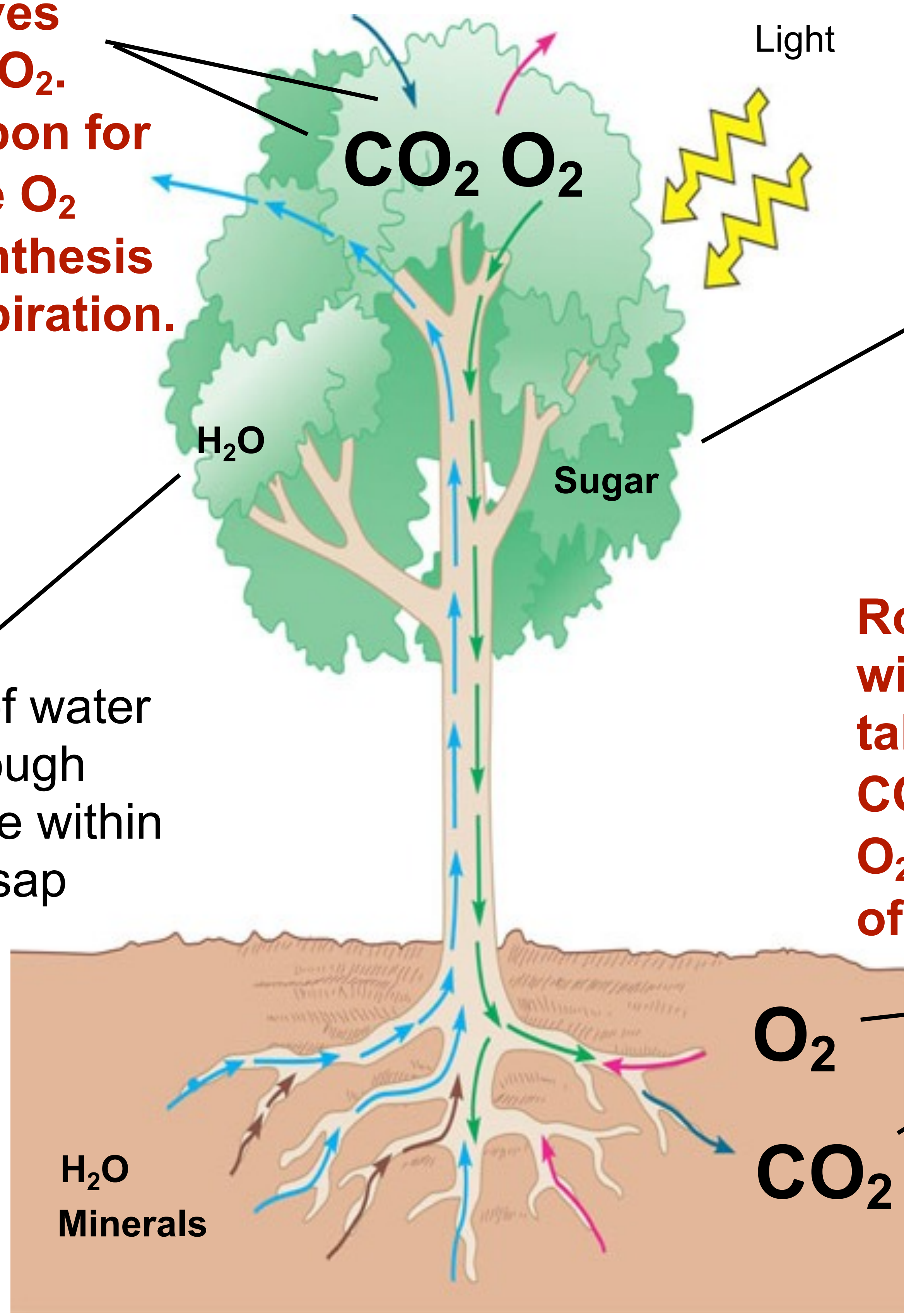
Review: Write down the equations for photosynthesis and cell respiration.



Exam hint – *do not make the elementary but common mistake of saying that plants photosynthesise by day and respire at night. Plants respire all the time.*

Review

Through stomata, leaves take in CO_2 and expel O_2. The CO_2 provides carbon for photosynthesis. Some O_2 produced by photosynthesis is used in cellular respiration.



Sugars are produced by photosynthesis in the leaves.

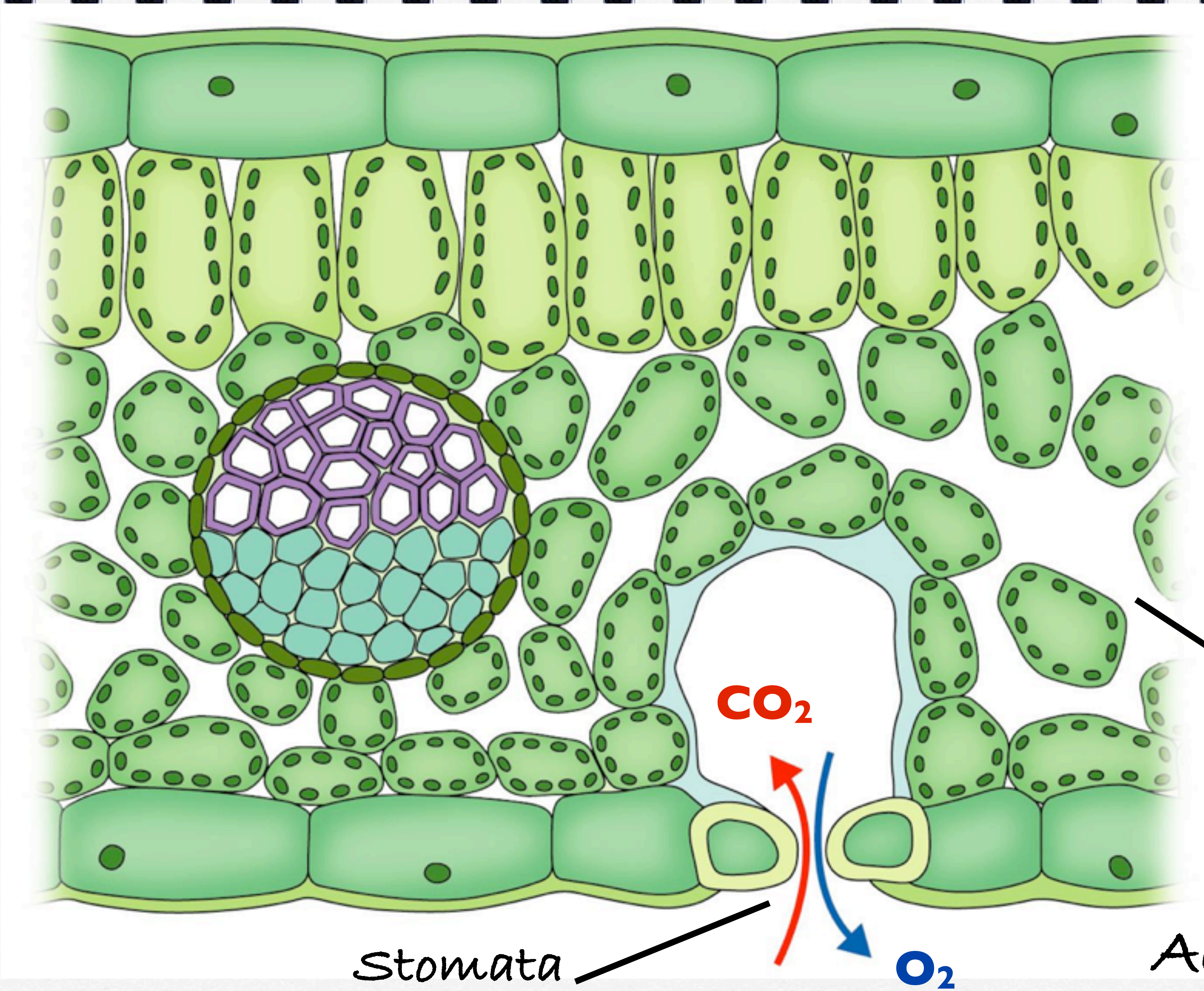
Transpiration, the loss of water from leaves (mostly through stomata), creates a force within leaves that pulls xylem sap upward.

Roots exchange gases with the air spaces of soil, taking in O_2 and discharging CO_2. In cellular respiration, O_2 supports the breakdown of sugars.

Gas Exchange in Plants

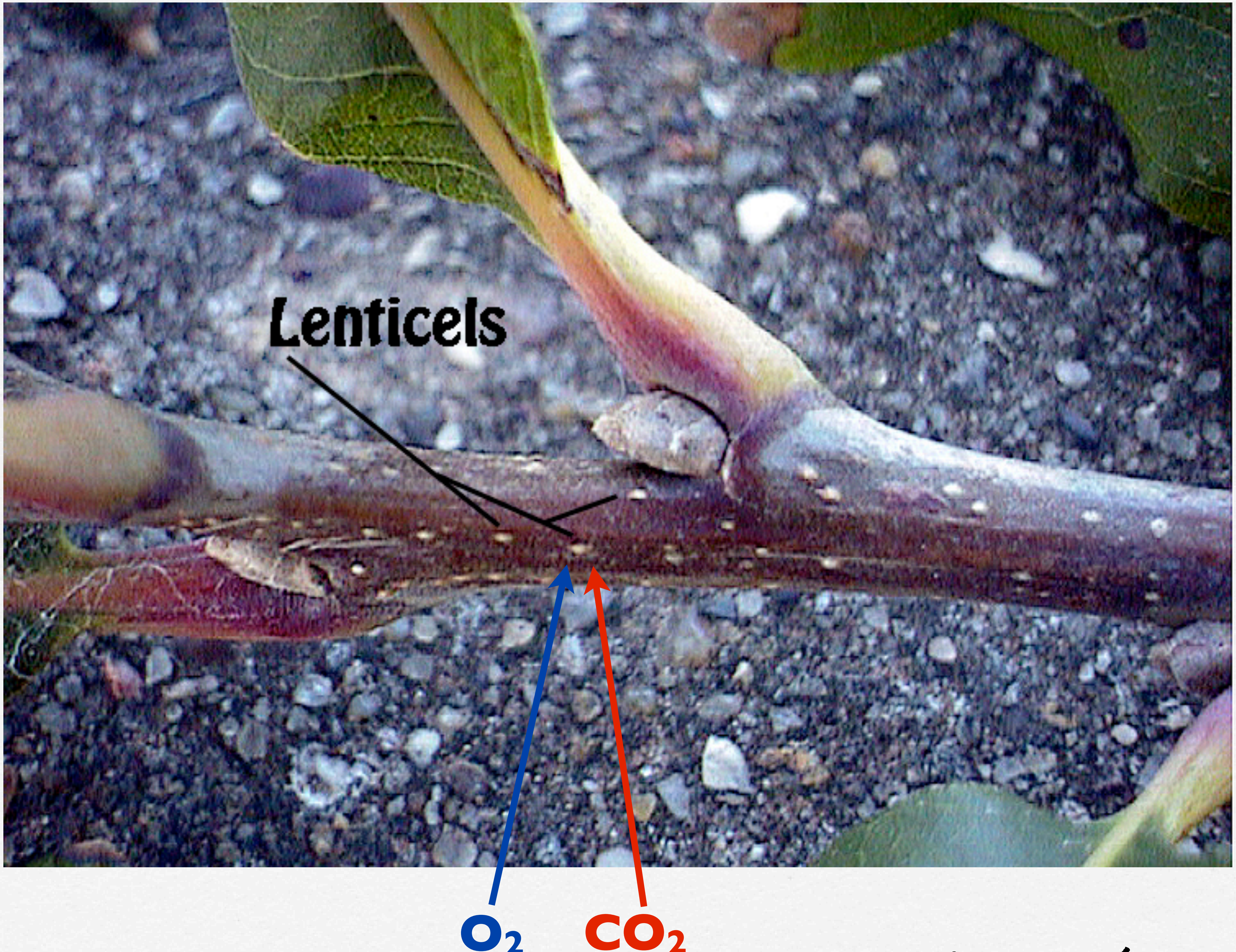
- *Plants have three organs: roots, shoots and leaves.*
- ***Each plant organ takes care of its own gas exchange needs*.**
    - although there is a liquid transport system in plants but it does not transport gases
    - every organ of a plant respires much less than animals, as a result they require much less gas exchange
    - none the less each organ has its own adaptations for gas exchange

