Big Idea 4: Biological systems interact, and these systems and their interactions possess complex properties.

Enduring understanding 4.B: Competition and cooperation are important aspects of biological systems.

Essential knowledge 4.B.2: Cooperative interactions within organisms promote efficiency in the use of energy and matter.

a. Organisms have areas or compartments that perform a subset of functions related to energy and matter, and these parts contribute to the whole. [See also 2.A.2, 4.A.2]

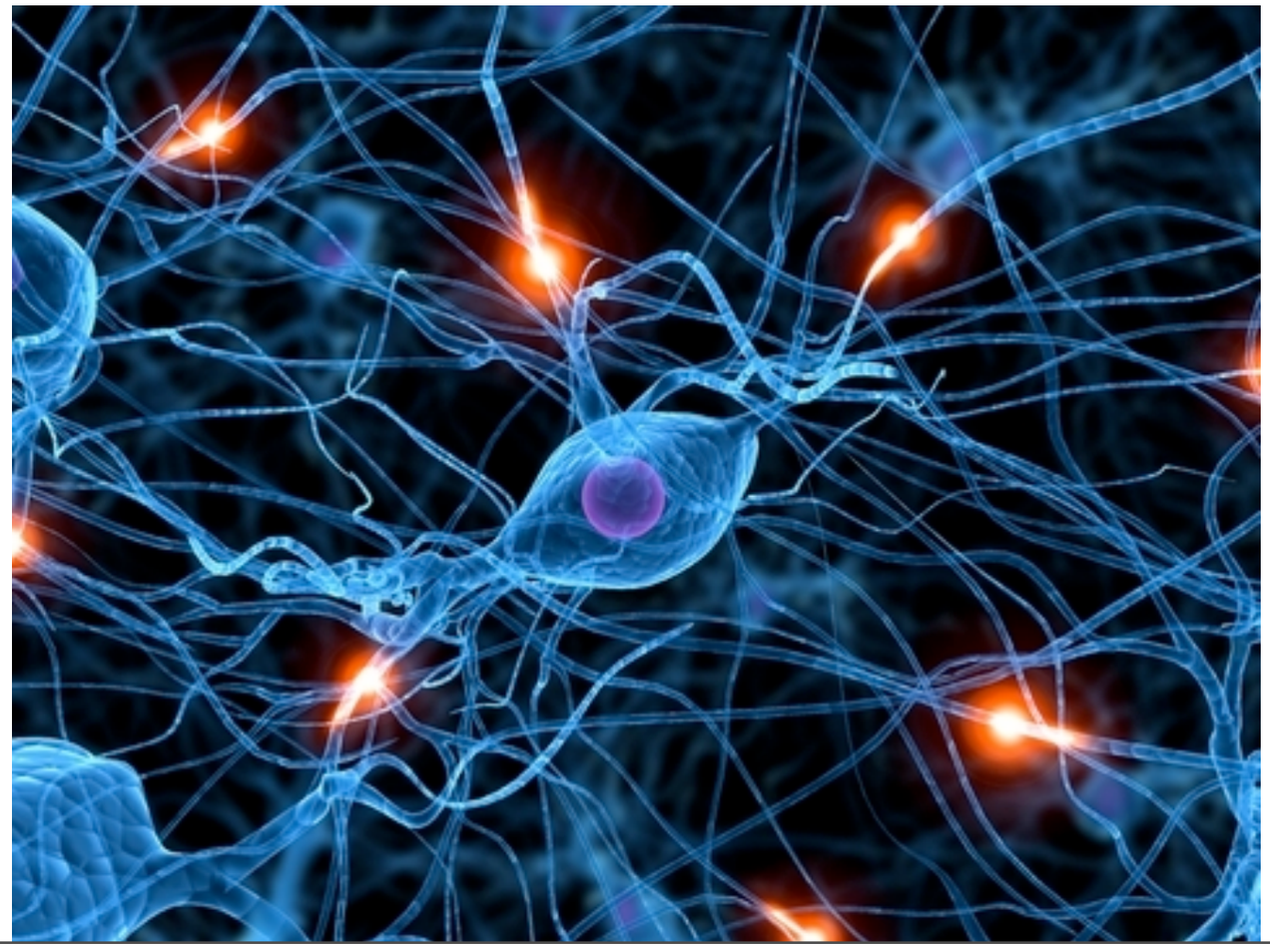
Evidence of student learning is a demonstrated understanding of each of the following:

1. At the cellular level, the plasma membrane, cytoplasm and, for eukaryotes, the organelles contribute to the overall specialization and functioning of the cell.

Tour of the Cell

Main Idea: Their are two distinct types of cells *eukaryotes & prokaryotes*.

Main Idea: Prokaryotes belong to the domains of bacteria and archaea. Eukaryotes belong to protista, fungi, animals and plants.



EUKARYOTIC CELLS HAVE INTERNAL MEMBRANES THAT COMPARTMENTALIZE THEIR FUNCTIONS

Comparing Eukaryotic and Prokaryotic cells

- ALL cells share some common features:
  - plasma membranes (selective barrier)
  - cytosol (semifluid substance)
  - chromosomes (information carrier)
  - ribosomes (protein builders)

Although all cells share these common features the first and most distinct differences between cells are seen in the division between eukaryotes and prokaryotes.

- **PROKARYOTES**
  - **older, less complex**
  - **No nucleus (DNA in nucleoid region)**
  - **No membrane bound organelles**
  - **smaller**
- **EUKARYOTES**
  - **younger, more complex**
  - **Has nucleus (contains DNA)**
  - **Has membrane bound organelles**
  - **larger**

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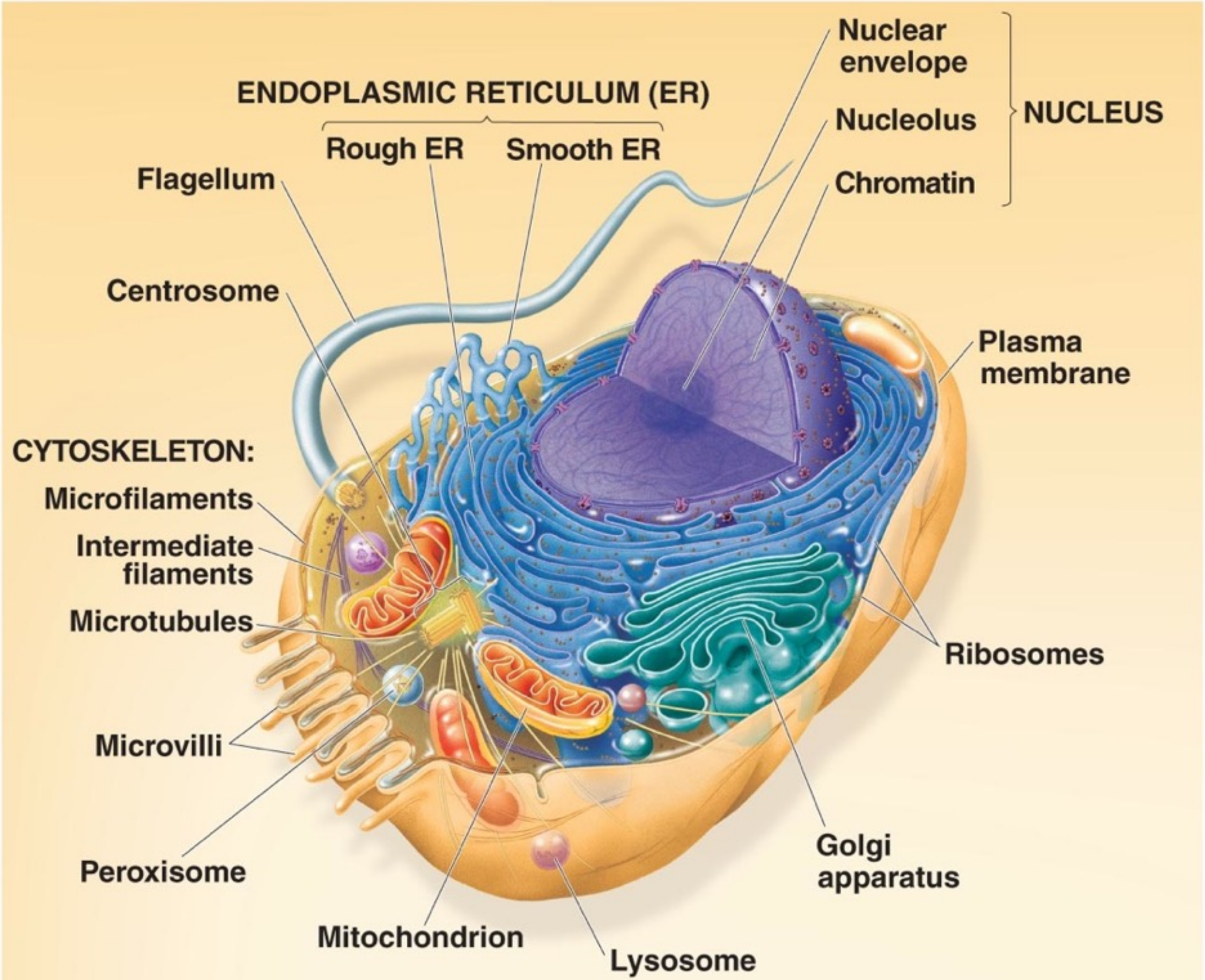
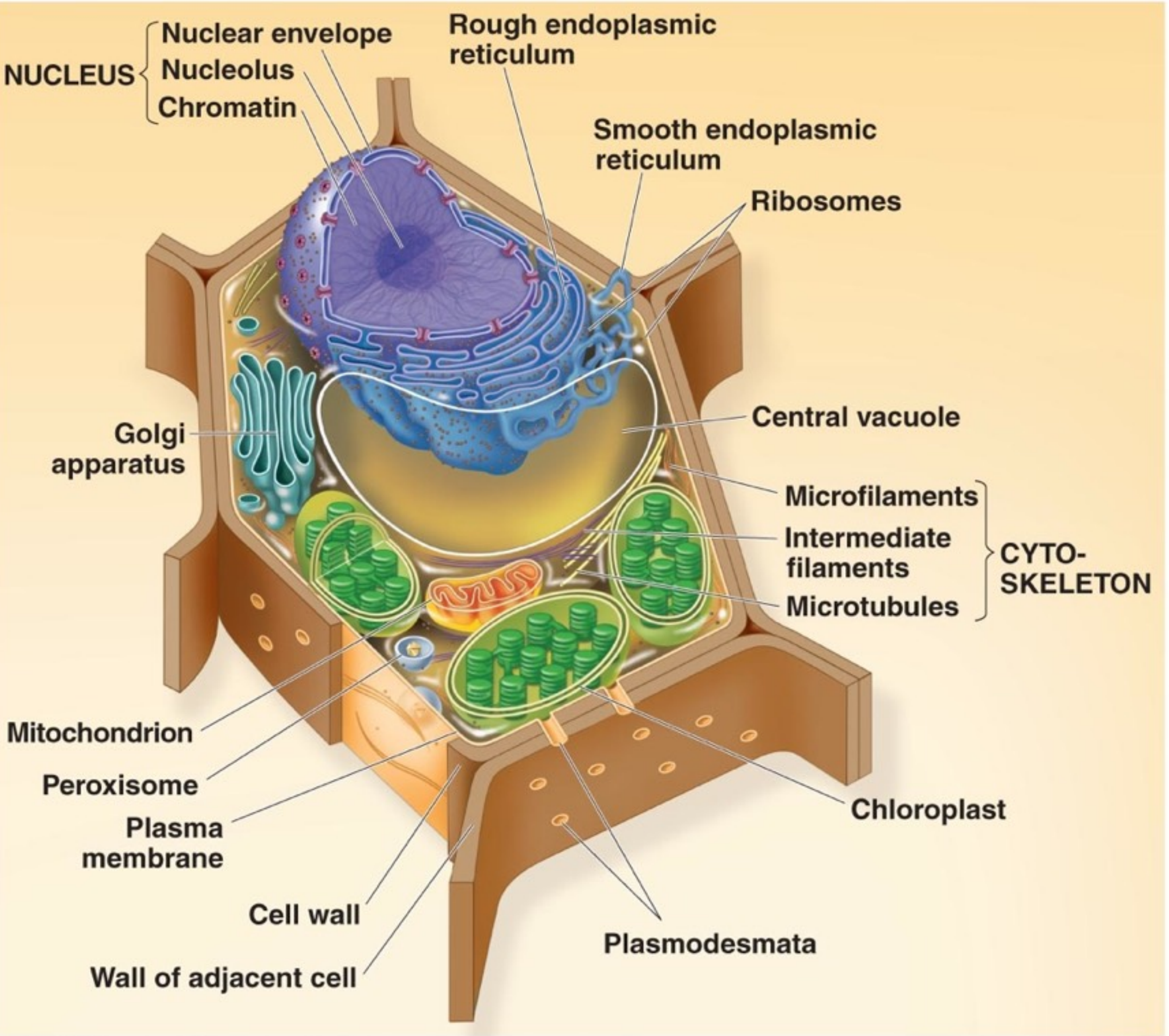
These differences are just the beginning a more comprehensive list is forth coming!

A Panoramic View of the Eukaryotic Cell

- Eukaryotic cells have elaborately arranged internal membranes that divide the cell into compartments.
    - Compartments provide different local environments that facilitate specific metabolic functions some of which are antagonistic.
- The membranes themselves are loaded with enzymes and thus participate directly in the cell's metabolism.

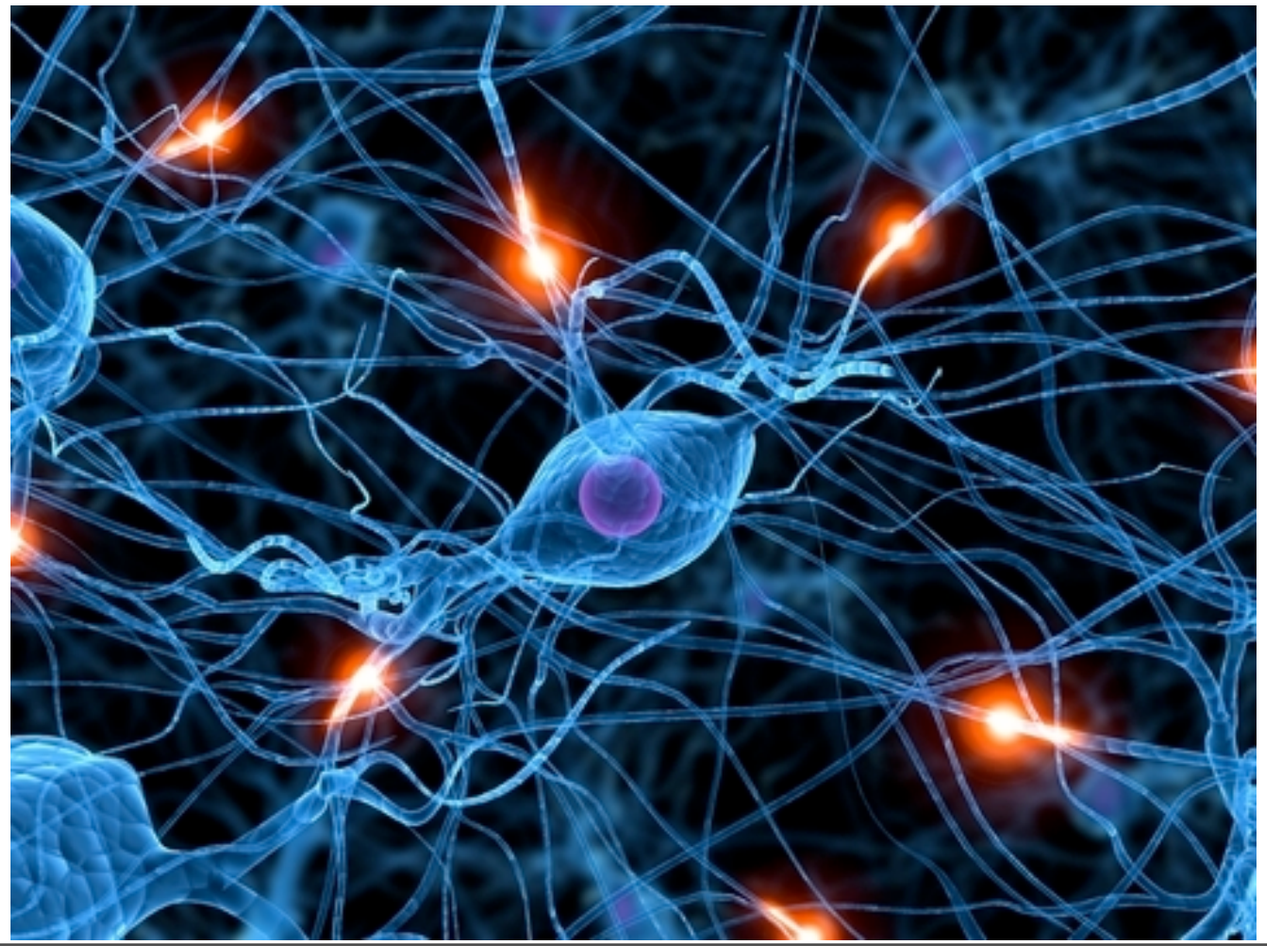
Membranes are so fundamental to the organization of cells and cellular functions we will dedicate an entire chapter to them


Nuclear envelope
ENDOPLASMIC RETICULUM (ER)
Nucleolus
NUCLEUS
Rough ER
Smooth ER
Flagellum
Chromatin
Centrosome
Plasma membrane
CYTOSKELETON:
Microfilaments
Intermediate filaments
Microtubules
Ribosomes
Microvilli
Peroxisome
Golgi apparatus
Mitochondrion
Lysosome


NUCLEUS
Nuclear envelope
Nucleolus
Chromatin
Rough endoplasmic reticulum
Smooth endoplasmic reticulum
Ribosomes
Golgi apparatus
Central vacuole
Microfilaments
Intermediate filaments
Microtubules
CYTO-SKELETON
Mitochondrion
Peroxisome
Plasma membrane
Cell wall
Wall of adjacent cell
Plasmodesmata
Chloroplast

Tour of the Cell

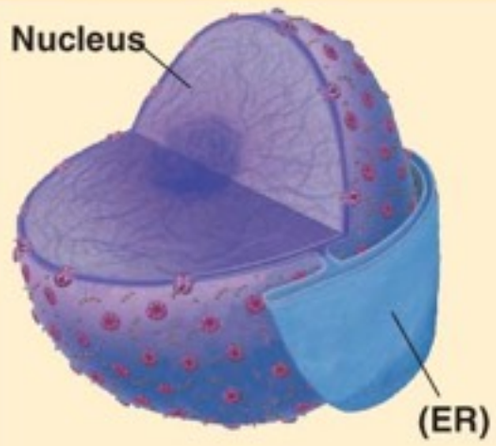
Main Idea: The nucleus and ribosomes are most involved in the genetic control of a cell.
Main Idea: The nucleus contains the "blueprints" for proteins and the ribosomes serve as the "builders" of proteins.