Leaf Cross Section



Adaptations

Roots & Shoots

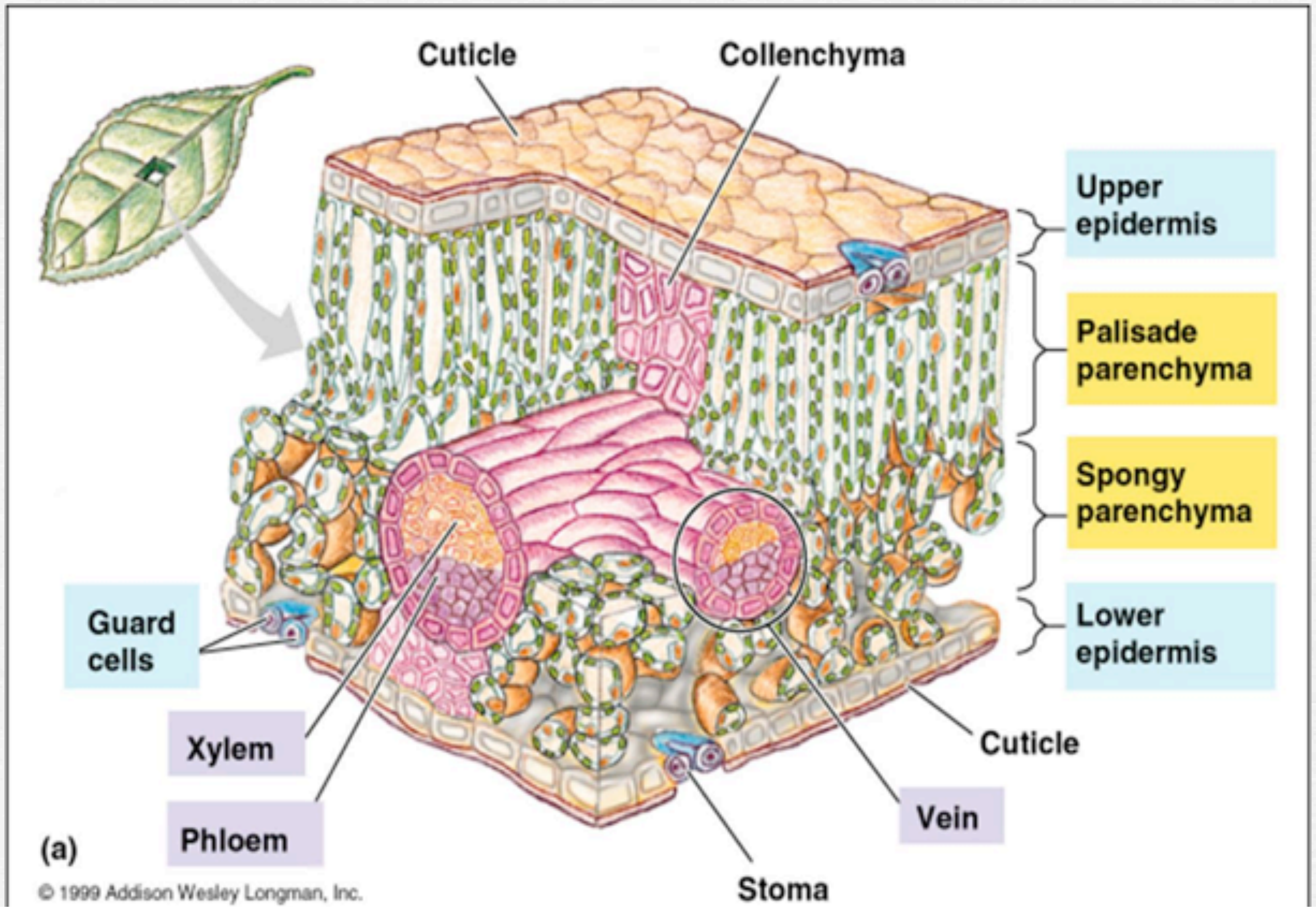


Adaptation... Lenticels

Stomata

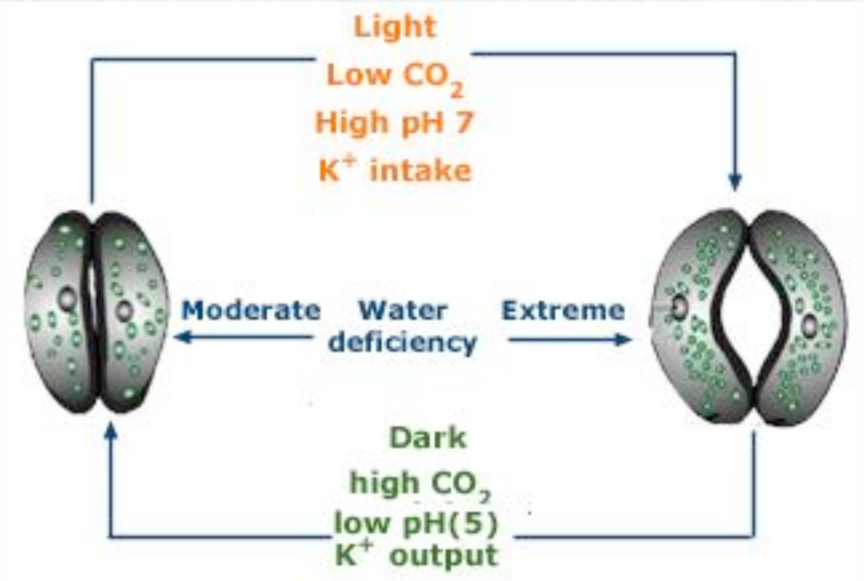
- **Stomata-** *pores on the surface of leaves (sometimes stems).*
- **Stomata-** *function to provide gas exchange between internal tissues and the atmosphere.*
    - usually more are located on the bottom surface of leaves
    - two kidney shaped "guard cells" make up the pore
    - most stomata open in the morning and close at night

For Reference Use



***Remember** – guard cells contain chloroplasts, enabling them to photosynthesise, whereas epidermal cells do not contain chloroplasts. Thus the epidermis is transparent and allows light to reach the mesophyll cells.*

Conditions that affect stomata opening/closing



Time	Osmotic Pressure, lb/in^2
7 A.M.	212
11 A.M.	456
5 P.M.	272
12 midnight	191

Osmotic pressure inside guard cells

Blue light triggers a proton pump

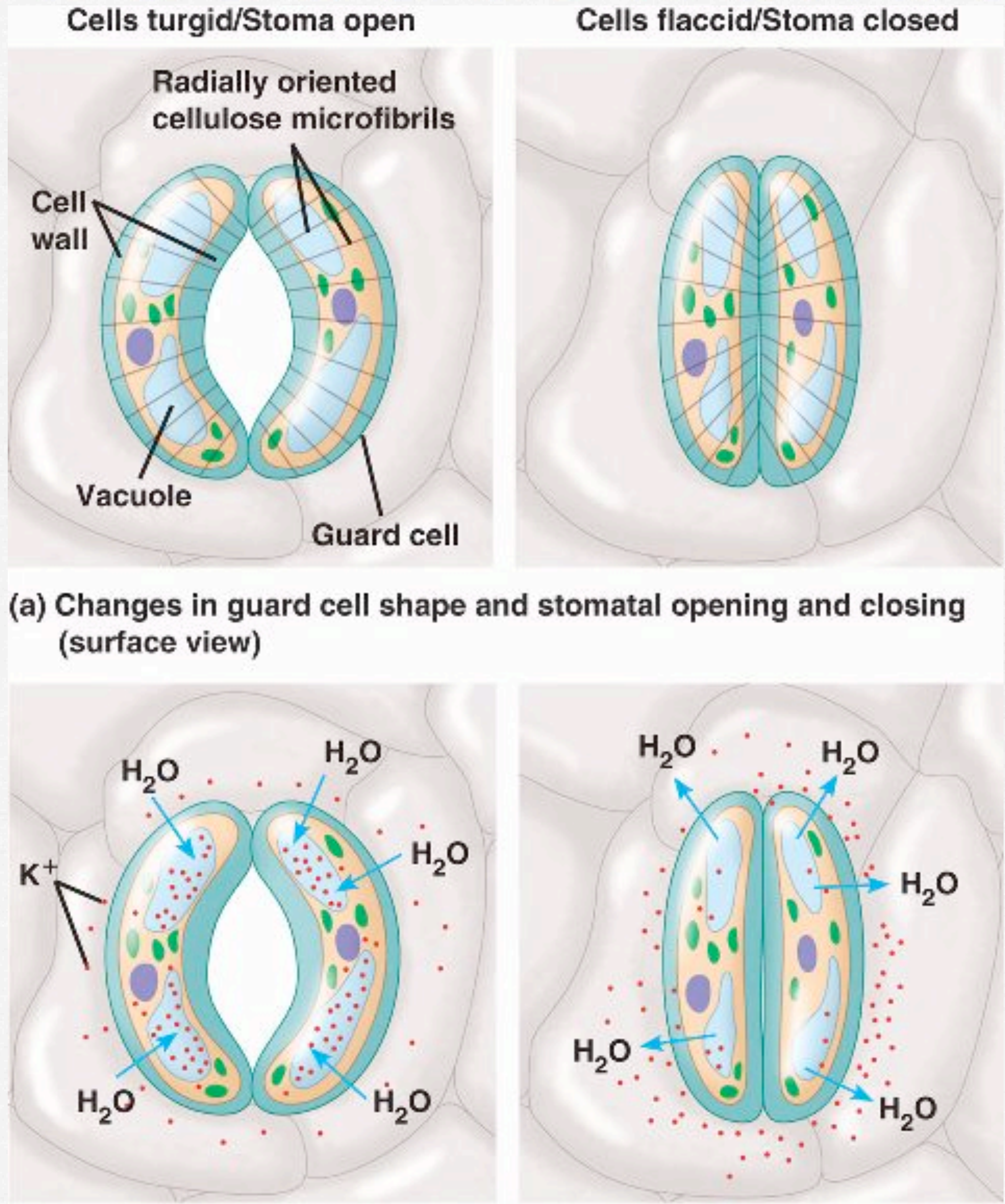
Hydrogen atoms pumped out

Inside becomes negative

Potassium moves in

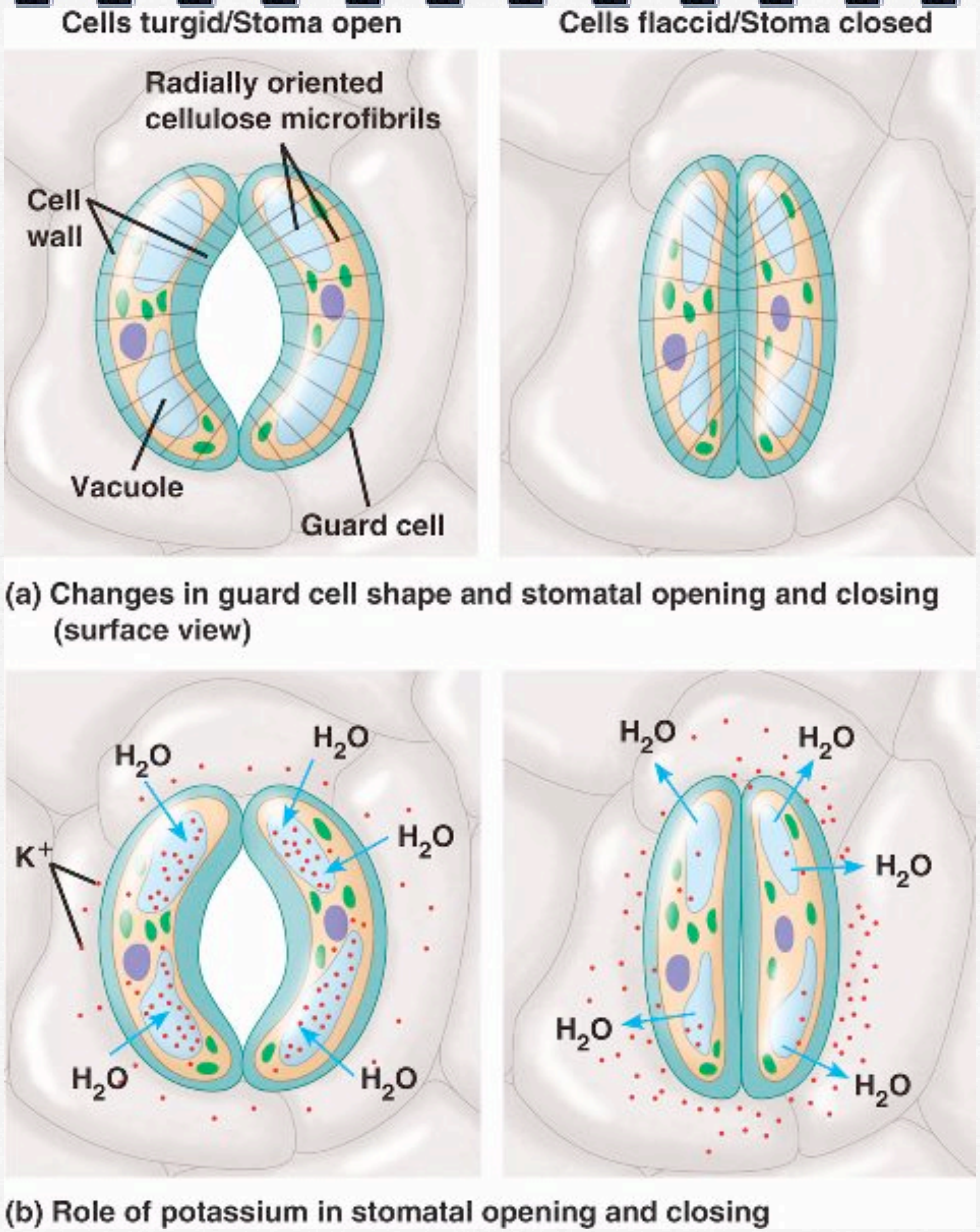
Water follows

Mechanism of stomatal opening →



(a) Changes in guard cell shape and stomatal opening and closing (surface view)

(b) Role of potassium in stomatal opening and closing



(a) Changes in guard cell shape and stomatal opening and closing (surface view)