THE EUKARYOTIC CELL'S GENETIC INSTRUCTIONS ARE HOUSED IN THE NUCLEUS AND CARRIED OUT BY THE RIBOSOMES

The Nucleus: Information Central

- The nucleus is usually the most prominent feature in a cell.
- The nucleus contains most of a cell's genes.
  - *The mitochondria and chloroplasts contain the rest.*

	Cell Component	Structure	Function
Concept 6.3 The eukaryotic cell's genetic instructions are housed in the nucleus and carried out by the ribosomes		Surrounded by nuclear envelope (double membrane) perforated by nuclear pores. The nuclear envelope is continuous with the endoplasmic reticulum (ER).	Houses chromosomes, made of chromatin (DNA, the genetic material, and proteins); contains nucleoli, where ribosomal subunits are made. Pores regulate entry and exit of materials.

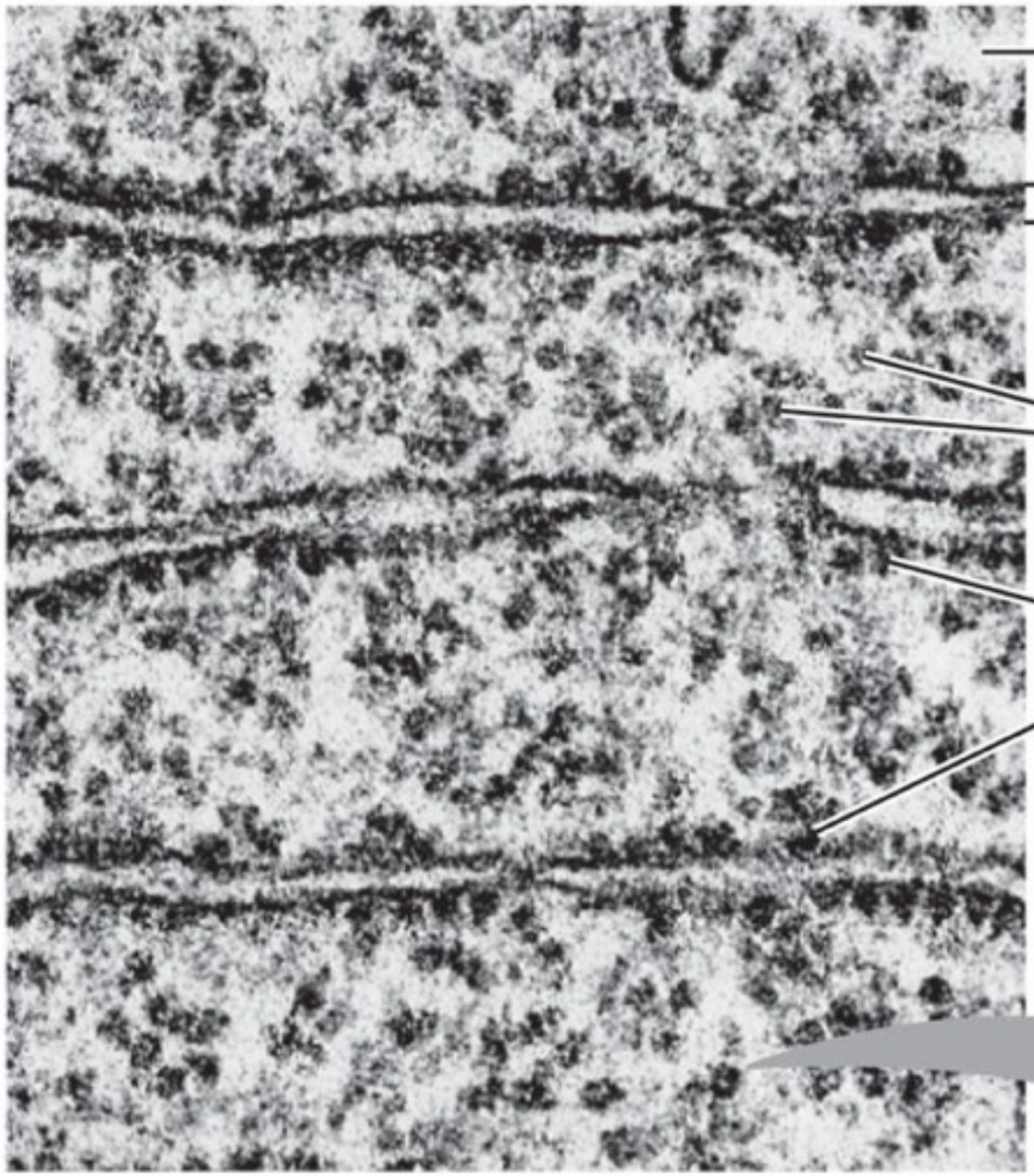
The Nucleus: review

- *nuclear envelope*, **perforated double membrane**
- *pore complex*, **regulates exchange of proteins/RNA in & out**
- *nuclear lamina*, **protein filaments support membrane**
- *nuclear matrix*, **protein fibers organize genetic material**
- *chromatin*, **more accessible, unraveled DNA (most of time)**
- *chromosomes*, **highly condensed DNA packaged for replication**
- *nucleolus*, **synthesizes rRNA, assembles ribosomes**

The Ribosomes: Protein Factories

- Complexes of rRNA and Protein
- Carrying out protein synthesis
  - Proteins are built in locations 1.) in cytoplasm or 2.) outside surface of the endoplasmic reticulum
- *Free ribosomes* assemble proteins in cytoplasm
  - these proteins are often destined to remain inside the cell
- *Bound ribosomes* assemble proteins on the surface of the endoplasmic reticulum or nuclear envelope
  - these proteins are often destined for insertion into membranes or to be exported from the cell

Ribosomes: continued



TEM showing ER and ribosomes

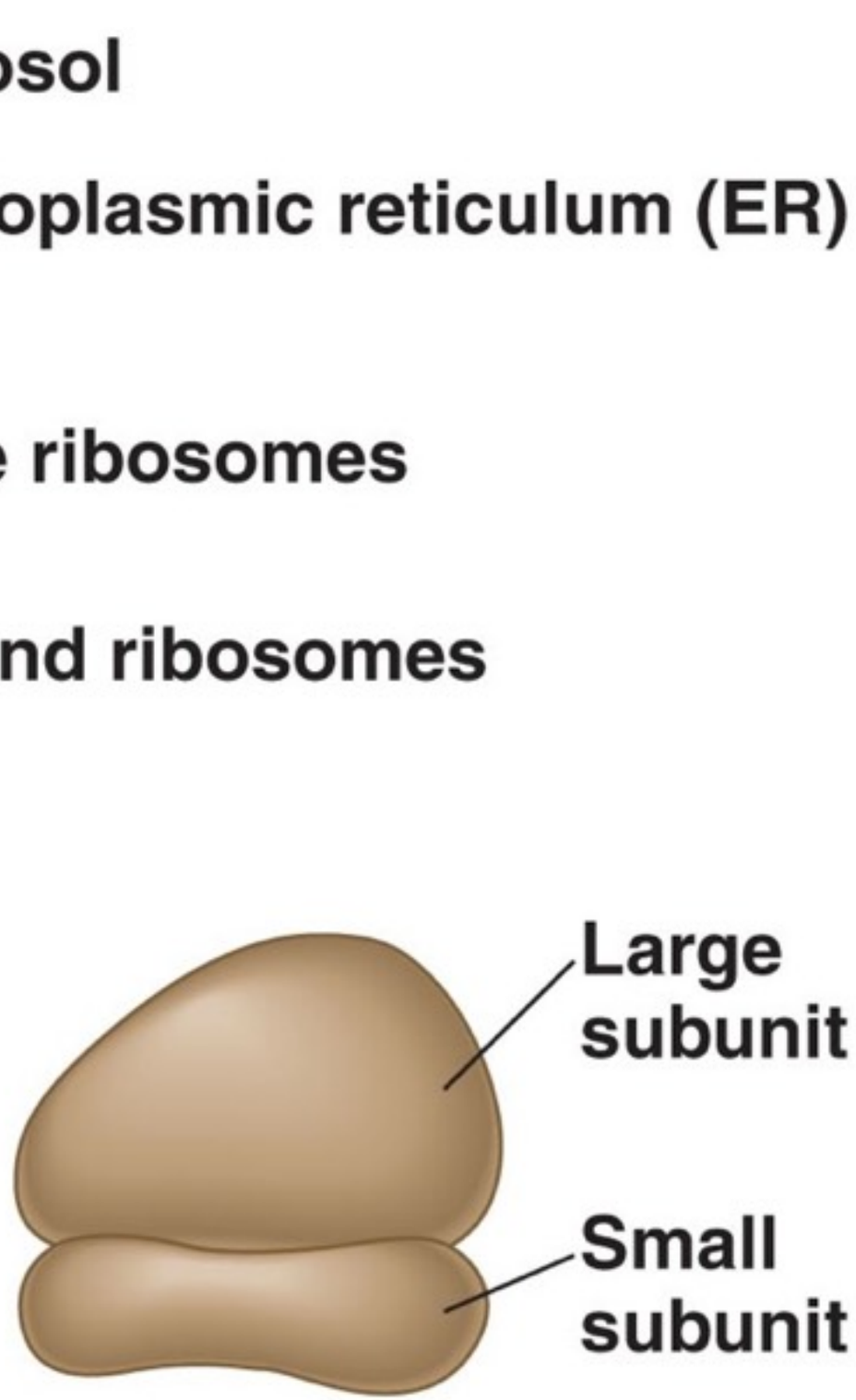
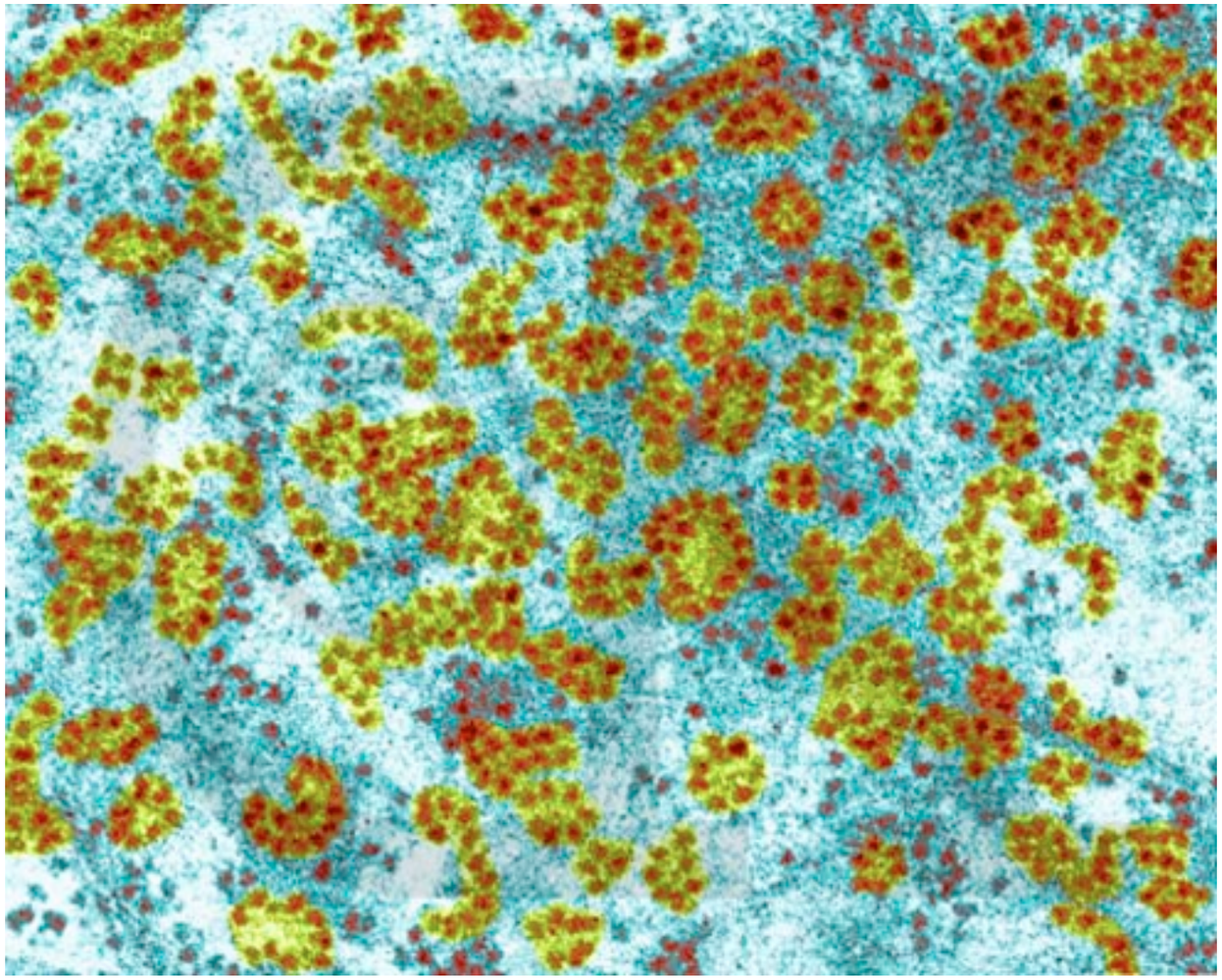
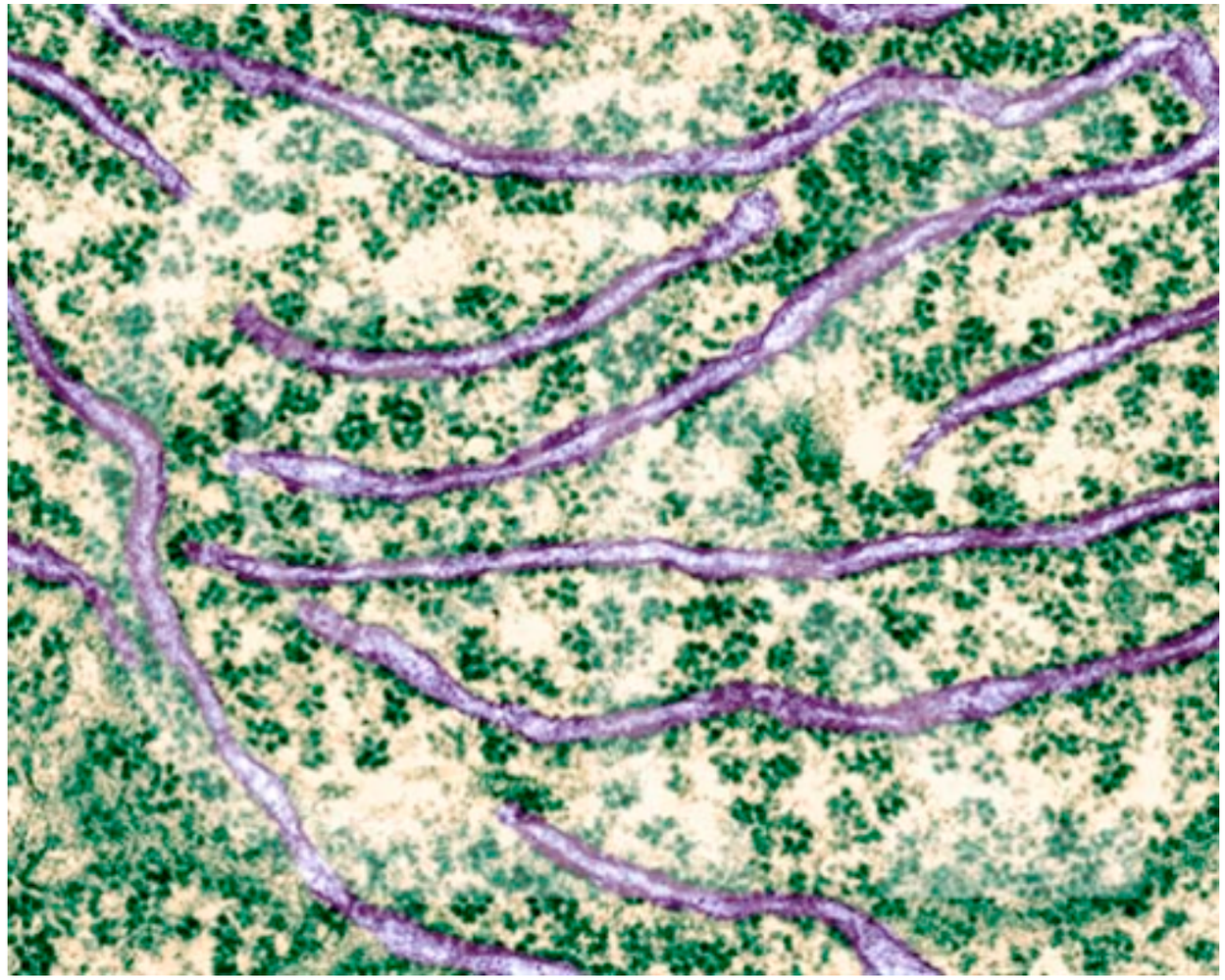
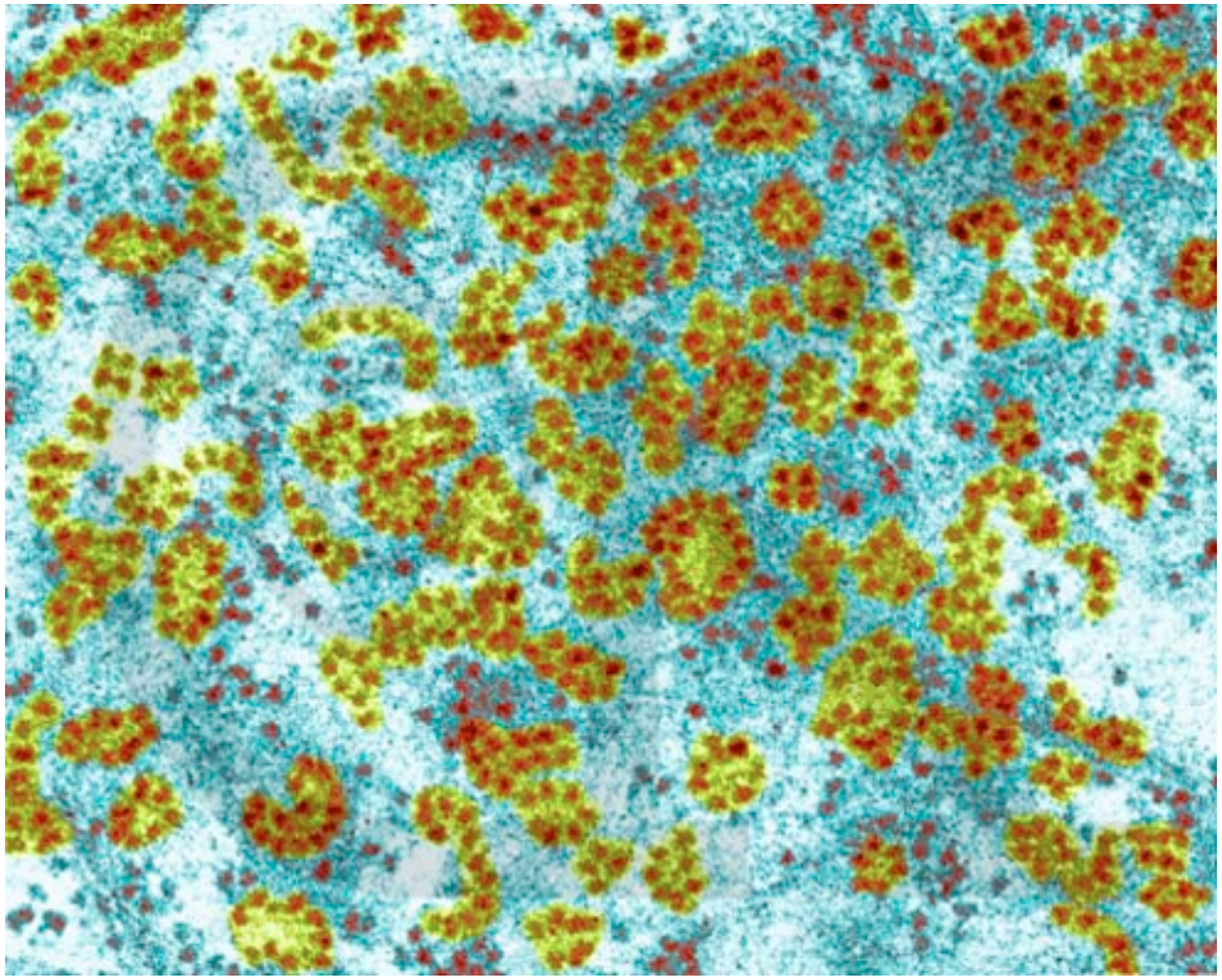
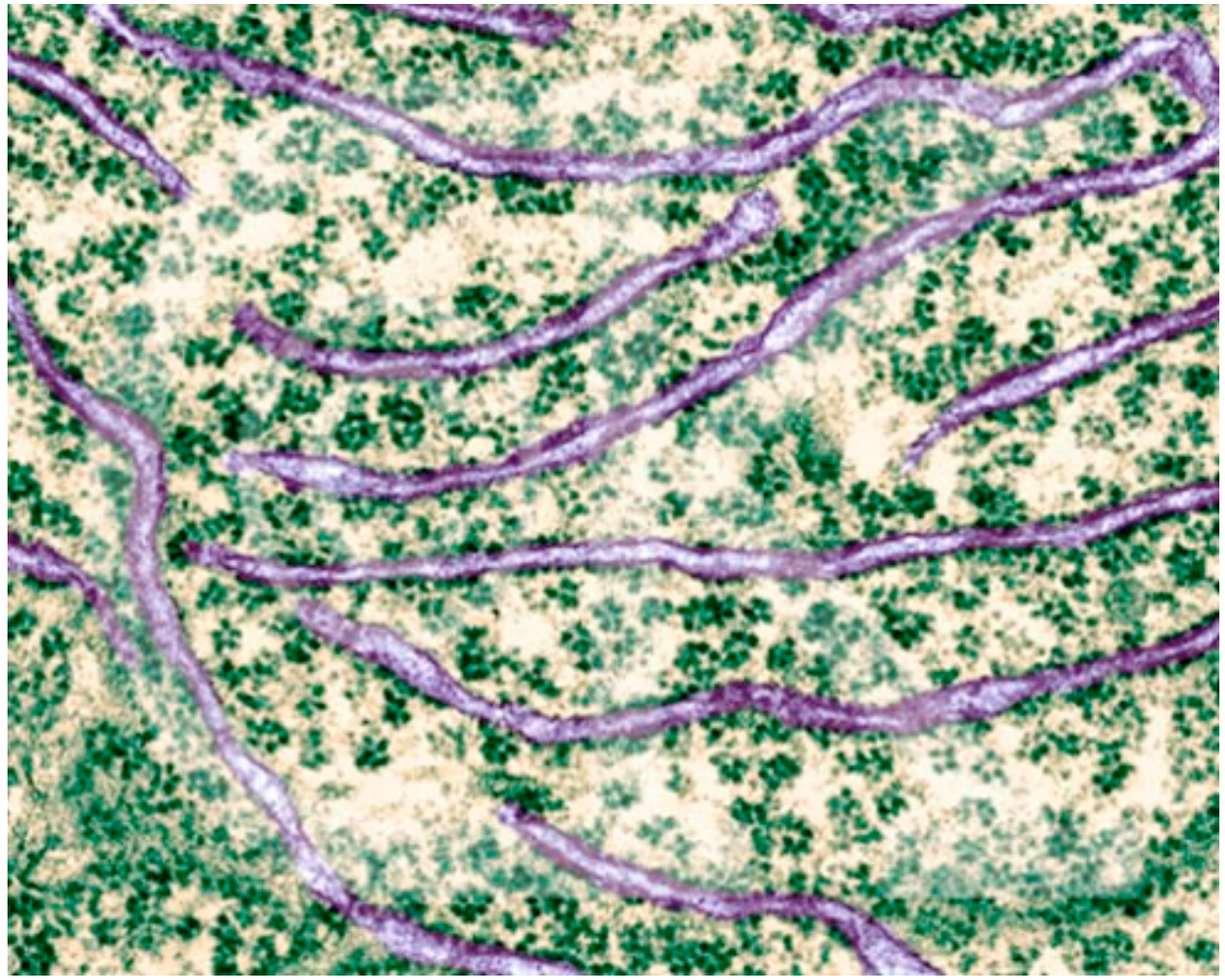