(b) Role of potassium in stomatal opening and closing

Plant hormone (ABA) binds to guard cell

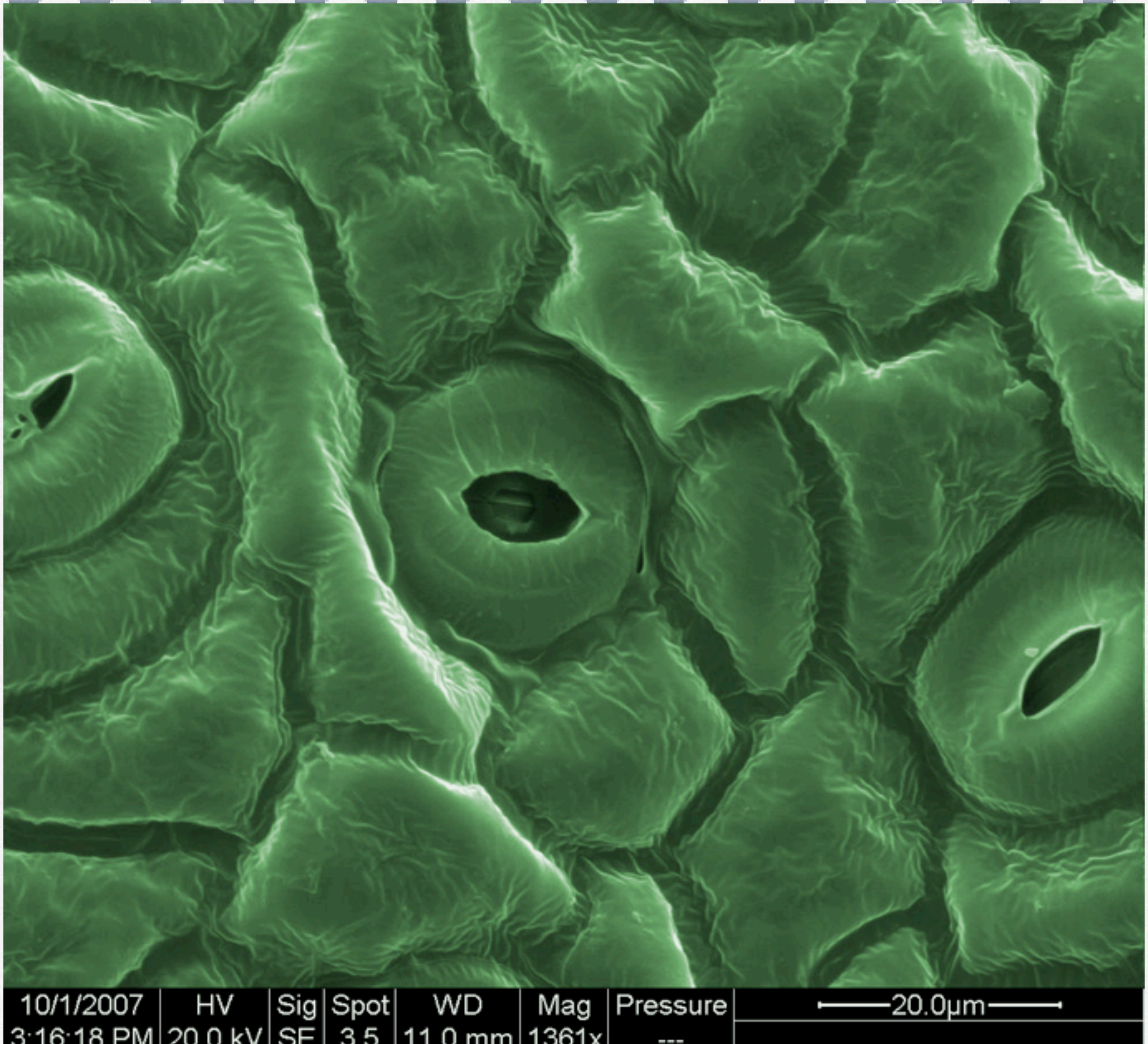
Raises cytosolic pH and Calcium

Negative ions and potassium diffuse out

Osmotic pressure drops

Water leaves guard cell

← Mechanism of stomatal closing

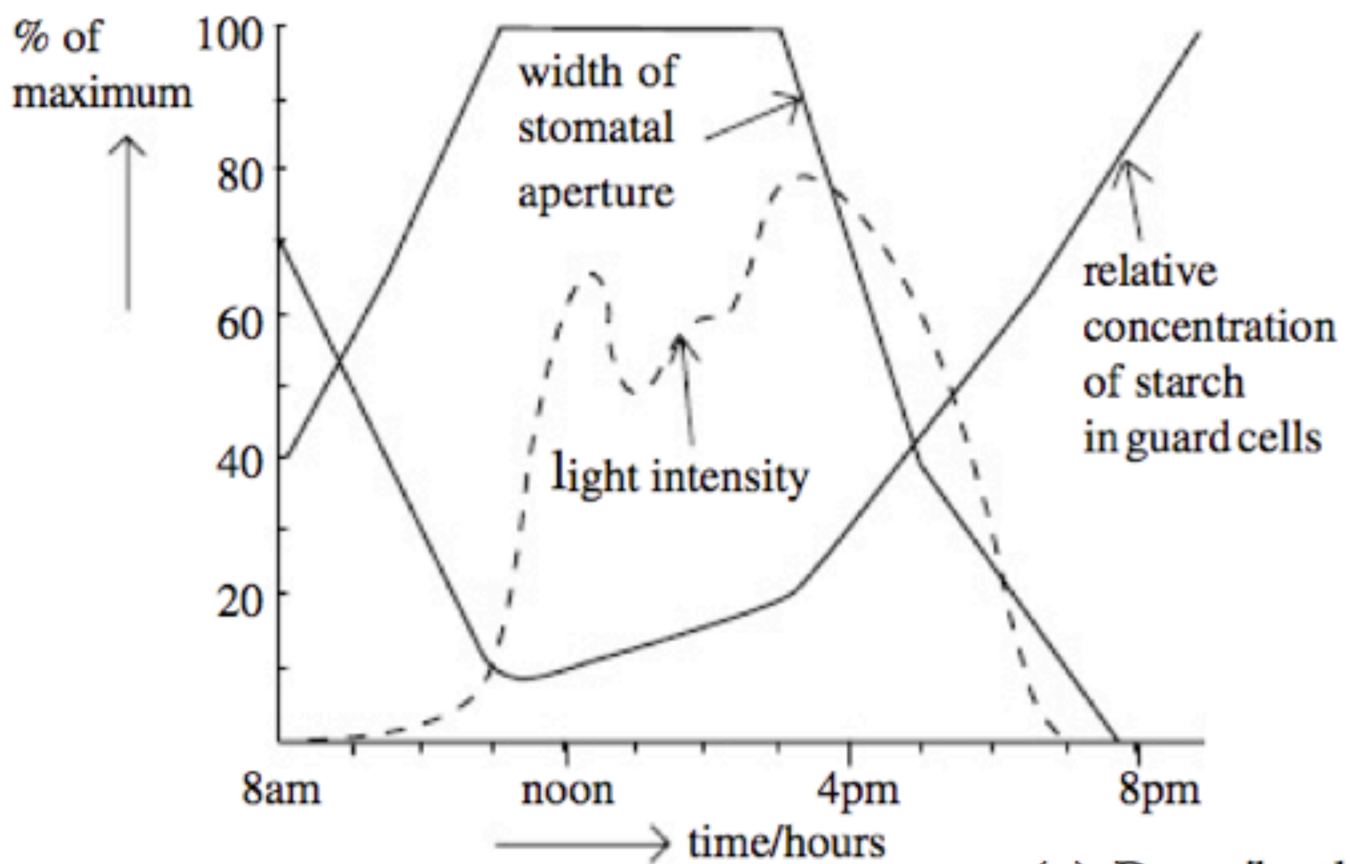

10/1/2007
3:16:18 PM
HV
20.0 kV
Sig
SE
Spot
3.5
WD
11.0 mm
Mag
1361x
Pressure

20.0µm

Stomata

QUESTION

2. The graph below shows results of investigations into the mechanism of stomatal opening.



(a) Describe the relationship between stomatal aperture width and starch concentration.

(i) Between 8.00 am and noon. 1

(ii) Between 4.00 pm and 8.00 pm. 1

(b) (i) Using information from the graph and your own knowledge, suggest a mechanism for stomatal opening. 5

(ii) What is meant by the term inverted stomatal rhythm? 1

Total 8

ANSWER

2. (a) (i) stomatal width increases as starch concentration decreases; 1
(ii) stomatal width decreases as starch concentration increases; 1

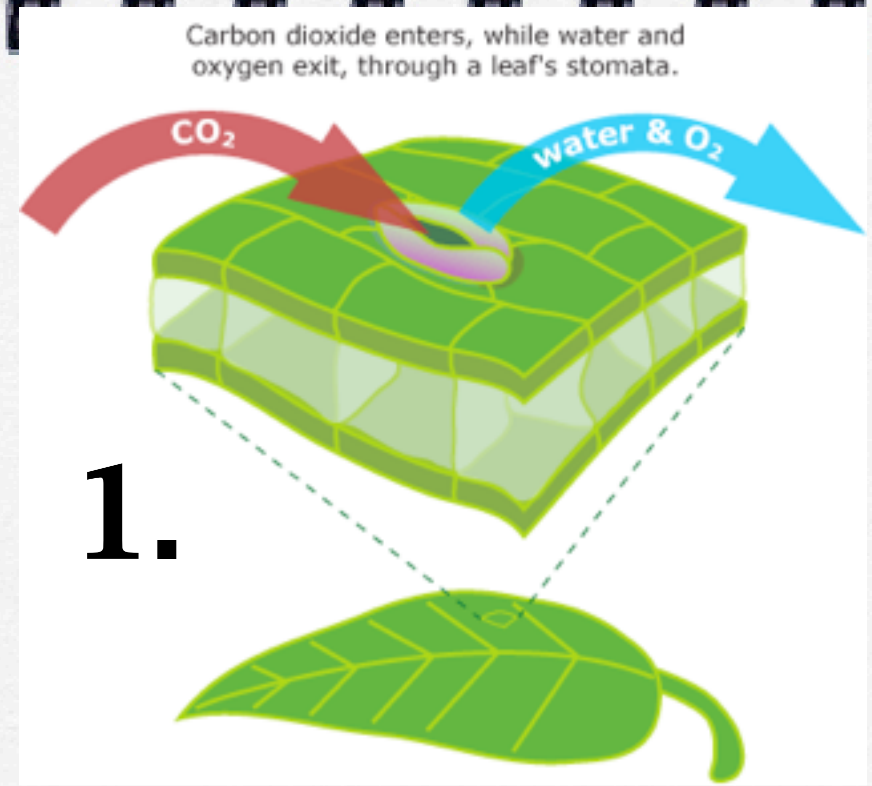
(b) (i) as light intensity increases starch is converted to sugars;
increased sugar concentration reduces water potential of guard cells;
water enters osmotically causing guard cells to swell;
due to uneven guard cell wall thickening the swelling causes the stomatal pore to open;
hydrogen ions also pumped out of guard cell and replaced by uptake of potassium ions;
sugars converted to negative malate ions which neutralise/ balance the positive potassium ions;
accumulation of malate and potassium ions also reduce water potential of guard cells; max 5

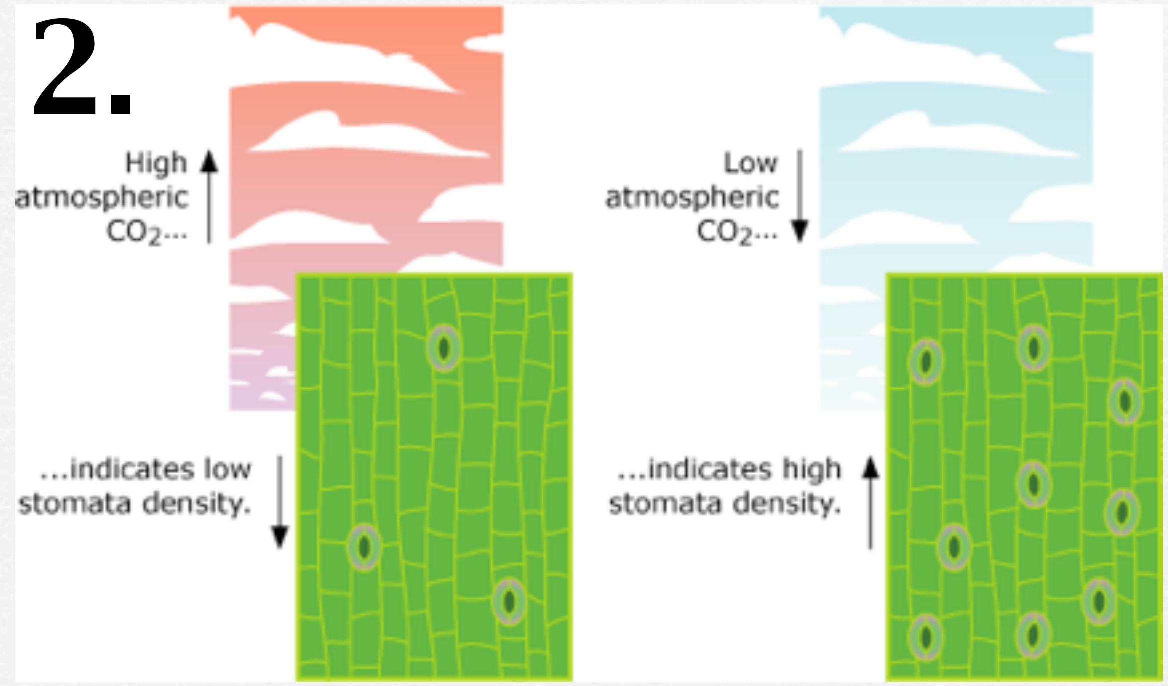
(ii) stomata open at night/closed during day; 1

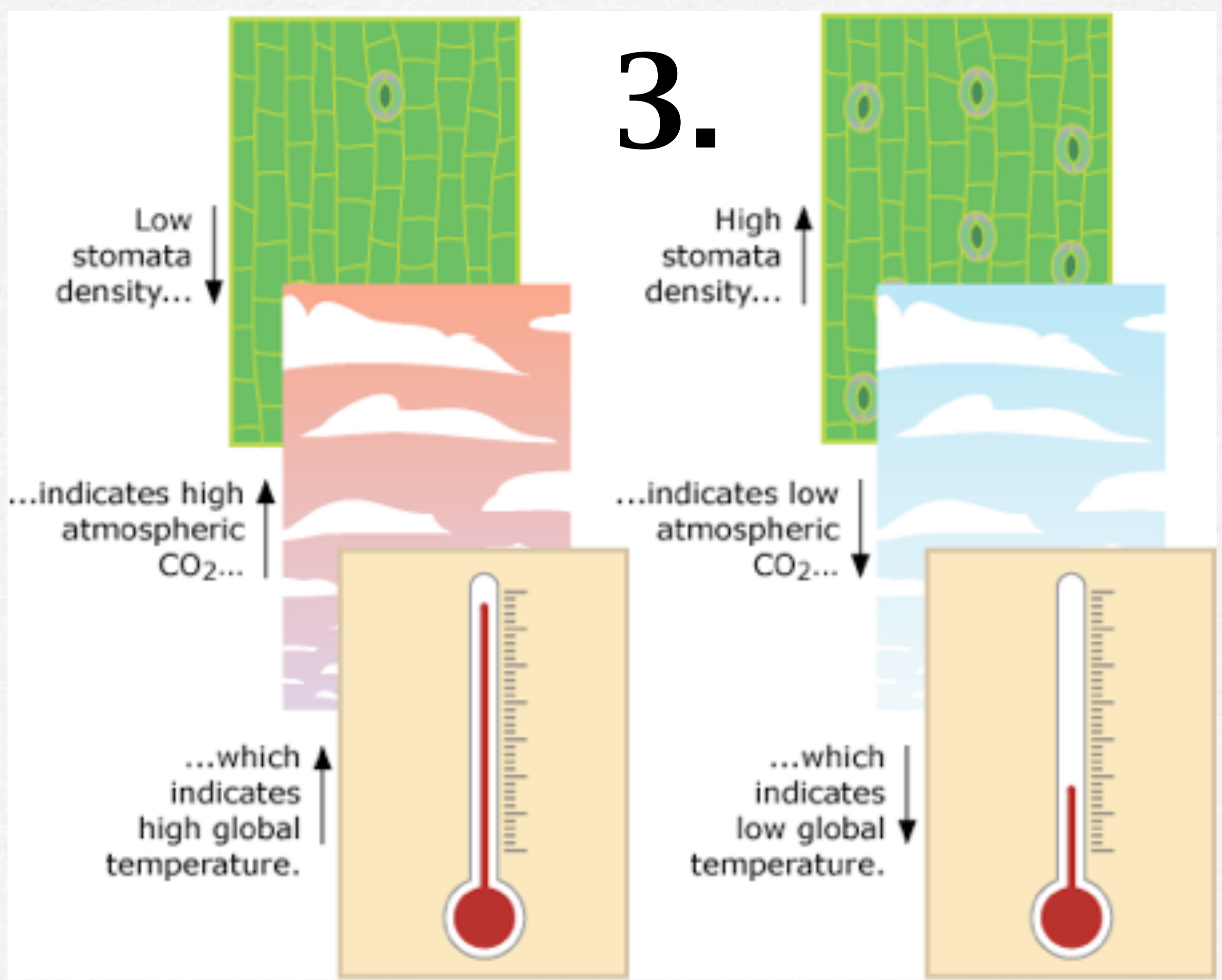
Total 8

Stomatal Density

- The number of stomates can be altered by plant.
- Certain conditions: temperature, humidity, light intensity and the concentration of carbon dioxide affect the density of stomates.
  - The concentration of carbon dioxide and the density of stomates are inversely related.
- The number of stomates on fossilized leaves can tell us about past carbon dioxide levels in the atmosphere.
  - *Stomatal indices were high in the Permian period and Pleistocene epoch both times have geological evidence of low carbon dioxide levels and ice ages.*
  - *Stomatal indices are low for the Cretaceous period, a time of warm climate.*


Carbon dioxide enters, while water and oxygen exit, through a leaf's stomata.
CO_2
water & O_2
1.


2.
High atmospheric CO_2...
...indicates low stomata density.
Low atmospheric CO_2...
...indicates high stomata density.

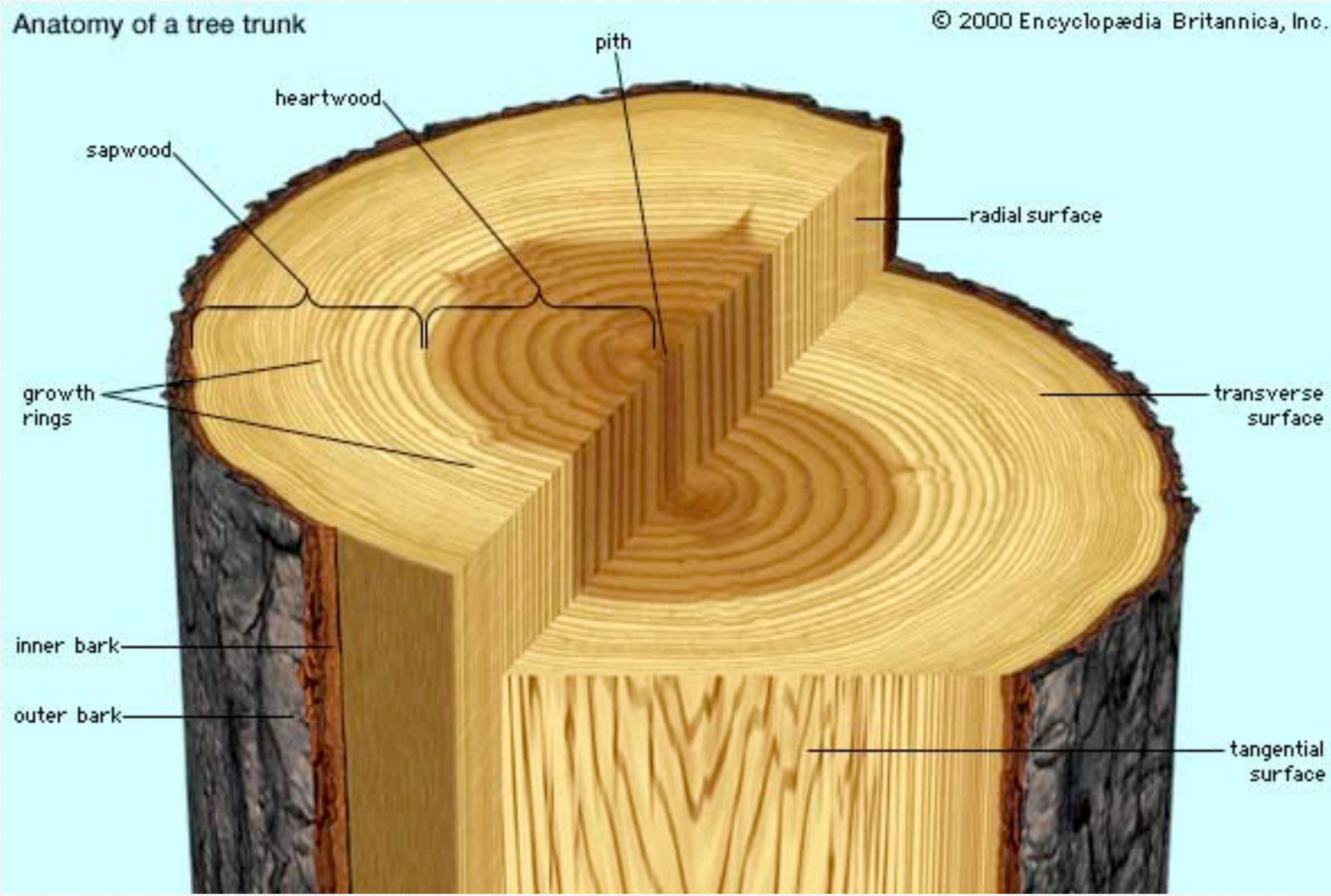

3.
Low stomata density...
...indicates high atmospheric CO_2...
...which indicates high global temperature.
High stomata density...
...indicates low atmospheric CO_2...
...which indicates low global temperature.

Lenticels

- **Lenticels-** *an aggregation of cells that form pores on the surface of stems and roots.*
- **Lenticels-** *function to provide gas exchange between internal tissues and the atmosphere.*
  - lenticel shape is one characteristic used to identify trees
  - annual plants or plants any plant with “green stems” have stomata in their stems instead of lenticels
  - most of the stems and roots have their surface covered with a waxy, waterproof, airproof covering called suberin, but lenticels provide a route for gas exchange

Consider this...

- **The distance that gases must travel in plants is NOT great, even big trees!**
- Should be obvious in flat leaves, but what about stems and roots?
  - The only living cells in stems are located just under the bark, the majority of the stem consists of dead cells only serving as support for the tree.
  - Like leaves the living cells (parenchyma) are loosely packed with air spaces surrounding them
  - Gases can diffuse thousands of times faster through air than liquid.


Anatomy of a tree trunk
© 2000 Encyclopædia Britannica, Inc.
pith
heartwood
sapwood
radial surface
growth rings
transverse surface
inner bark
outer bark
tangential surface


Girdling


Drive Thru Tree

Which tree will die?

Or will neither die?

Or will both die?

WHY?

QUESTION

Practice Questions

1. The equation below represents Fick's Law of diffusion across membranes:

$$J = DA \frac{\Delta c}{\Delta x}$$

where
- J = net rate of diffusion
- D = diffusion constant of the dissolved solute
- A = surface area of the membrane
- Δc = concentration difference across the membrane
- Δx = thickness of the membrane

.

(a) Explain why, with reference to Fick's Law, a typical dicotyledonous leaf favours a high rate of diffusion and an efficient gas exchange. 4

(b) Suggest why lenticels only take up oxygen and give out carbon dioxide. 2

Total 6

ANSWER

Answers

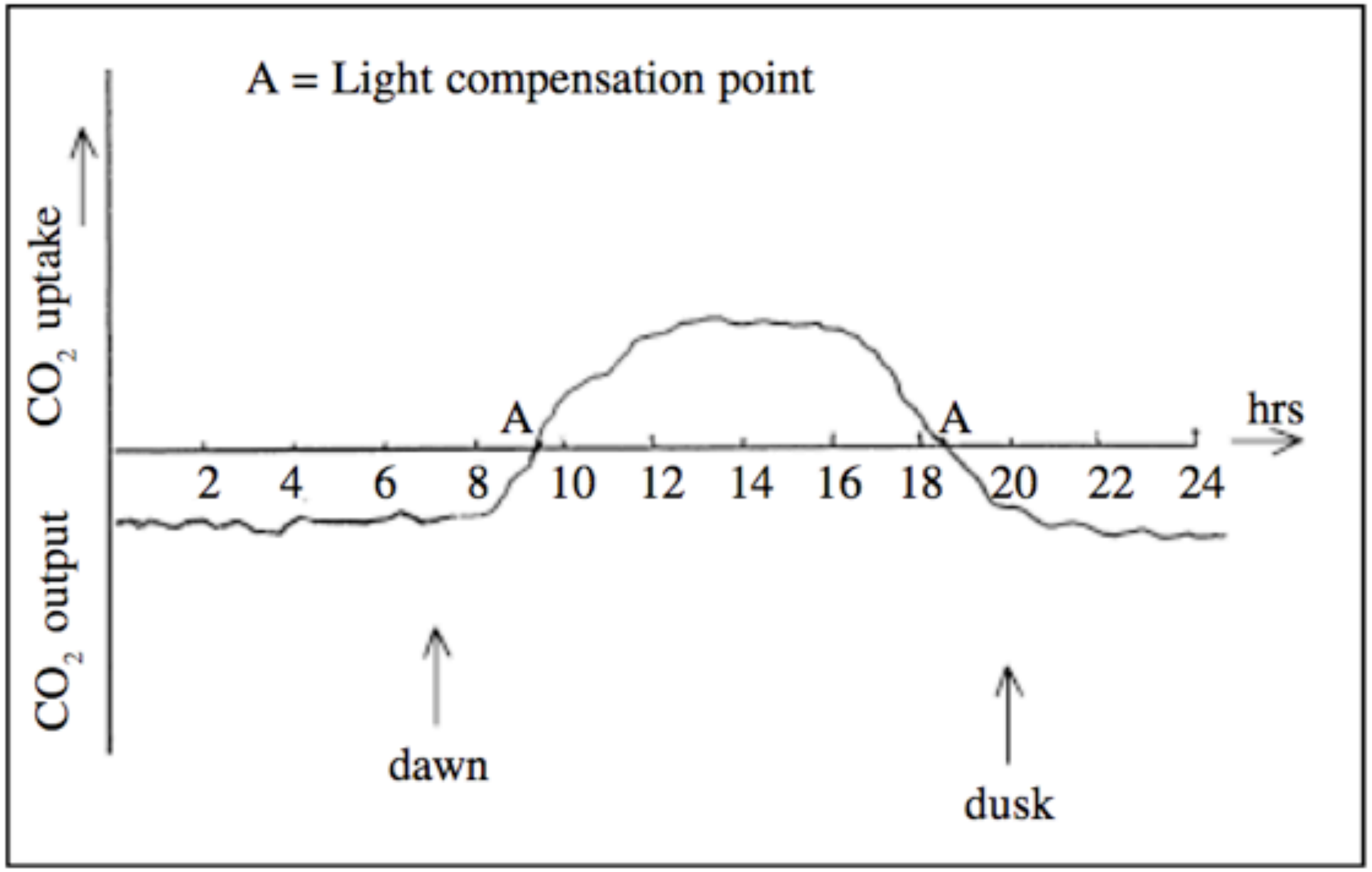
Semi colons indicate marking points.