Diagram of a ribosome

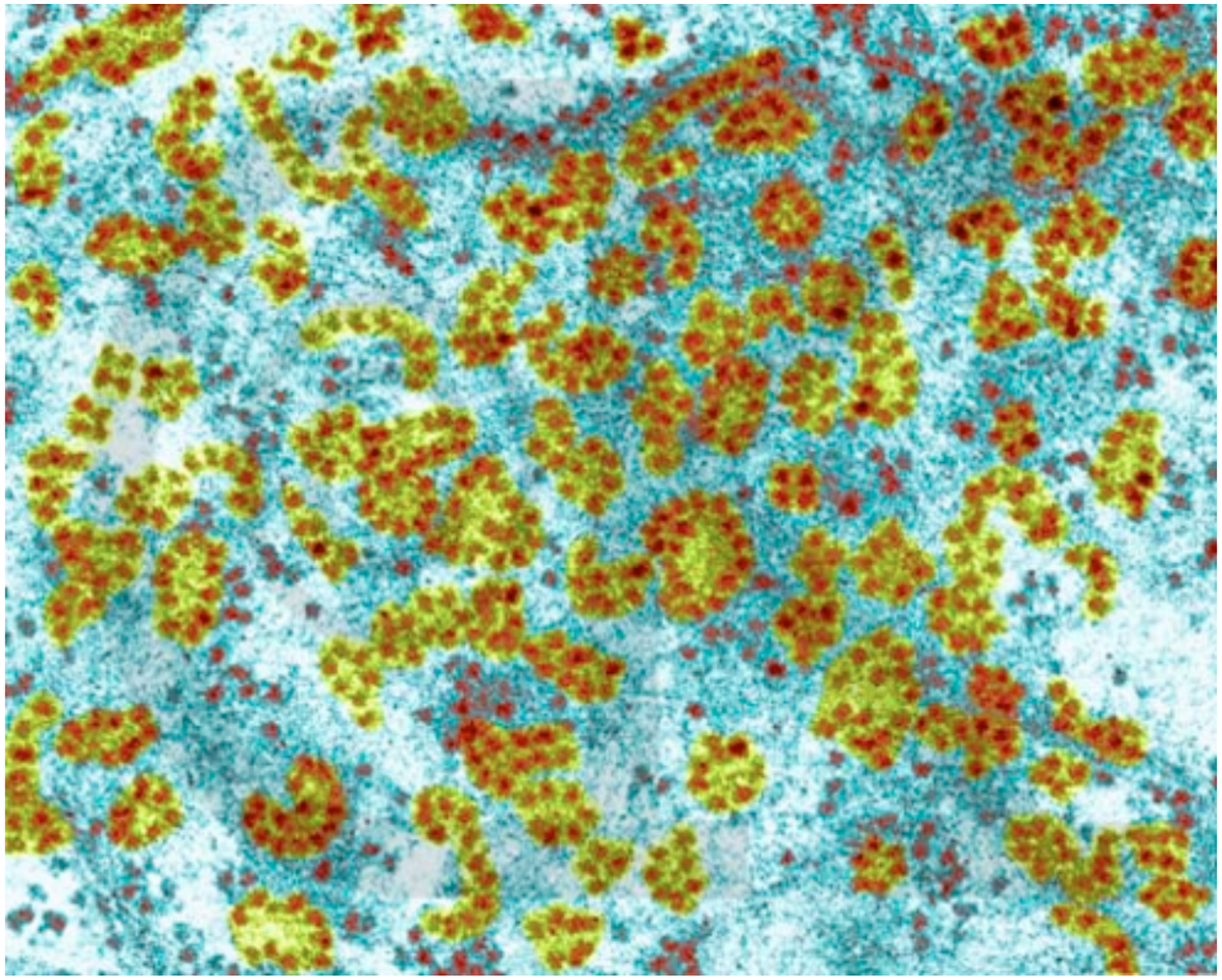


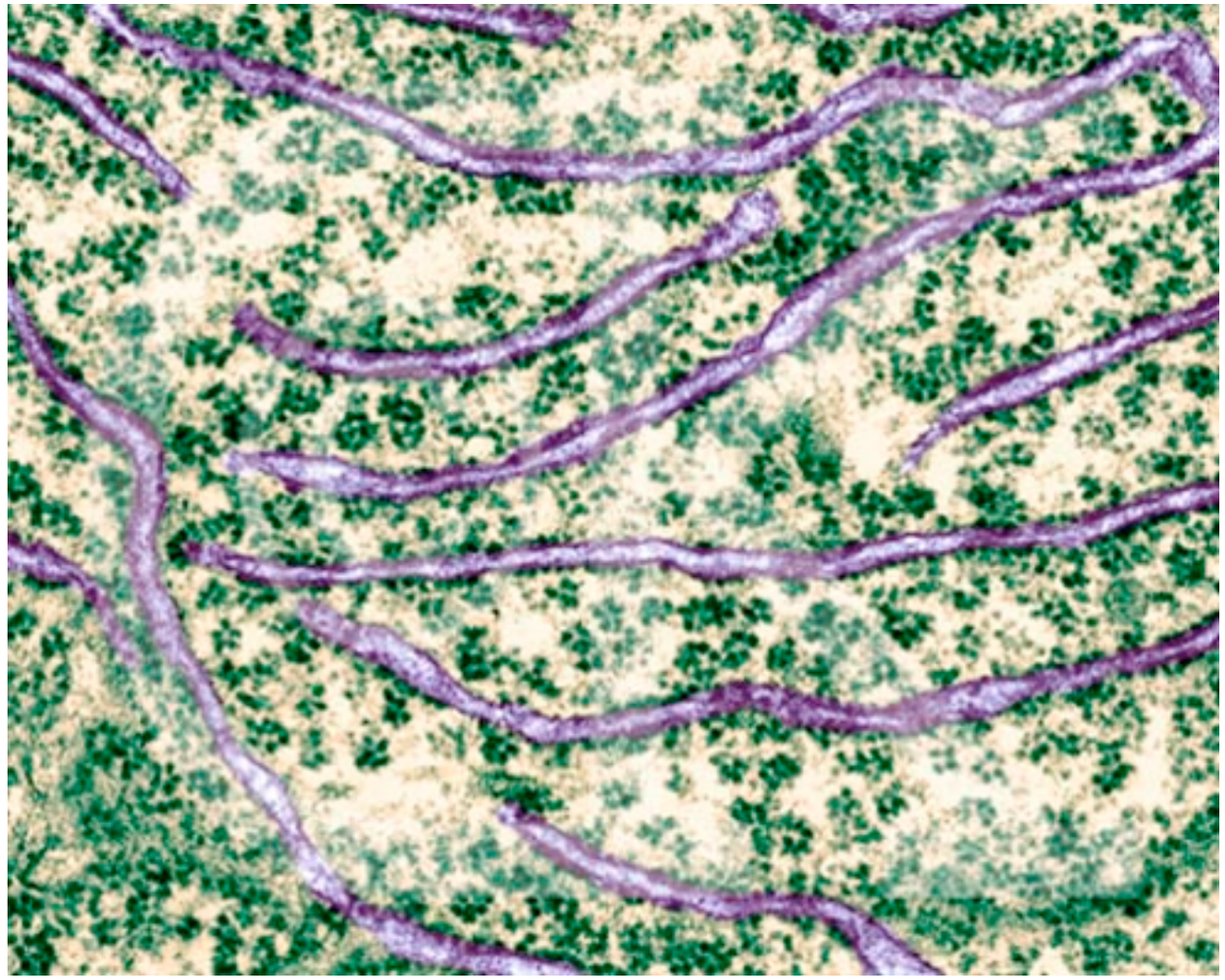






What trait(s) would a cell have if it possessed an above average number of ribosomes?