1. (a) (palisade) mesophyll cells provide a huge surface area for exchange;
   when A is large then J/net rate of diffusion must be large;
   leaf is thin so Δx is small thus J/net rate of diffusion is large;
   if J is large then gas exchange must be fast/ efficient;
   4

   (b) lenticels only occur in (woody) stems which do not photosynthesise/use CO_2;
   but stem tissues do respire and so require oxygen and give out carbon dioxide; 2

   Total 6

Fig 3. Exchange of carbon dioxide by mesophyll cells over a 24 hour period



QUESTION

3. (a) Describe the gas exchange surface in the leaf. 3

(b) How do leaf cells get oxygen when the stomata are closed? 3

(c) Roots absorb some ions by active transport. This requires a supply of respiratory ATP. How do root cells obtain the oxygen essential for this process? 3

Total 9

Answer

3. (a) large surface area of cells (in contact with air spaces);
wet cell surfaces to dissolve gases;
ref to spongy mesophyll and palisade mesophyll; 3

(b) diffuses slowly through cuticle;
and closed stomata;
some oxygen already present in air spaces (as photosynthetic by-product during light); 3

(c) air between soil particles contains oxygen;
oxygen diffuses through the root surface cells/particularly through root hair cells;
cells also obtain oxygen from intercellular air spaces in the root;
3

Total 9

Fungi

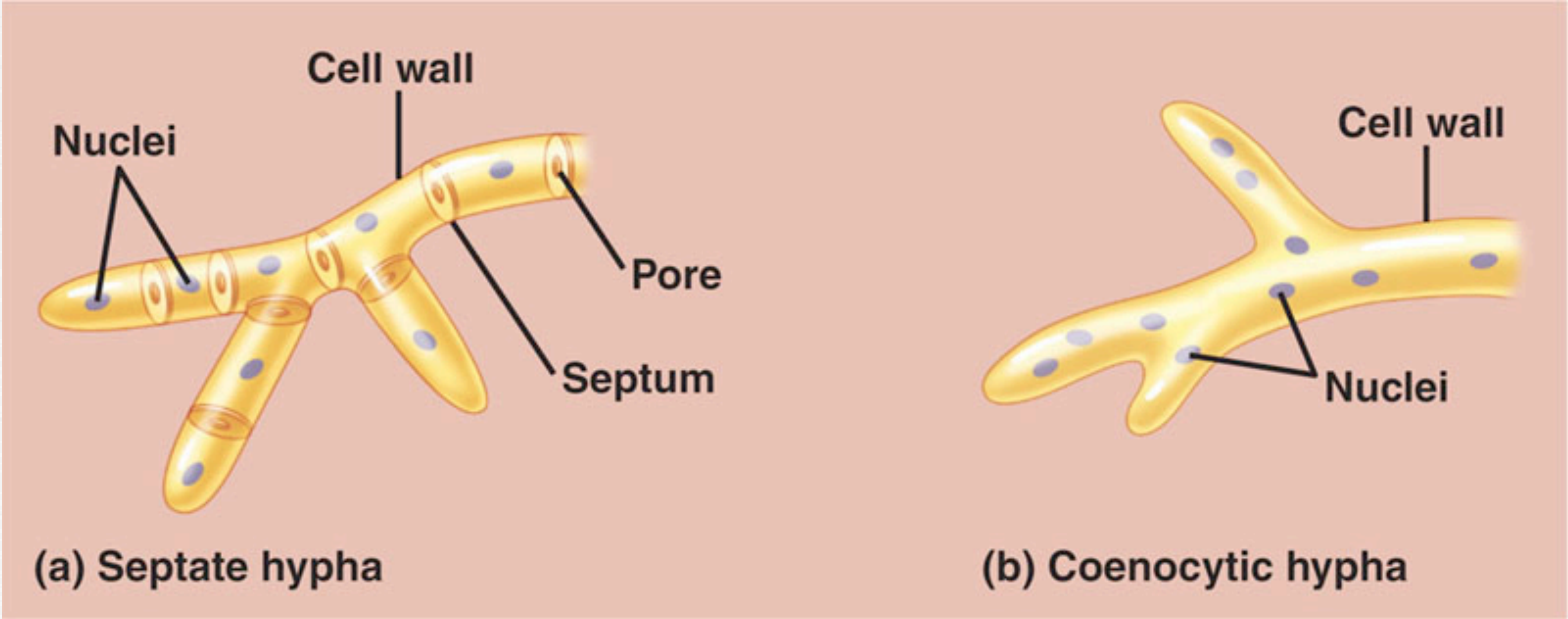
Gas Exchange

- **Every cell exchanges "gases" with its environment.**
- **Every cell uses ATP as its energy currency or cellular fuel.**
- **Autotrophs utilizes solar energy to build organic molecules out of carbon dioxide**
  - **Photosynthesis**
- **Heterotrophs and autotrophs utilize the chemical energy in organic molecules to produce ATP**
  - **Cell respiration**
- **Most eukaryotic cells and some prokaryotic carry out aerobic respiration**
  - **It is likely that even anaerobic cells exchange some gases**
- **Both photosynthesis and aerobic cell respiration require the exchange of carbon dioxide and oxygen.**

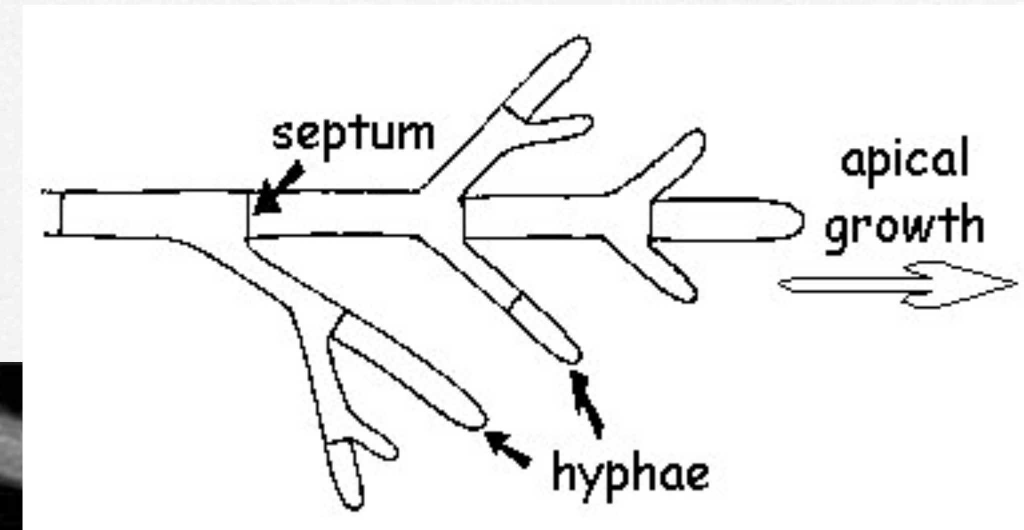
- **Ultimately all life exchanges gas with its environment at the cellular level...the plasma membrane.**
    - **In unicellular organisms, exchange occurs directly with the external environment.**
    - **In multicellular organisms this direct transfer of materials (gas) is not possible.**
    - **Instead MOST multicellular organisms require special systems:**

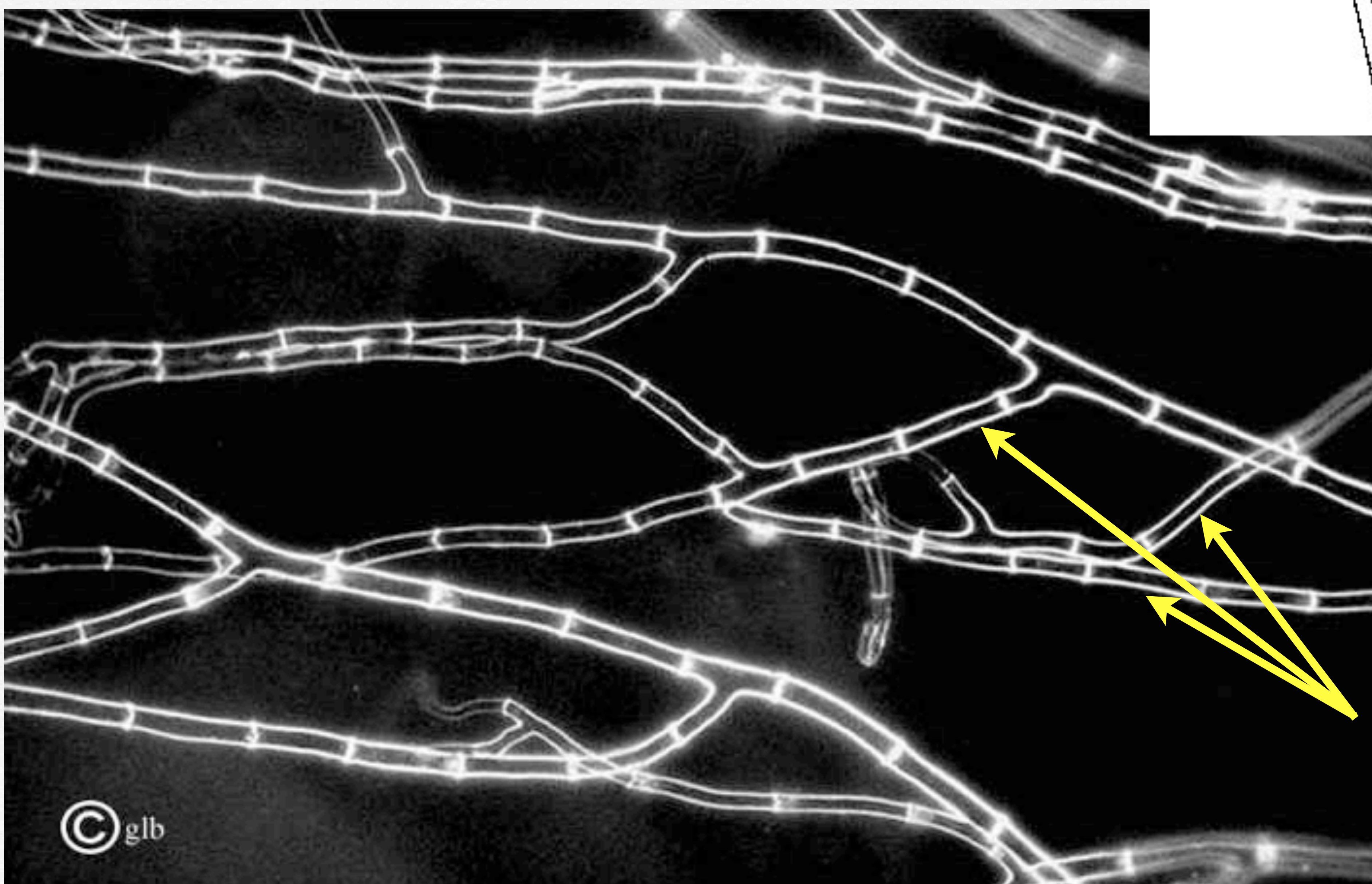
- Strictly speaking fungi are multicellular.
- Fungi do not have circulatory systems or respiratory systems.
- Although they are multicellular organisms the body plan of fungi ensures that every cell is in contact with its environment.

Review



The growth of fungi is longitudinal and branching





Hyphae (cells)

Protists

Gas Exchange

- **Every cell exchanges “gases” with its environment.**
- **Every cell uses ATP as its energy currency or cellular fuel.**
- **Autotrophs utilizes solar energy to build organic molecules out of carbon dioxide**
    - **Photosynthesis**
- **Heterotrophs and autotrophs utilize the chemical energy in organic molecules to produce ATP**
    - **Cell respiration**
- **Most eukaryotic cells and some prokaryotic carry out aerobic respiration**
    - **It is likely that even anaerobic cells exchange some gases**
- **Both photosynthesis and aerobic cell respiration require the exchange of carbon dioxide and oxygen.**

This remains true...

- **Ultimately all life exchanges gas with its environment at the cellular level...the plasma membrane.**
  - **Remember: In most multicellular organisms this direct transfer of materials (gas) is not possible.**
  - **BUT in unicellular organisms, exchange occurs directly with the external environment.**

Protistan Diversity

- Many organisms in this kingdom are unicellular and thus exchange directly with environment.
- Some organisms in this kingdom are *colonial*, meaning they are cells living together and benefiting one another (but unlike a multicellular organism they can separate and live on their own).
  - regardless these cells that make up the colony are arranged in a manner that allows them to directly exchange with their environment.
- Yet other organisms in this kingdom are *multicellular*, who exchange gases in similar ways as a plant or fungi would.

Bacteria

Gas Exchange

This remains true...

- **Ultimately all life exchanges gas with its environment at the cellular level...the plasma membrane.**
  - **Remember: In most multicellular organisms this direct transfer of materials (gas) is not possible.**
  - **BUT in unicellular organisms, exchange occurs directly with the external environment.**

- **Every cell exchanges “gases” with its environment.**
- **Every cell uses ATP as its energy currency or cellular fuel.**
- **Autotrophs utilizes solar energy to build organic molecules out of carbon dioxide**
  - **Photosynthesis**
- **Heterotrophs and autotrophs utilize the chemical energy in organic molecules to produce ATP**
  - **Cell respiration**
- **Most** eukaryotic cells and **some** prokaryotic carry out aerobic respiration
  - It is likely that even anaerobic cells exchange some gases
- Both photosynthesis and aerobic cell respiration require the exchange of carbon dioxide and oxygen.

- **Not all bacteria require oxygen!**
- **Every cell uses ATP as its energy currency or cellular fuel.**
- **But not all ATP production requires oxygen.**
- **Aerobic cell respiration utilizes the chemical energy in organic molecules to produce ATP and it requires oxygen to do so.**
  - **this type of respiration generates the most ATP and most cells require much ATP, thus they depend on oxygen**
- **Anaerobic Cell Respiration and Fermentation utilize the chemical energy in organic molecules to produce ATP and BUT they do not require oxygen to do so.**
  - **these mechanisms generate much less ATP, but some cells (bacteria) do require much ATP, thus they do not require oxygen**

Respiration and Fermentation

- Both Aerobic and Anaerobic Respiration harvest chemical energy from organic molecules and produce ATP
  - BOTH REQUIRE membranes and oxygen (or some other electron acceptor)
    - (they also need proton gradients, electron carriers, electron acceptors and ATP synthase enzymes)
- Fermentation also harvests chemical energy from organic molecules and produces ATP
  - But DOES NOT REQUIRE membranes and oxygen

Respiration: Aerobic vs. Anaerobic

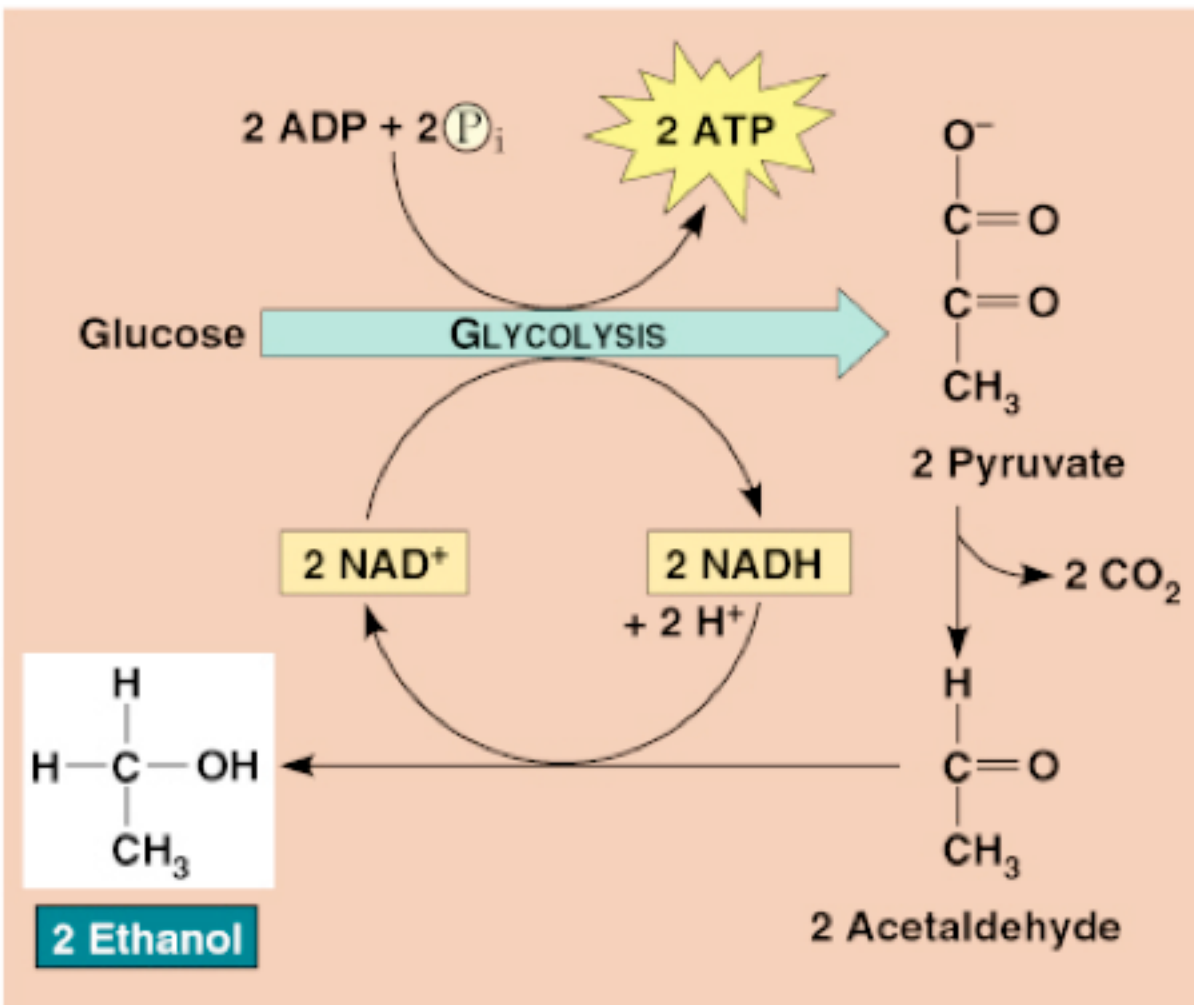
- Aerobic and Anaerobic Respiration utilize membranes, proton gradients, electron carriers, electron acceptors and ATP synthase enzymes.
- In aerobic respiration oxygen serves as the final electron acceptor in the electron transport chain and integral component in respiration.
  - **Aerobic Respiration requires oxygen.**
- In anaerobic respiration a molecule other than oxygen serves as the final electron acceptor in the electron transport chain.
  - **Anaerobic Respiration does not require oxygen.**

Fermentation

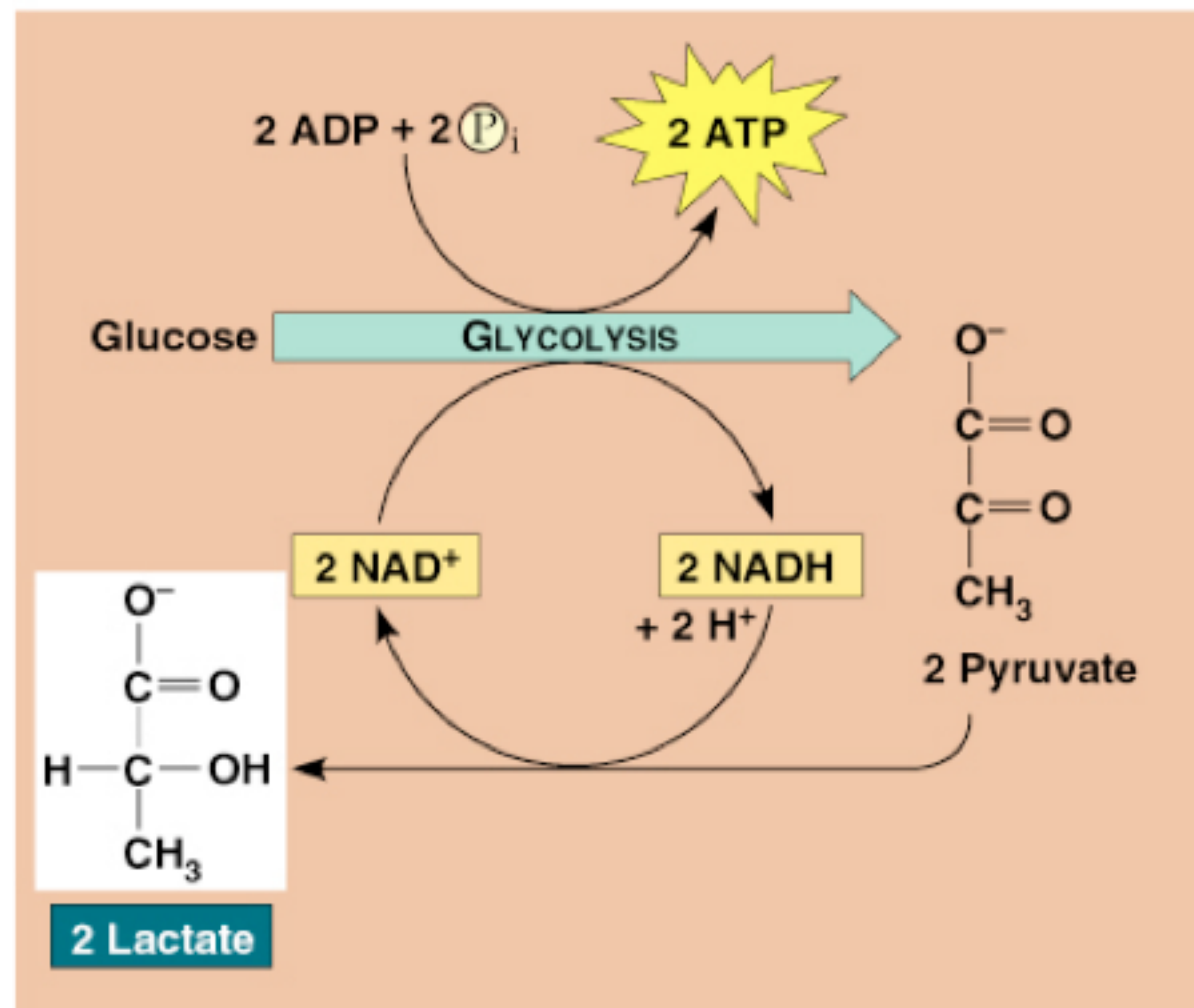
- Fermentation, Aerobic Respiration and Anaerobic Respiration all three breakdown organic molecules into a 3 carbon compound called pyruvate, produce 2 ATP and harvest electrons (this called Glycolysis).
- Technically the difference lies in the fate of these electrons, but we will learn about this later.
- When electrons are carried away to an electron transport chain we call that mechanism respiration.
- When electrons are transferred to another organic molecule we call that fermentation.
- **Fermentation is special type of glycolysis neither requires oxygen!**

Types of Fermentation

- Two common types include alcohol fermentation and lactic acid fermentation.