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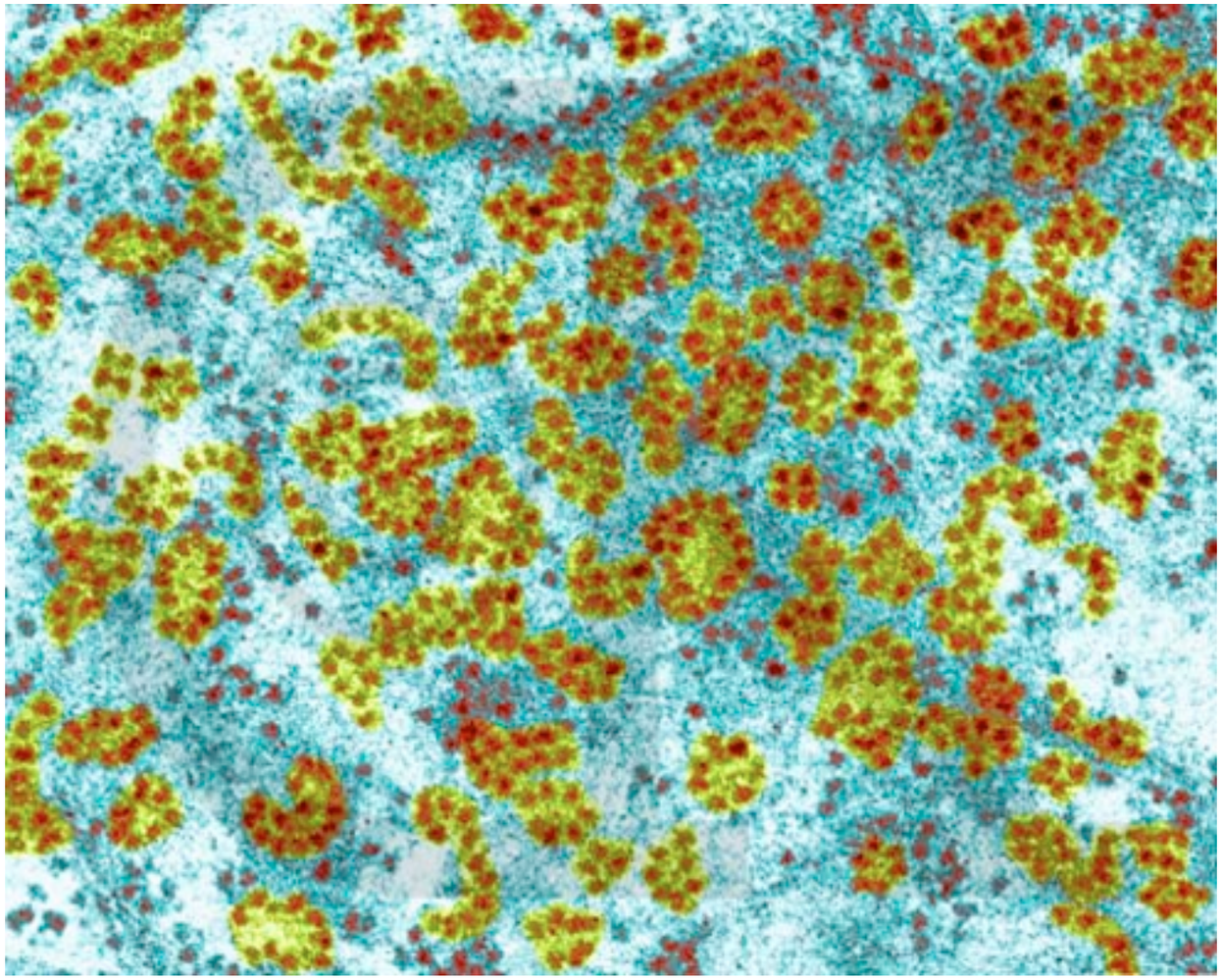
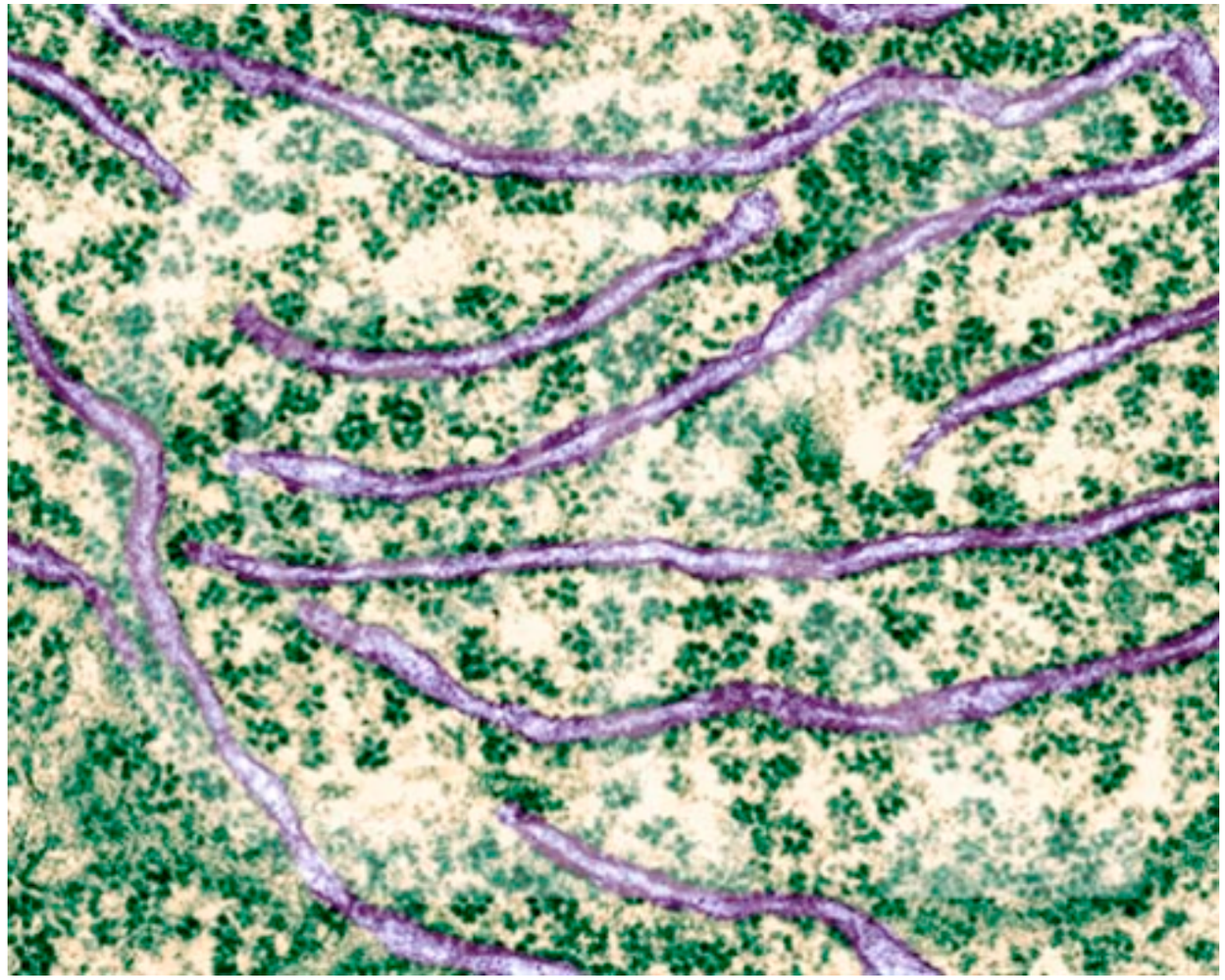
metabolically active, secretes enzymes





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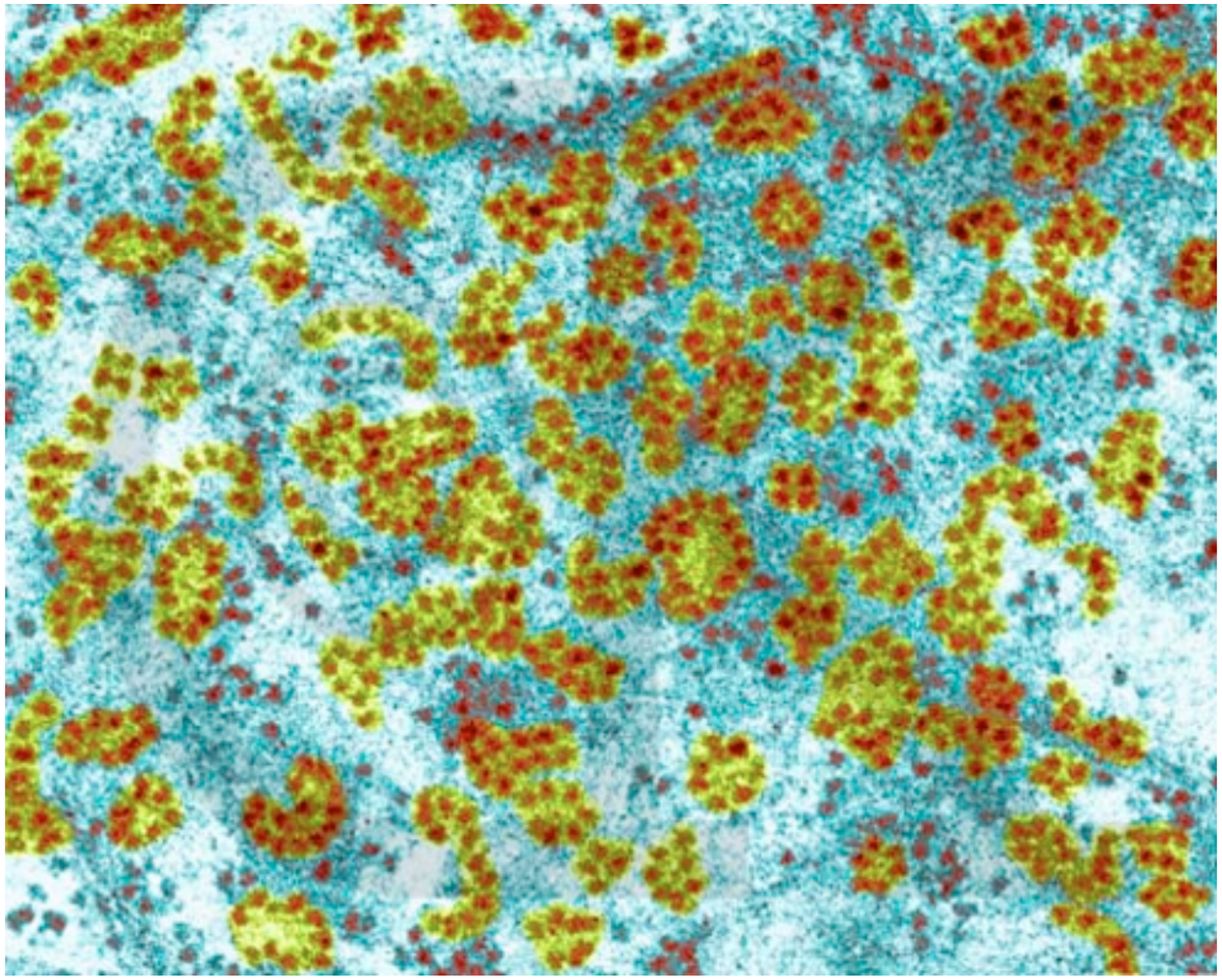

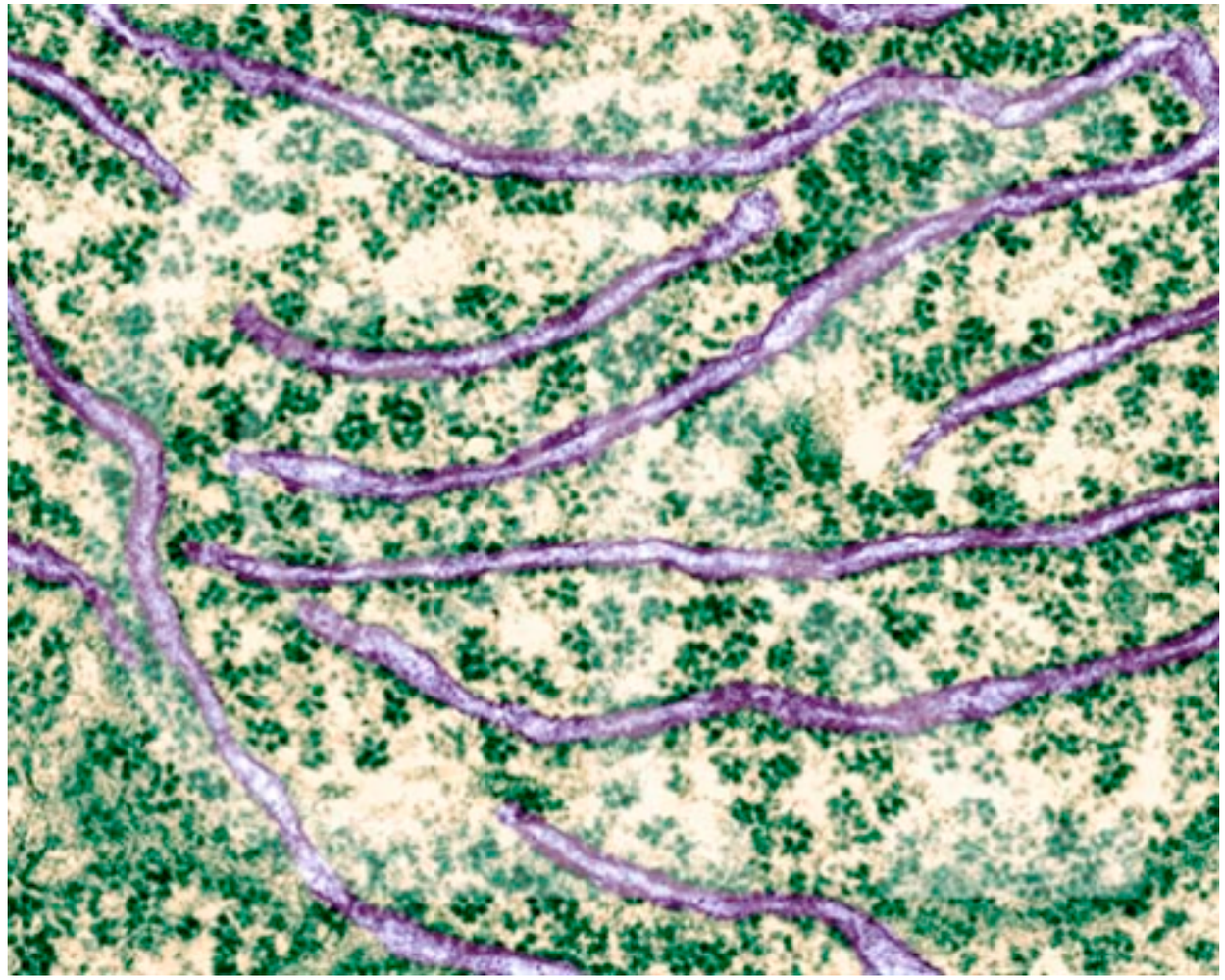

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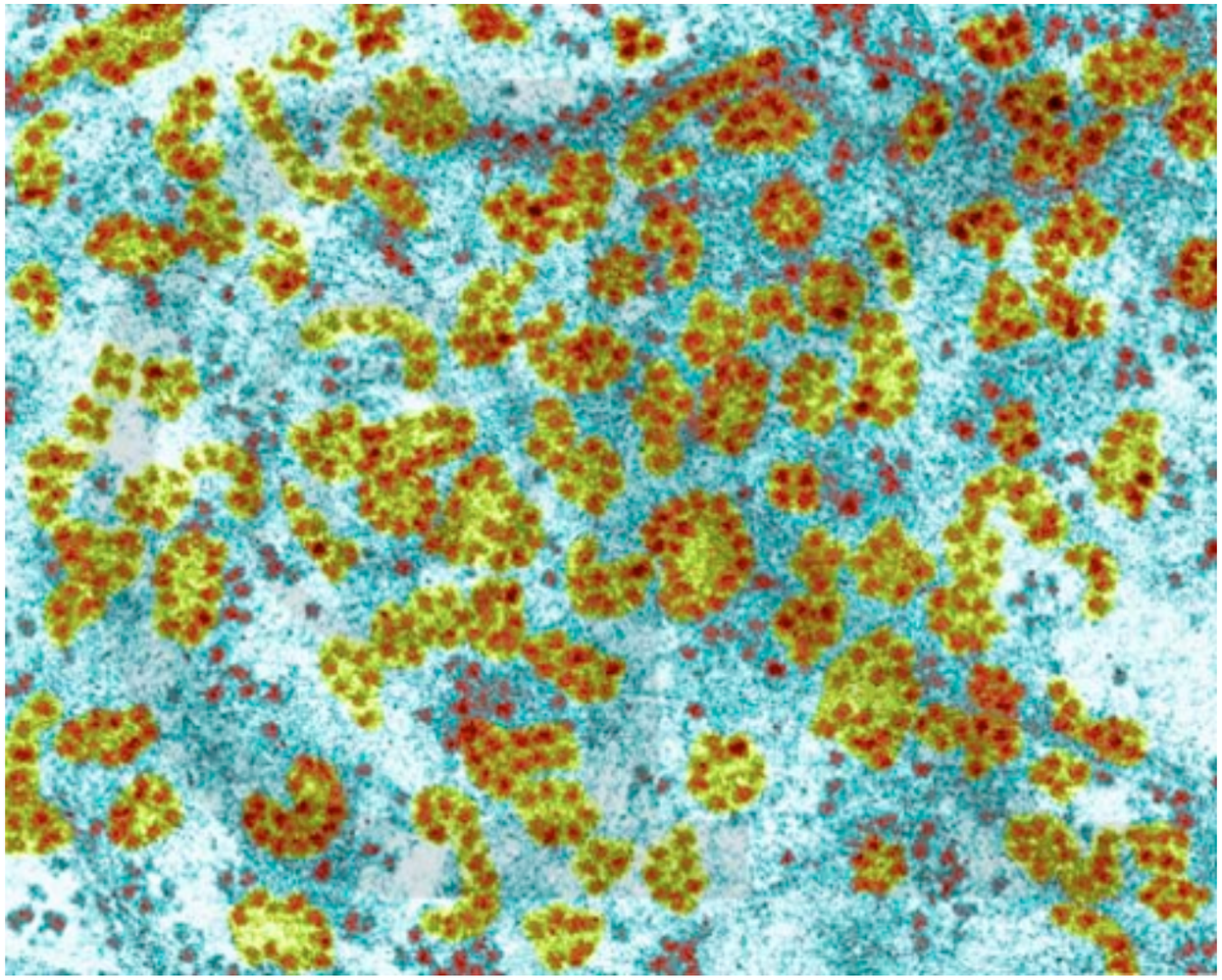
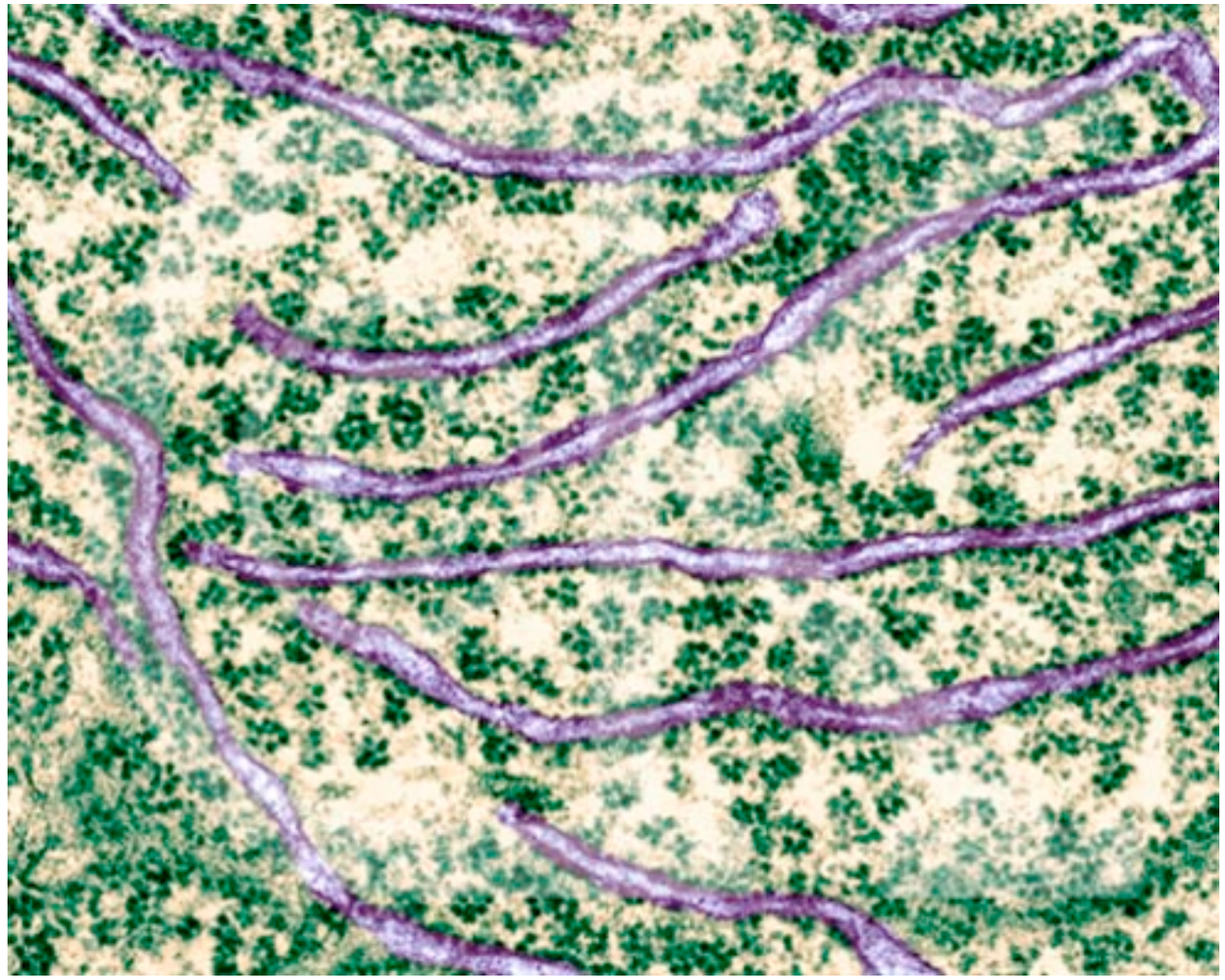
liver cells, pancreas cells, stomach cells





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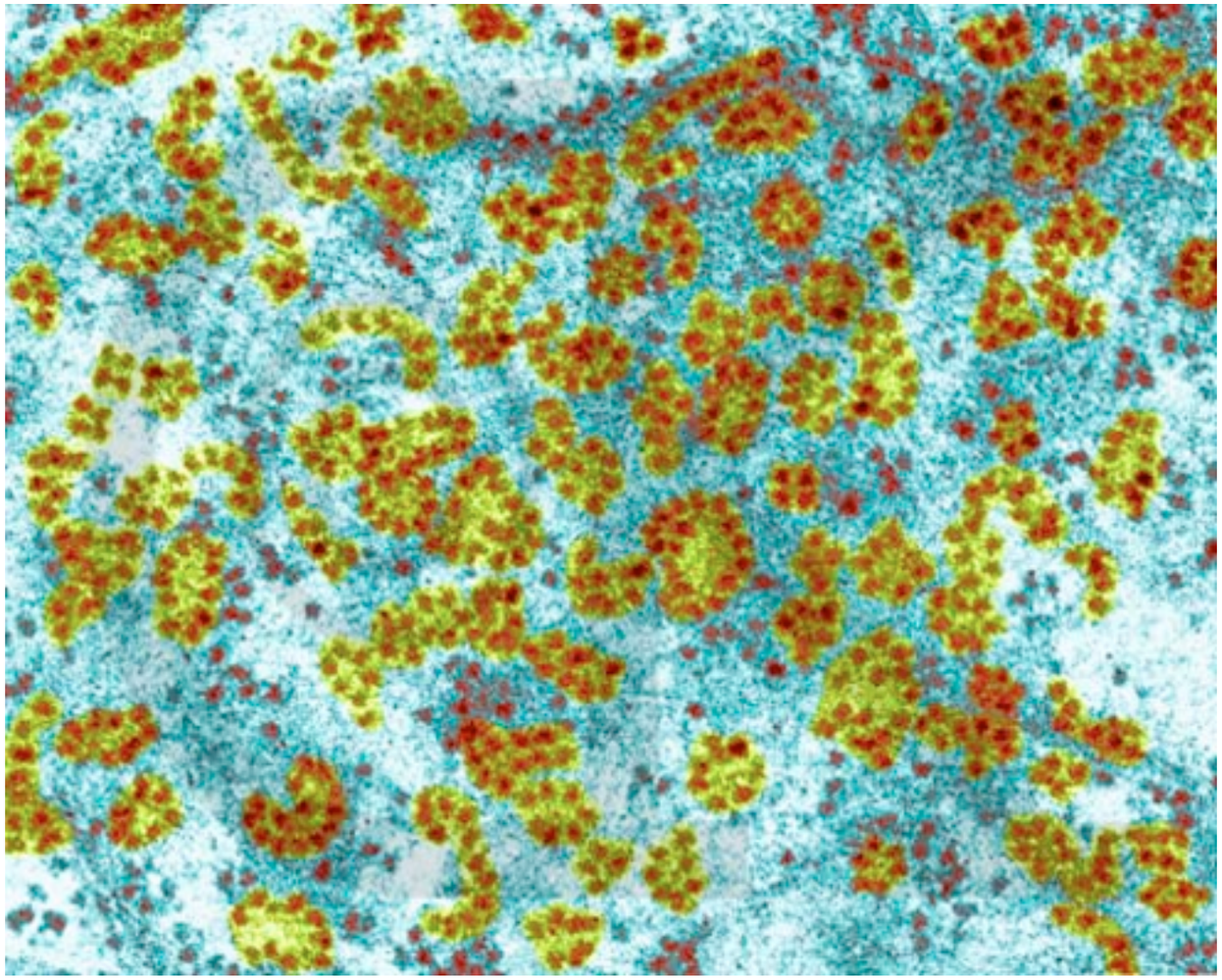
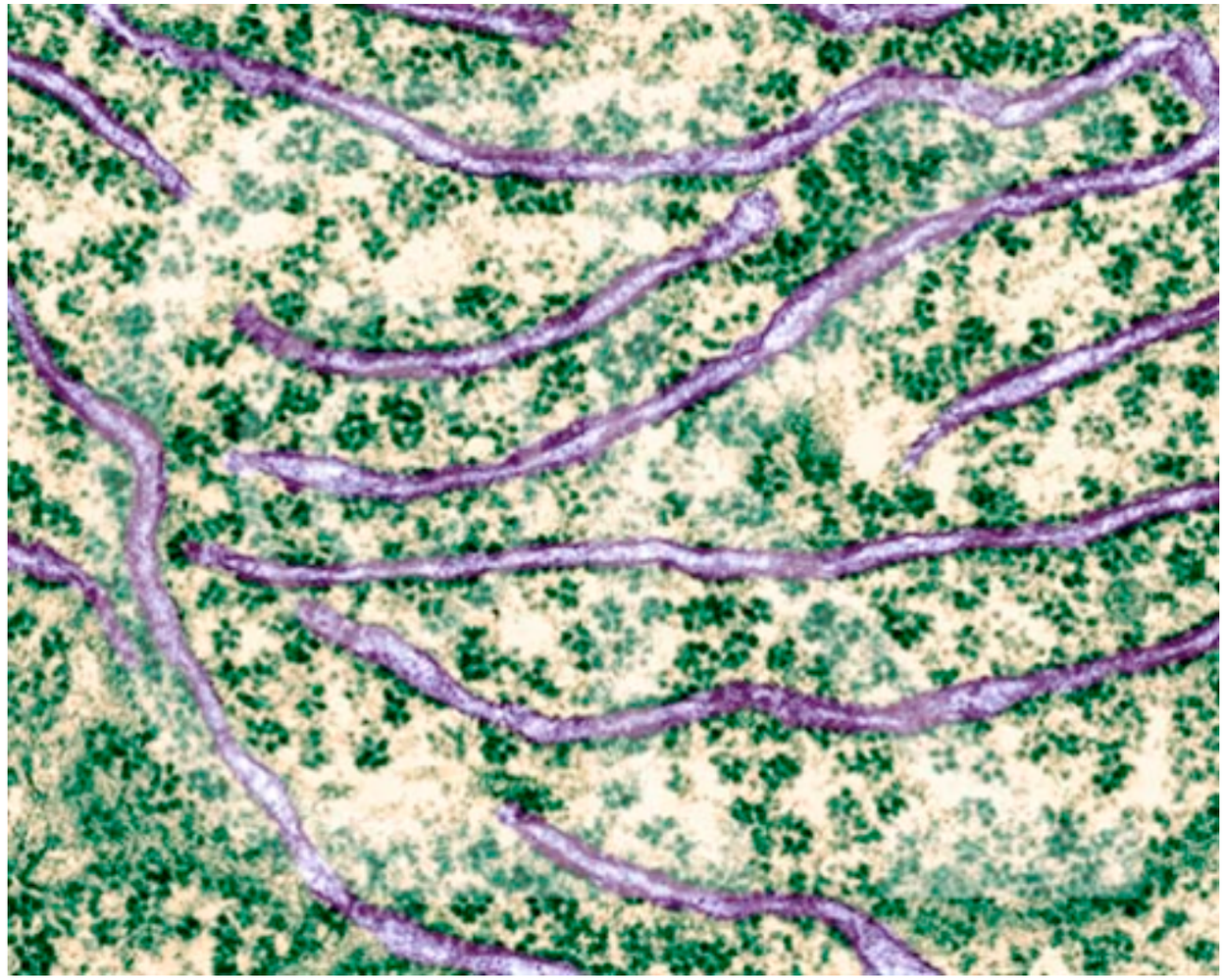
Mature red blood cells expel their nucleus, how many ribosomes would expect to find in these cells?





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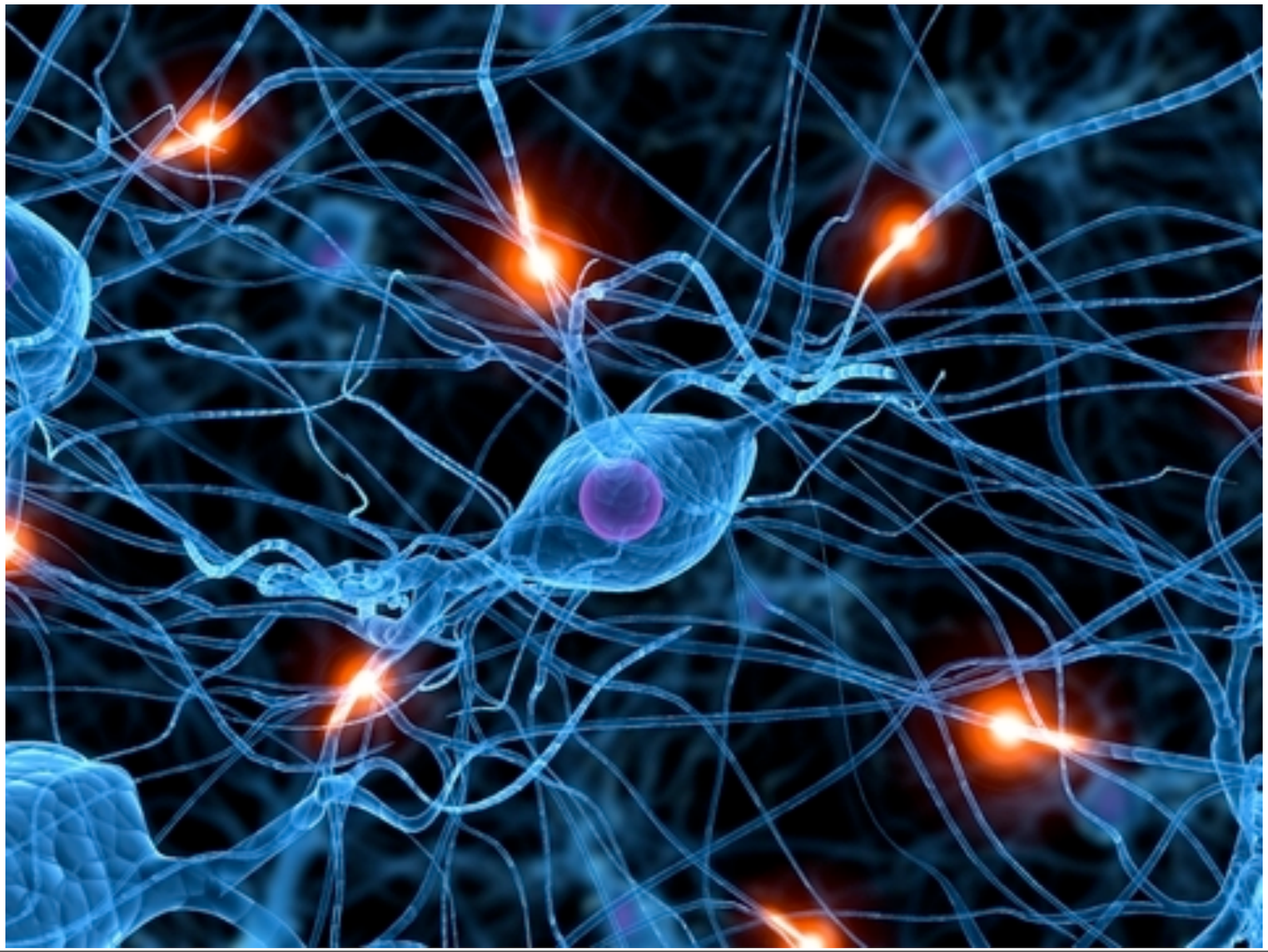
zero

Tour of the Cell

Main Idea: Membrane bound organelles work together to perform a variety of important metabolic functions.



THE ENDOMEMBRANE SYSTEM REGULATES PROTEIN TRAFFIC AND PERFORMS METABOLIC FUNCTIONS IN THE CELL

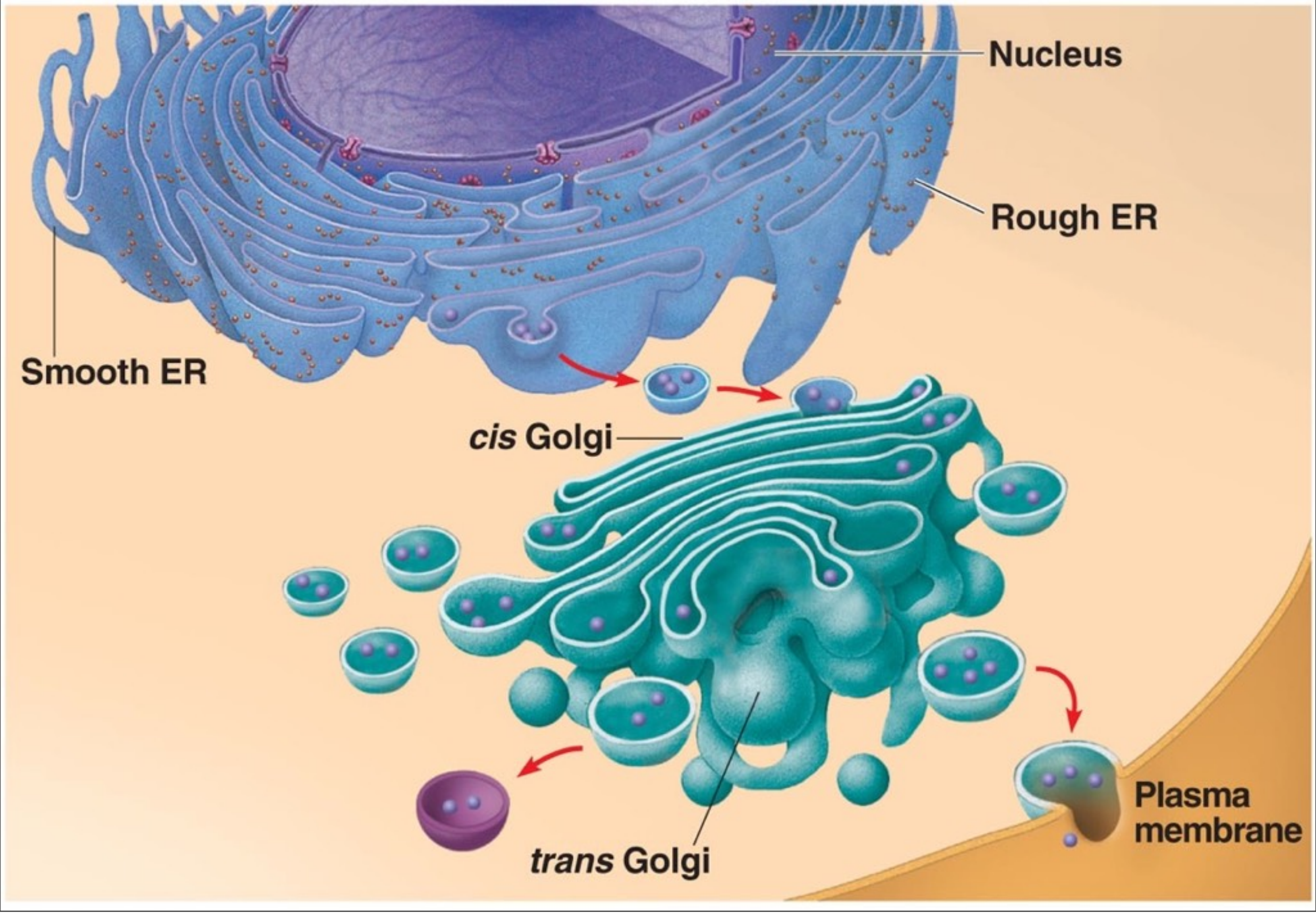
Structures

- Nuclear Envelope
- Endoplasmic Reticulum
- Golgi Apparatus
- Lysosomes
- Vesicles
- Plasma Membrane