(a) Alcohol fermentation



(b) Lactic acid fermentation

Types of Fermentation

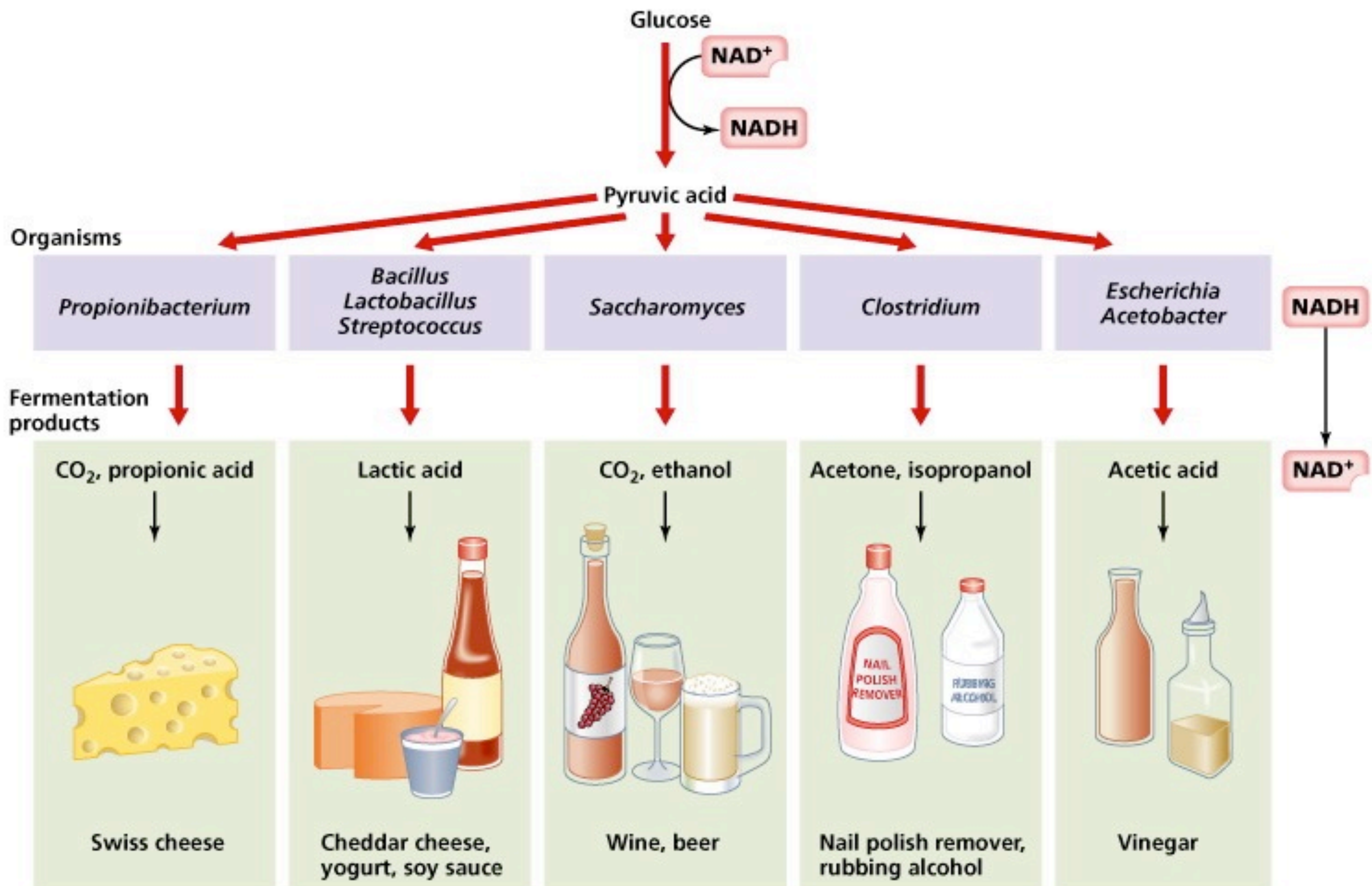
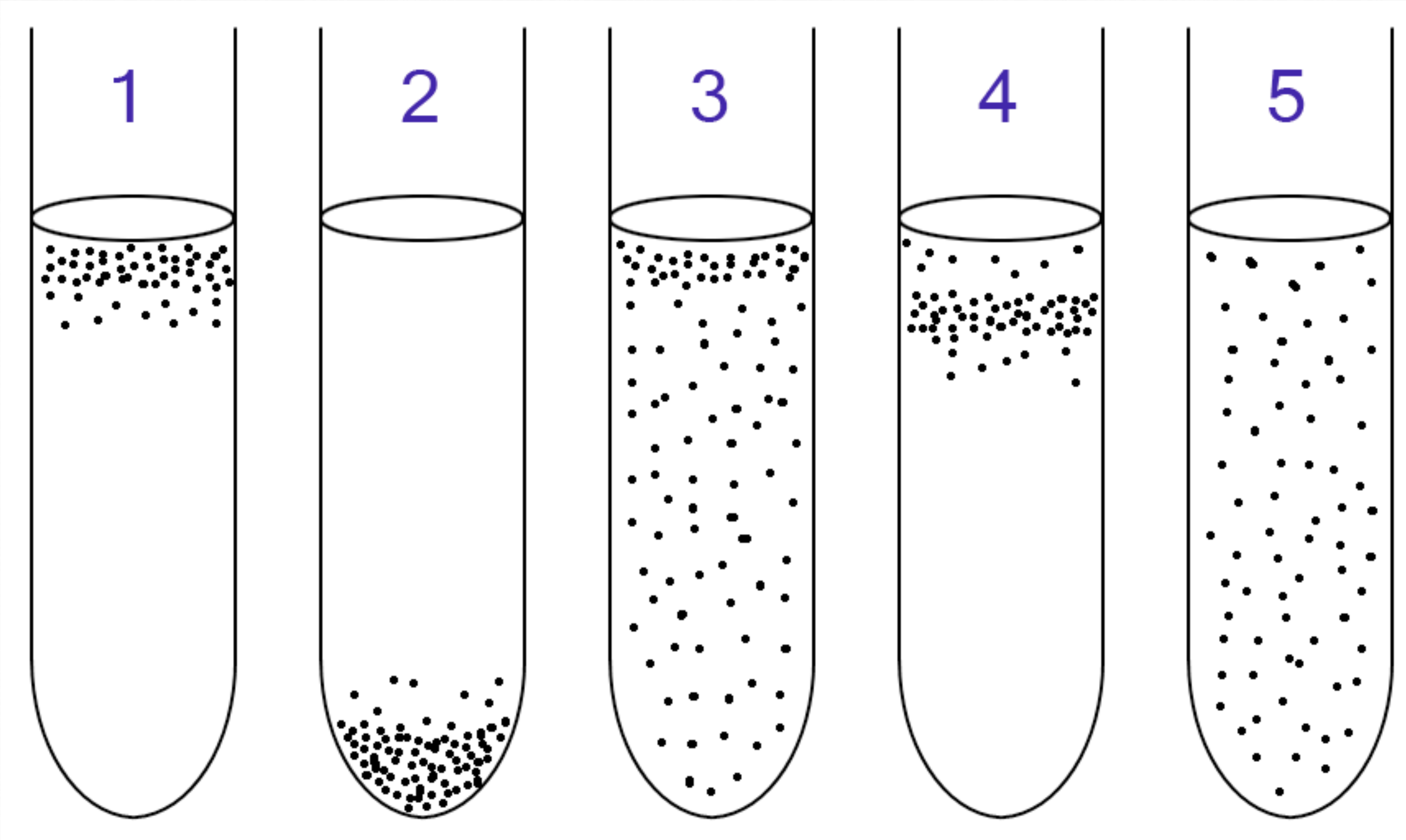


TABLE 5.4 Some Industrial Uses for Different Types Of Fermentations

Fermentation End-Product(s)	Industrial or Commercial Use	Starting Material	Microorganism
Ethanol	Beer	Malt extract	*Saccharomyces cerevisiae* (yeast, a fungus)
	Wine	Grape or other fruit juices	*Saccharomyces cerevisiae* var. *ellipsoideus*
	Fuel	Agricultural wastes	*Saccharomyces cerevisiae*
Acetic Acid	Vinegar	Ethanol	*Acetobacter* (bacterium)
Lactic Acid	Cheese, yogurt	Milk	*Lactobacillus, Streptococcus* (bacteria)
	Rye bread	Grain, sugar	*Lactobacillus delbruckii* (bacterium)
	Sauerkraut	Cabbage	*Lactobacillus plantarum* (bacterium)
	Summer sausage	Meat	*Pediococcus* (bacterium)
Propionic Acid and Carbon Dioxide	Swiss cheese	Lactic acid	*Propionibacterium freudenreichii* (bacterium)
Acetone and Butanol	Pharmaceutical, industrial uses	Molasses	*Clostridium acetobutylicum* (bacterium)
Glycerol	Pharmaceutical, industrial uses	Molasses	*Saccharomyces cerevisiae*
Citric Acid	Flavoring	Molasses	*Aspergillus* (fungus)
Methane	Fuel	Acetic acid	*Methanosarcina* (bacterium)
Sorbose	Vitamin C (ascorbic acid)	Sorbitol	*Gluconobacter*

Aerobic vs. Anaerobic Organisms

- Obligate Aerobes require oxygen to survive.
- Obligate Anaerobes can not use oxygen and is toxic.
- Aerotolerant organisms can not use oxygen but can tolerate it.
- Facultative anaerobes can survive without oxygen but they can utilize oxygen if present.
- Microaerophiles require oxygen but in very small concentrations



What type of bacteria are found in each test tube?

Explain

Answer

1. Obligate aerobic bacteria gather at the top of the test tube in order to absorb maximal amount of oxygen.
2. Obligate anaerobic bacteria gather at the bottom to avoid oxygen.
3. Facultative bacteria gather mostly at the top, since aerobic respiration is advantageous (ie, energetically favorable); but as lack of oxygen does not hurt them, they can be found all along the test tube.
4. Microaerophiles gather at the upper part of the test tube but not at the top. They require oxygen, but at a lower concentration.
5. Aerotolerant bacteria are not affected at all by oxygen, and they are evenly spread along the test tube.