Functions

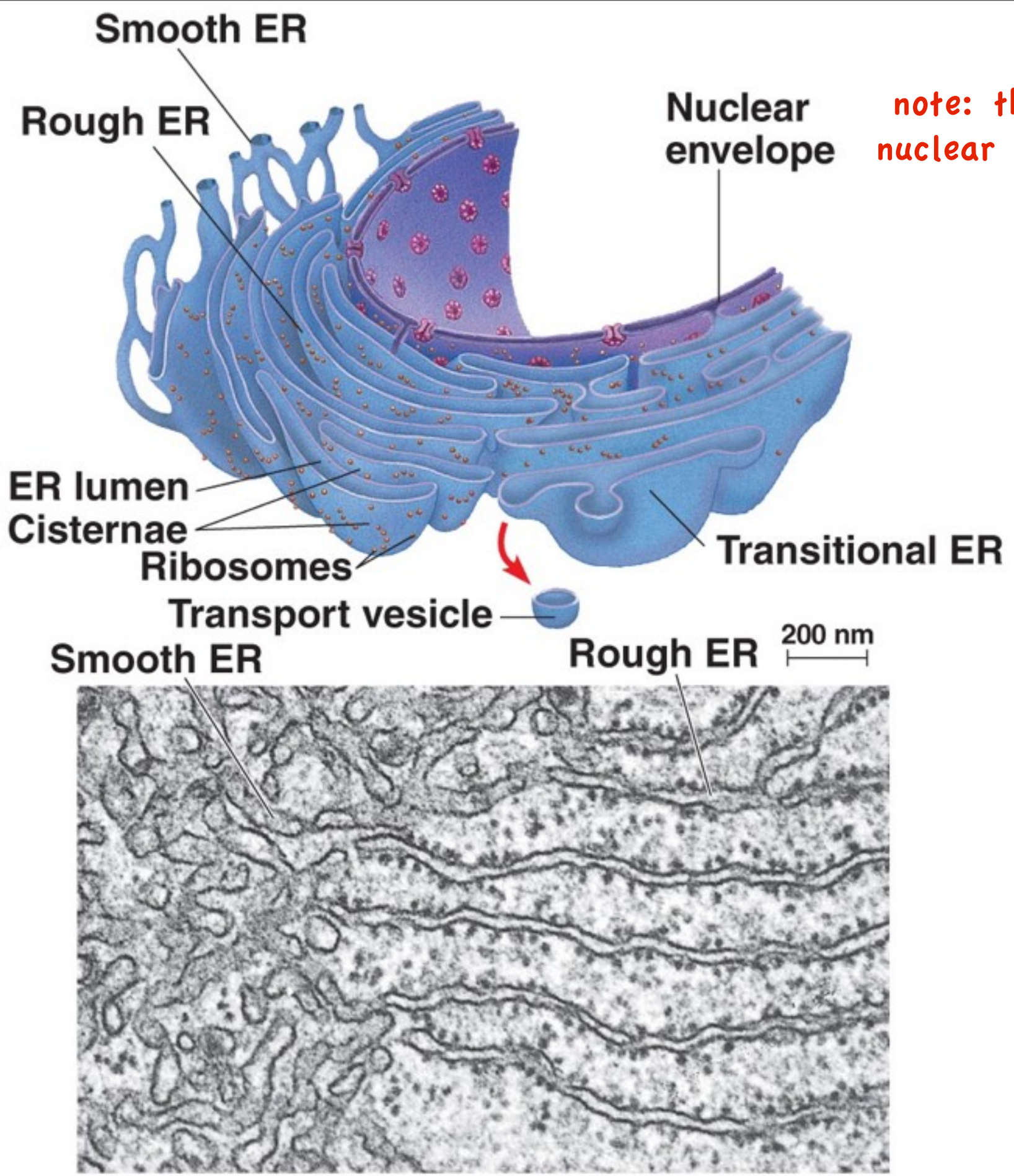
- Protein Synthesis
- Transportation of Proteins
- Chemical Reactions (metabolism)
- Transportation of Lipids
- Detoxification of Poisons

Endomembrane System



The Endoplasmic Reticulum: Biosynthetic Factory

- extensive network of membranes
- accounts for more than half of the total cell membrane
- two distinct types (each differs in structure and function)
- Smooth E.R. (lacks ribosomes)
- Rough E.R. (has ribosomes)



note: the cytoplasmic side of nuclear envelope has ribosomes

Functions of Smooth ER

- **Diverse functions that vary with cell type.**
  - **Synthesis of lipids, *phospholipids* and *steroids***
    - *testes, ovaries, adrenal glands* produce sex hormones as a result they have an abundance of smooth E.R.
  - **Enzymes that help detoxify drugs and poison**
    - adding hydroxyl groups to drugs/poison makes them more soluble and easier to secrete
    - drug addicts have more smooth E.R.
    - additional smooth E.R. contributes to their increased tolerance for drugs
  - **Stores calcium in muscle cells**

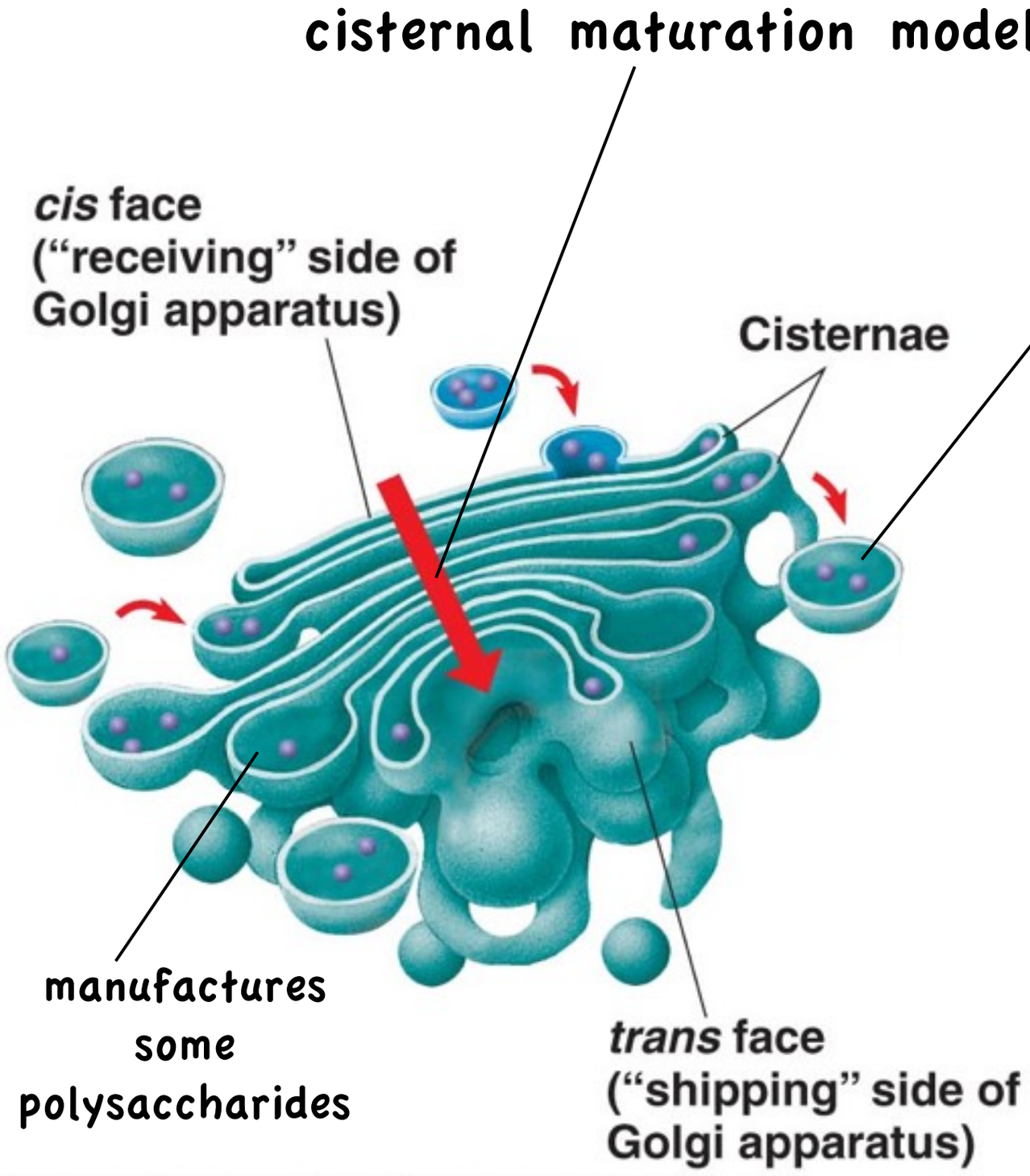
Functions of Rough ER

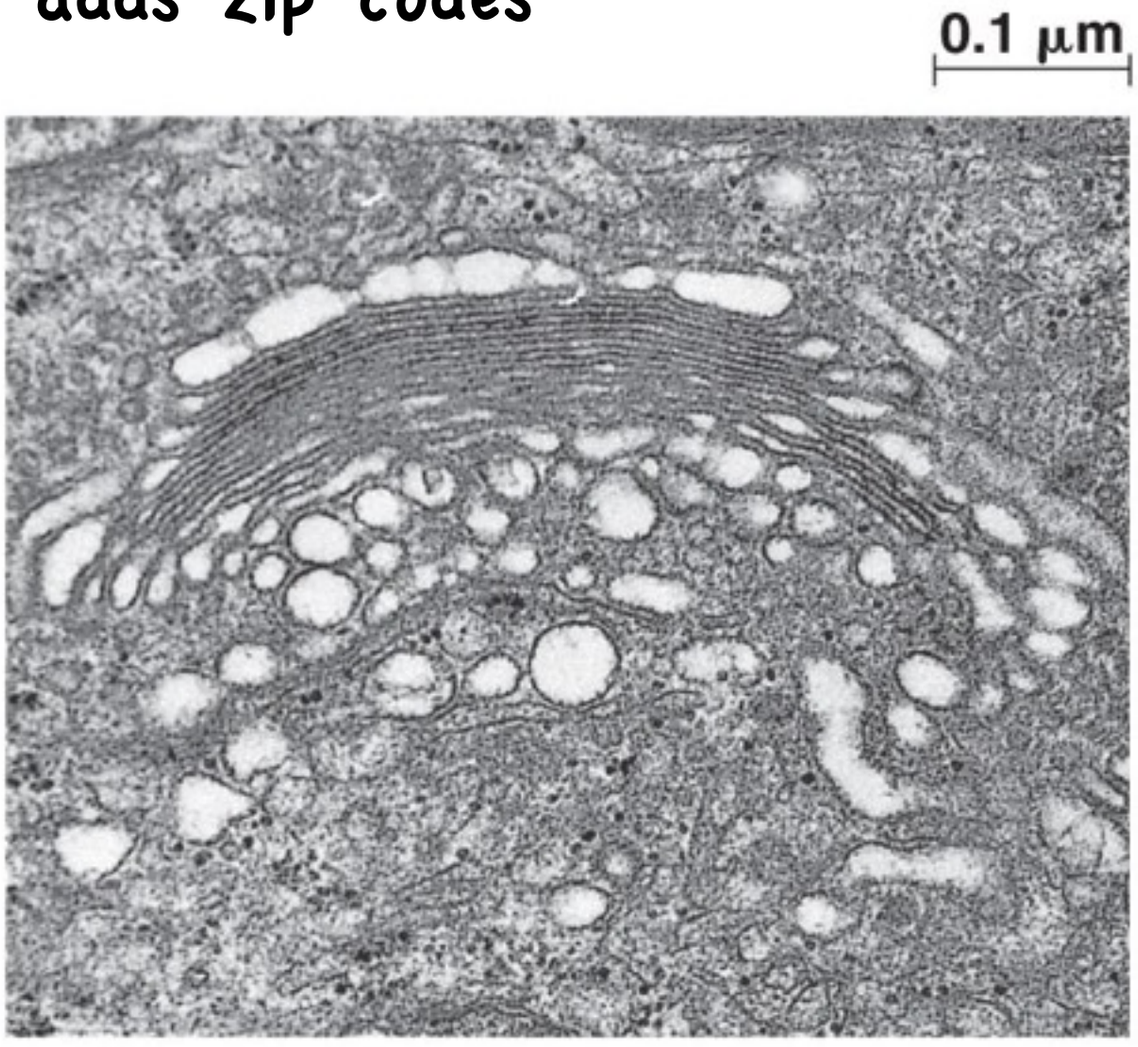
- **The rough E.R. is still "E.R." it has the same functions as the smooth E.R. + some!**
- The rough E.R. specializes in producing proteins that are destined for export or to become part of a membrane, they are called ***secretory proteins***
  - Most *secretory proteins* are ***glycoproteins***, they have sugars attached to them
    - These proteins are kept separate from cytoplasmic proteins by the endomembrane system
- ***Transport vesicles*** move these proteins from the E.R. to their destination

The Golgi Apparatus: Shipping & Receiving Center

- Receives products of E.R., *these products are modified then stored or sent to their destination.*
- The Golgi stacks have distinct structural directionality
  - The E.R. side is called the *cis side... it receives*
  - The side closest to the plasma membrane is called the *trans side...it ships*

Specifically modifies glycoproteins & phospholipids





TEM of Golgi apparatus

Lysosomes: Digestive Compartments

- A membranous sac of hydrolytic enzymes that animal cell uses to digest macromolecules
- These hydrolytic enzymes work best in acidic environments, found in lysosomes
- **Theme: Internal environment different from external environment**

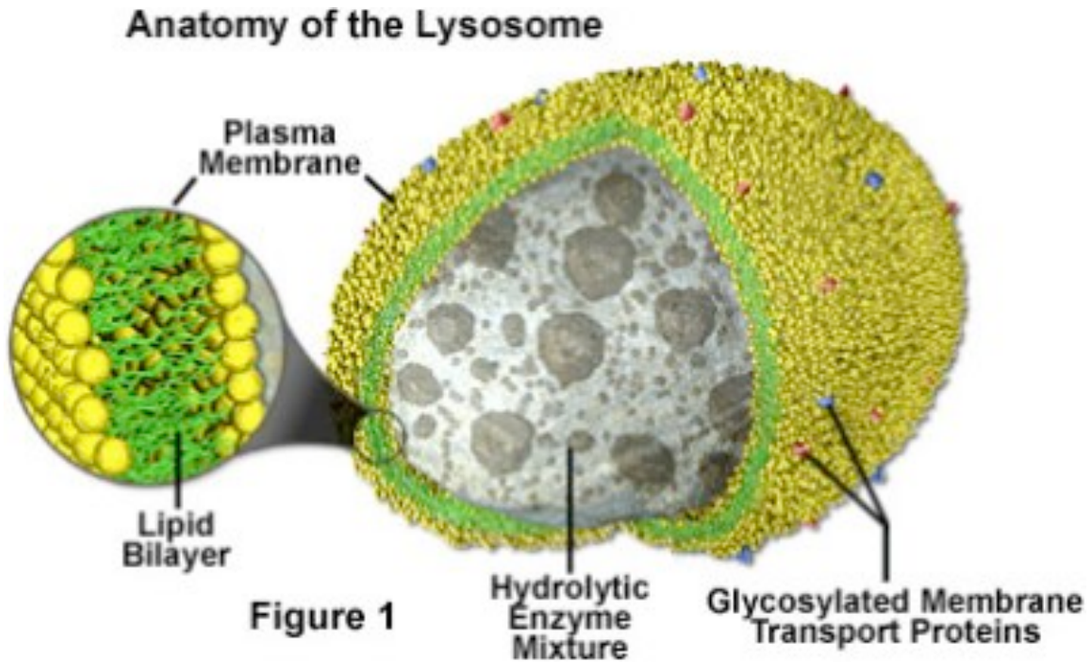


Figure 1

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Animal Cells Only

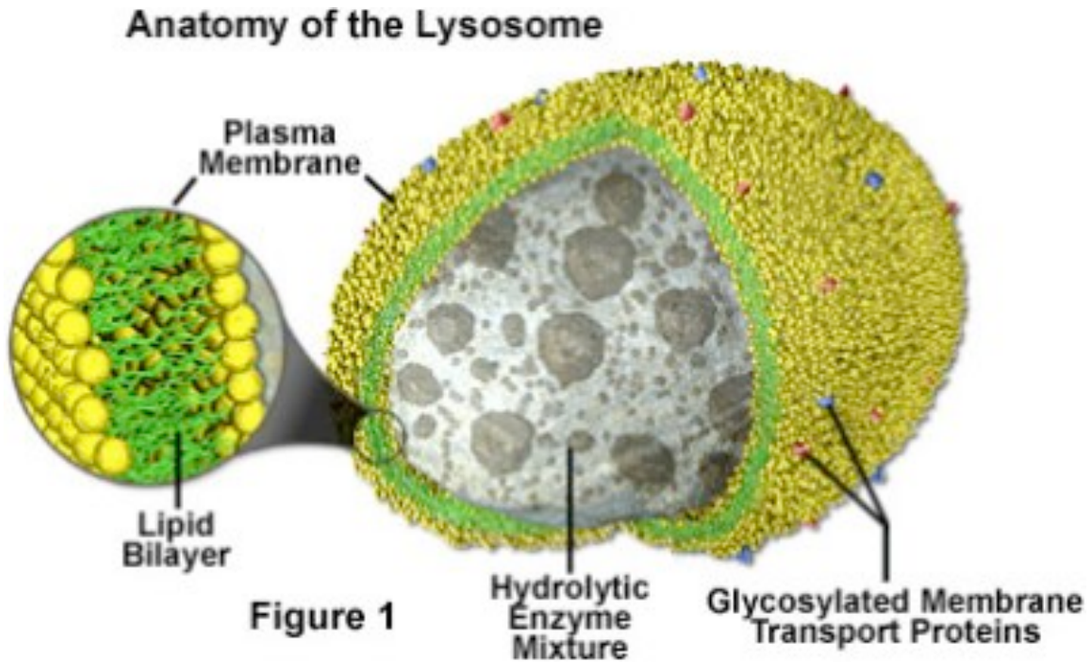
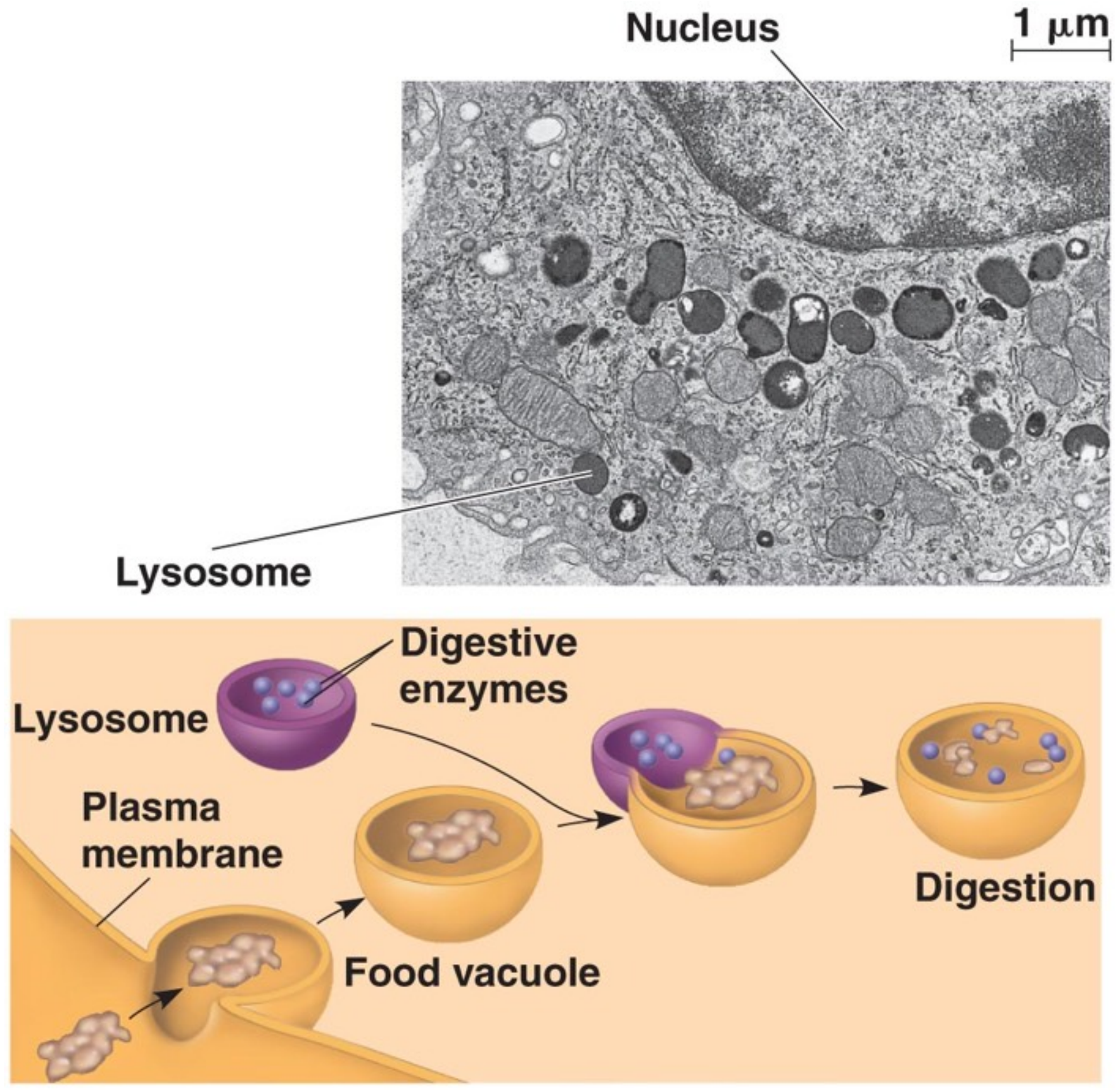
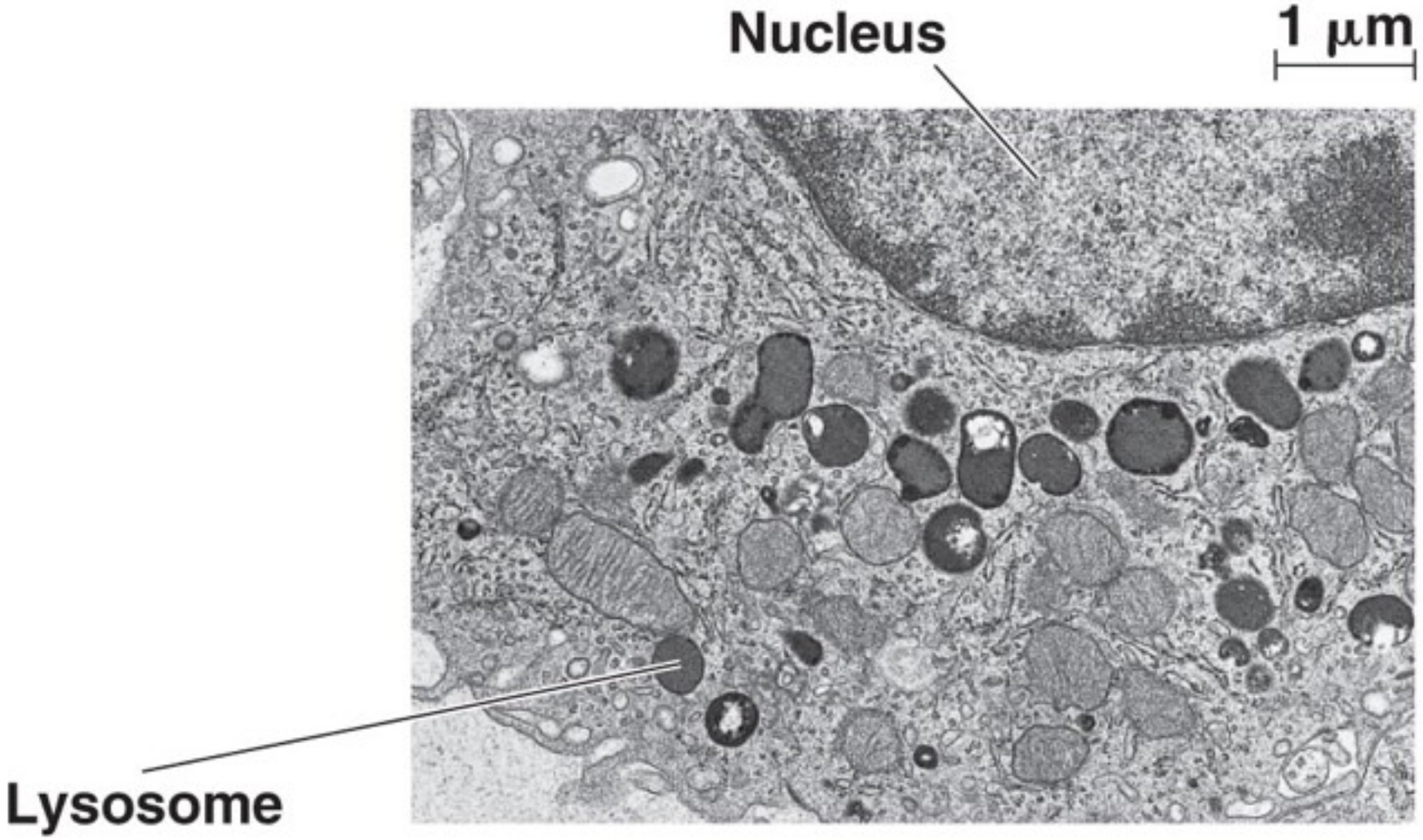


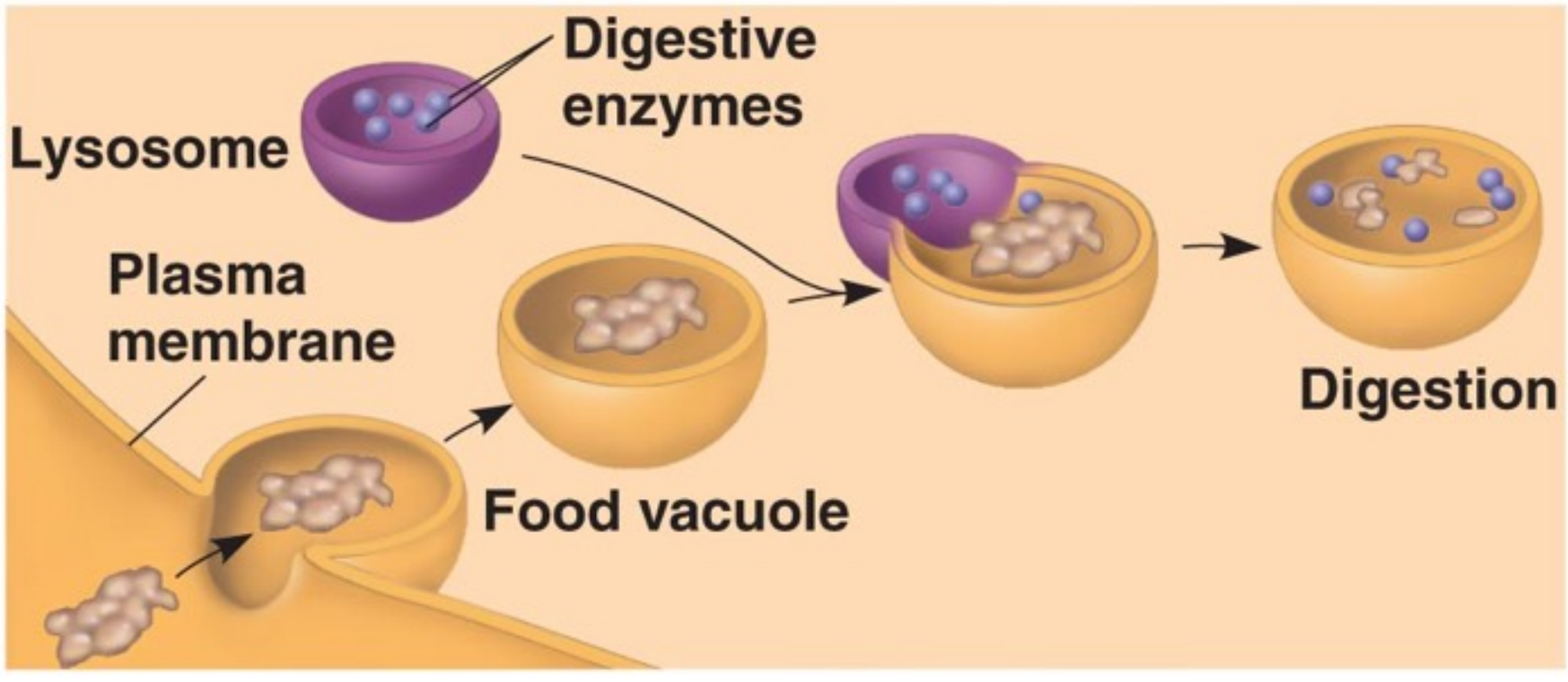
Figure 1



(a) Phagocytosis

White Blood Cells fight infections through phagocytosis





(a) Phagocytosis

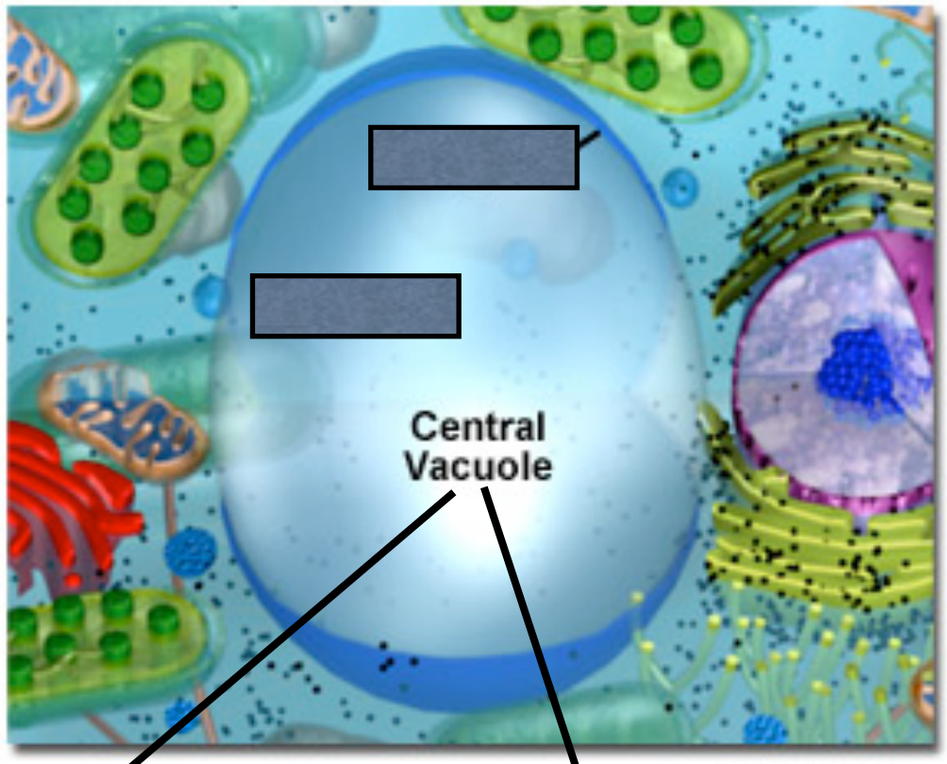
Vacuoles: Diverse Maintenance Compartments

- Large vesicles derived from E.R. or Golgi
  - **Theme: Internal environment different from external environment**
- Performs a variety of functions:
  - *Food vacuoles*; protists (last slide)
  - *Contractile Vacuoles*; freshwater protists (use them to pump out excess water thus controlling solute concentrations

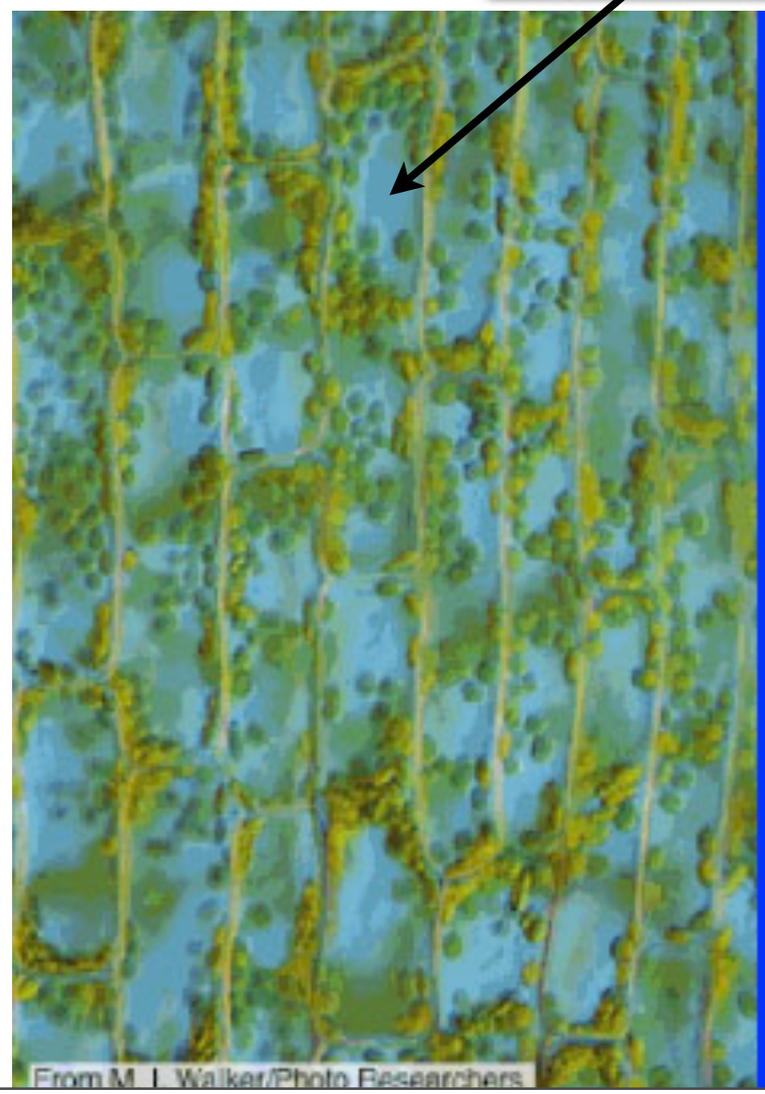
Vacuoles: continued

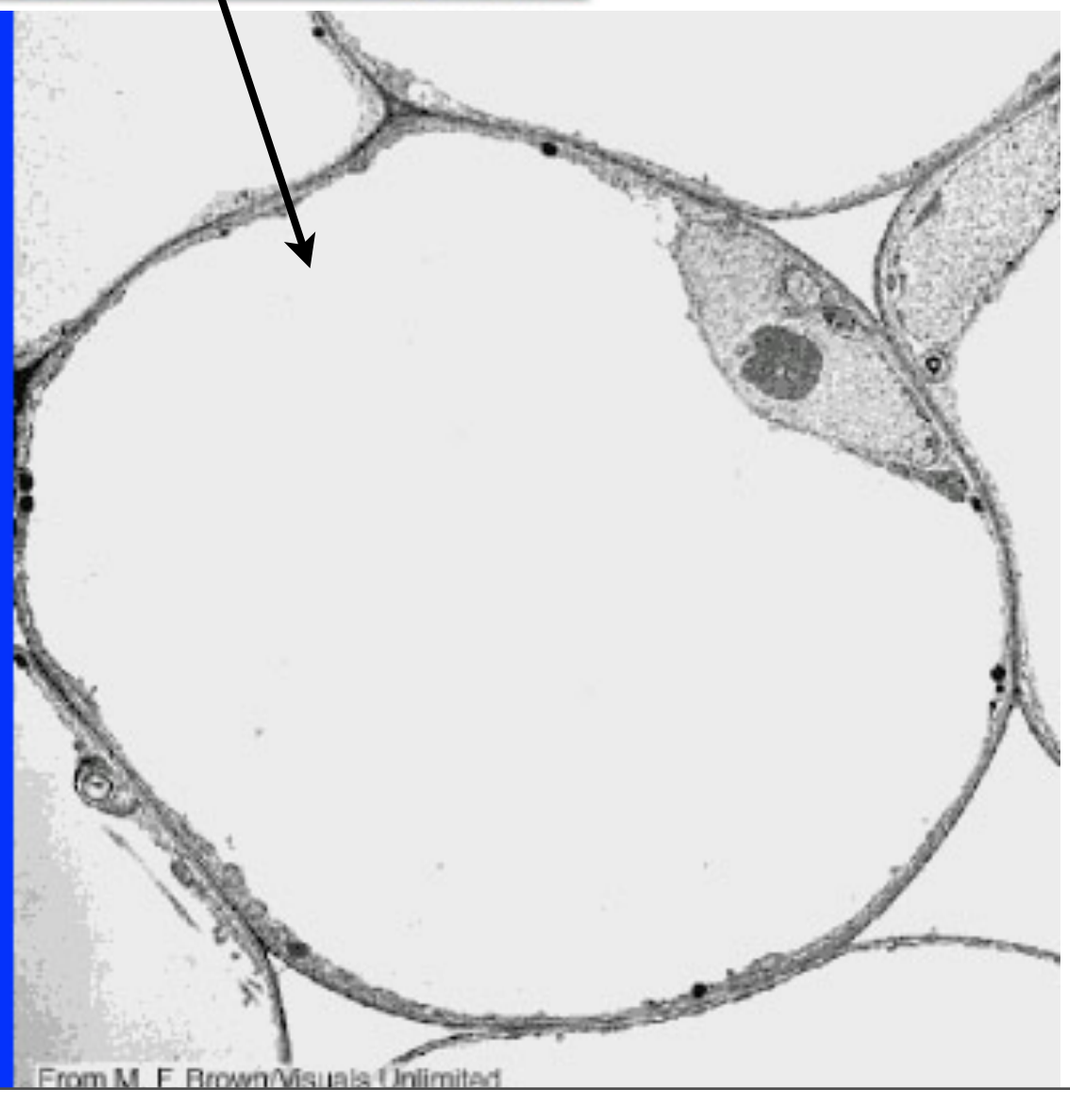
- Performs a variety of functions, perhaps plants and fungi show the most variation in their use of vacuoles:
  - *Hydrolytic vacuoles*; analogous to animal lysosomes
  - *Storage Vacuoles*;
    - a reserve of important organic compounds
    - a reserve of poisonous compounds for defense
    - container of pigments to attract pollinators
  - *Central Vacuoles*; a large vacuole that is repository of inorganic ions (calcium, potassium)
    - Important for plant cell growth, water is absorbed... cell enlarges with minimal investment in new cytoplasm

Plant Cell Central Vacuole

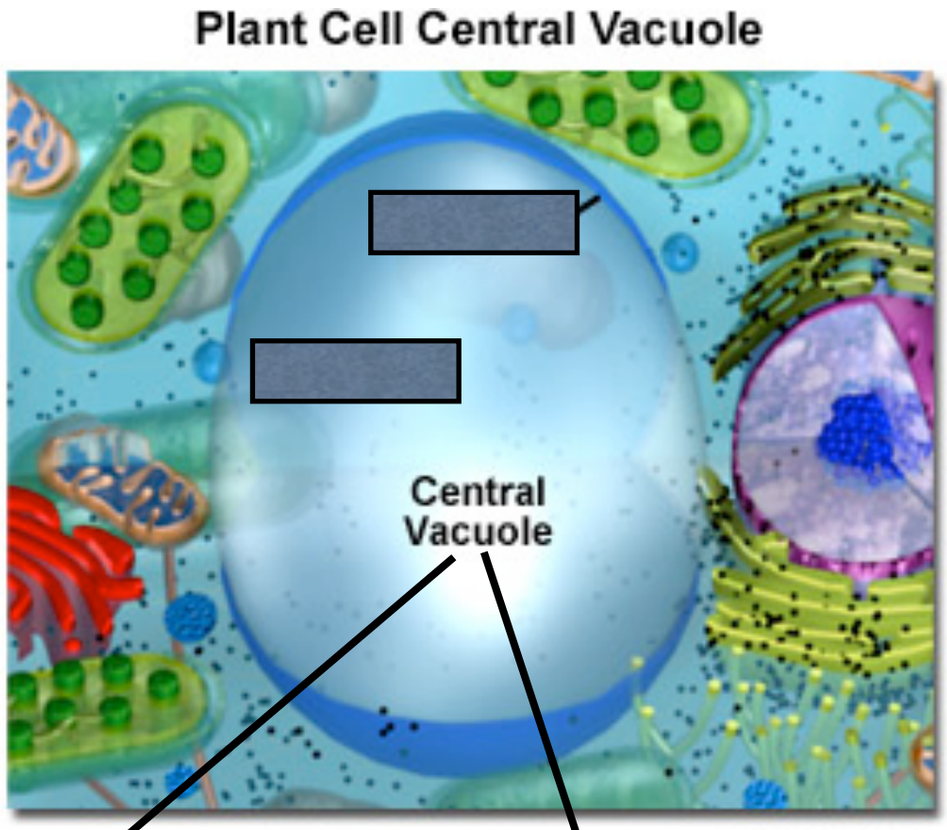


Can account for 50-70% of Cell Volume





Plant Cells Only



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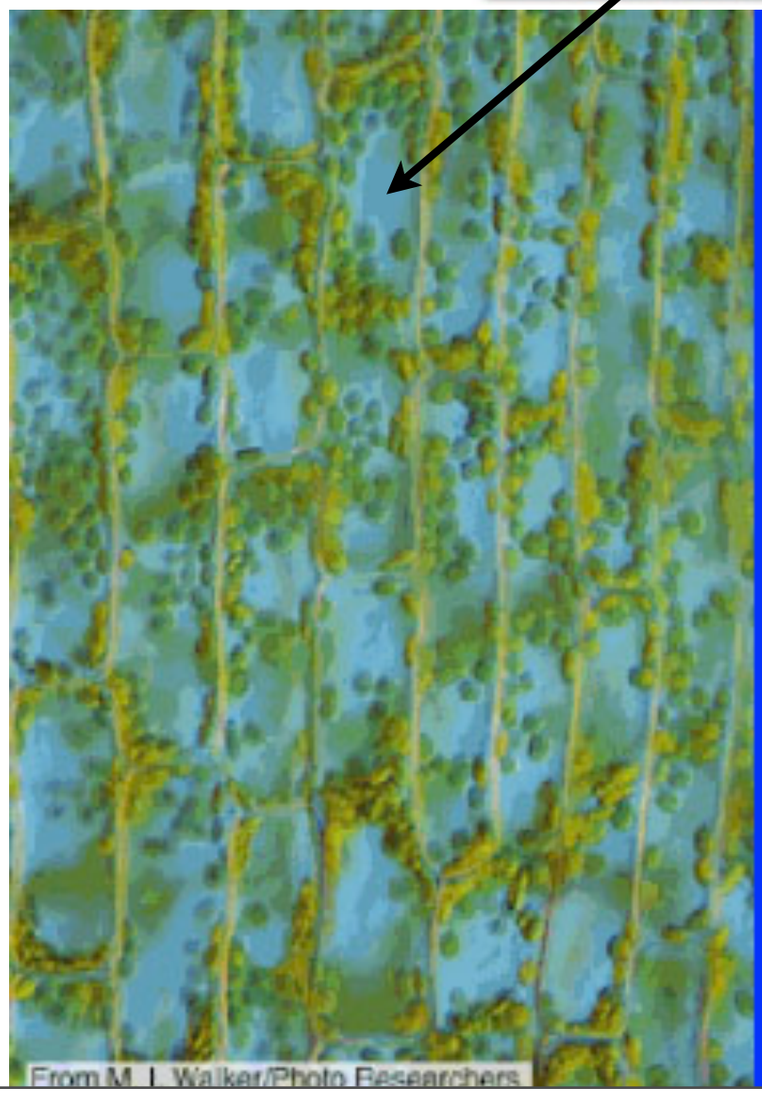

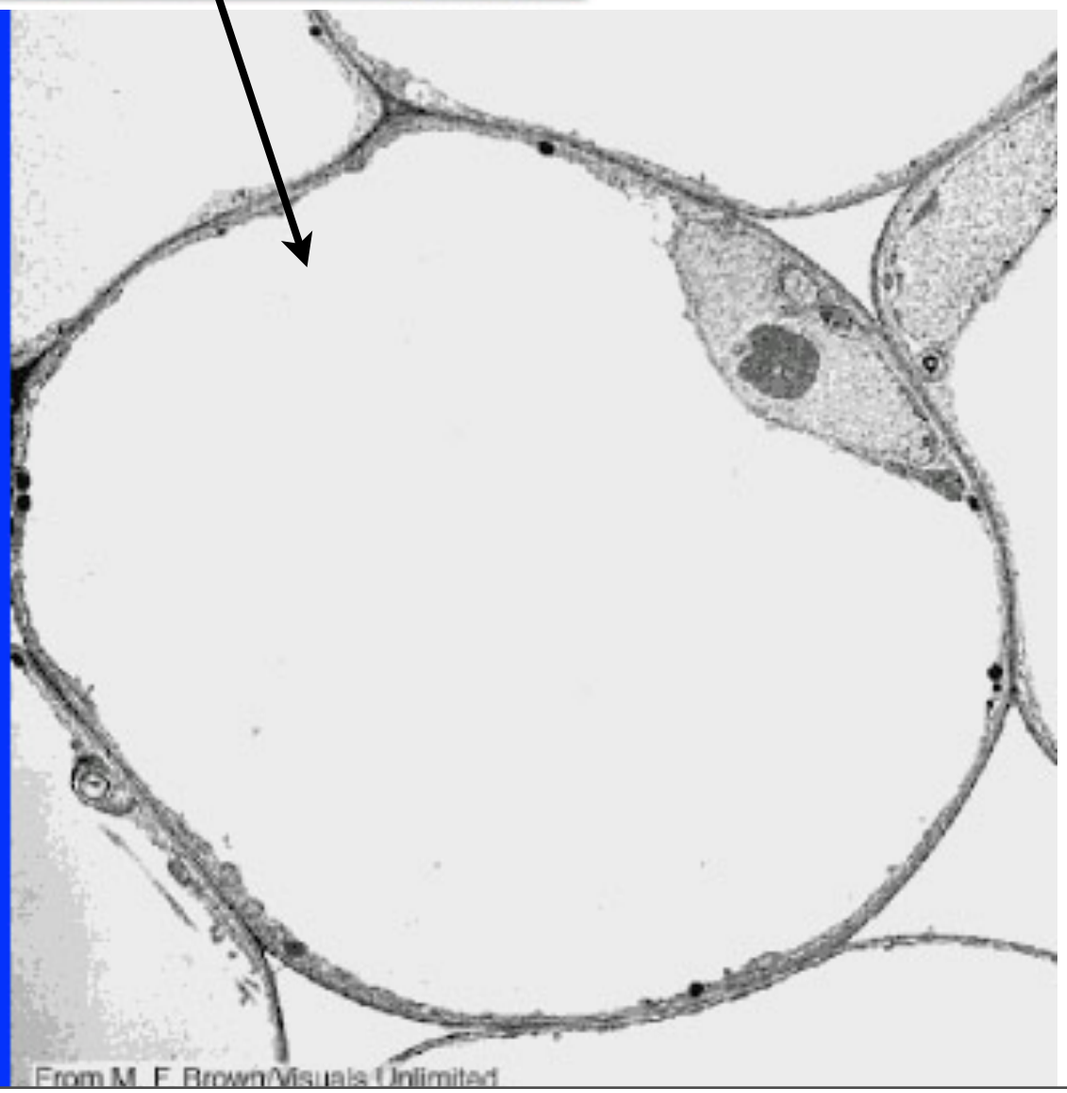

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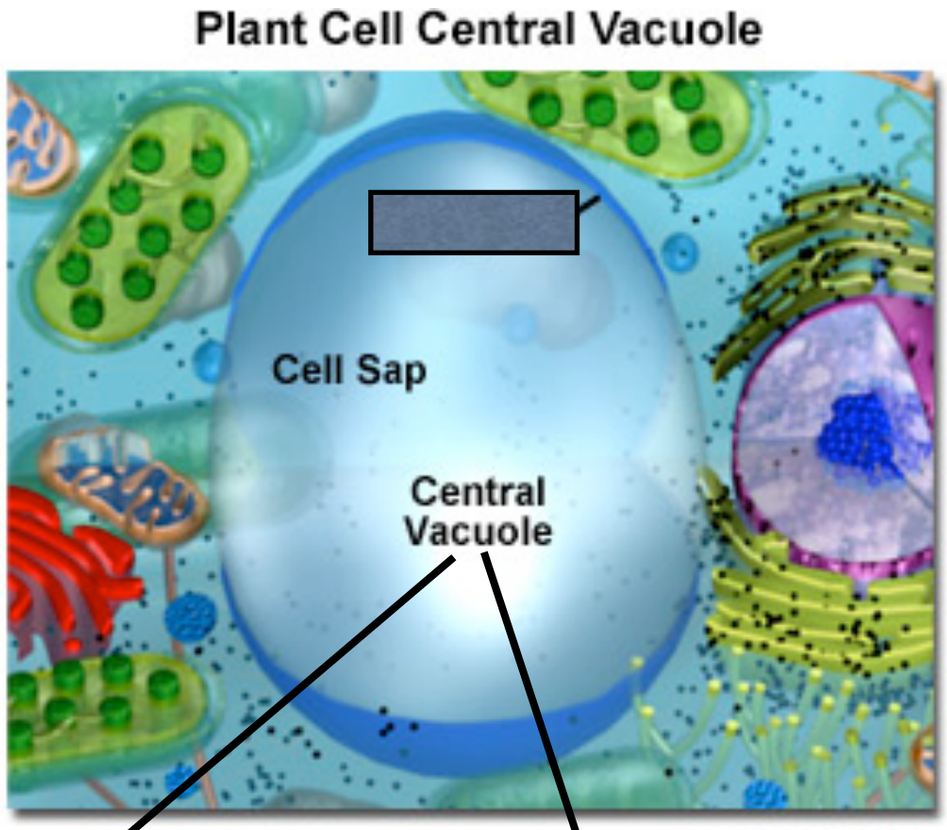

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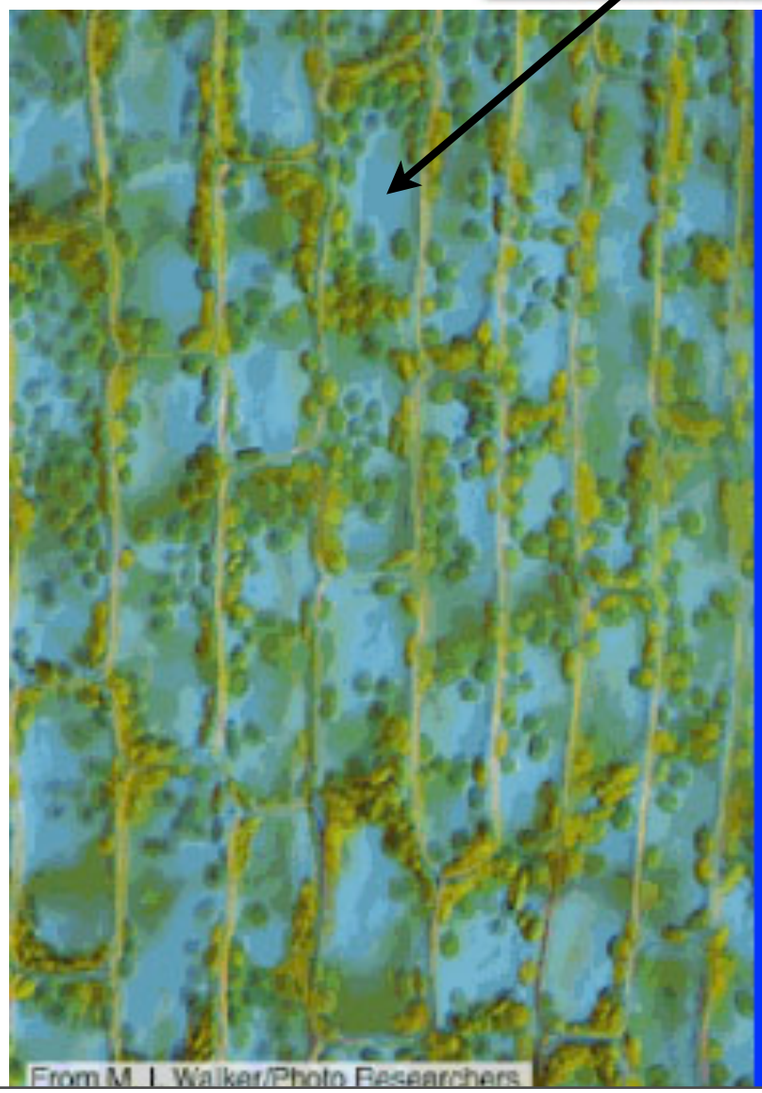

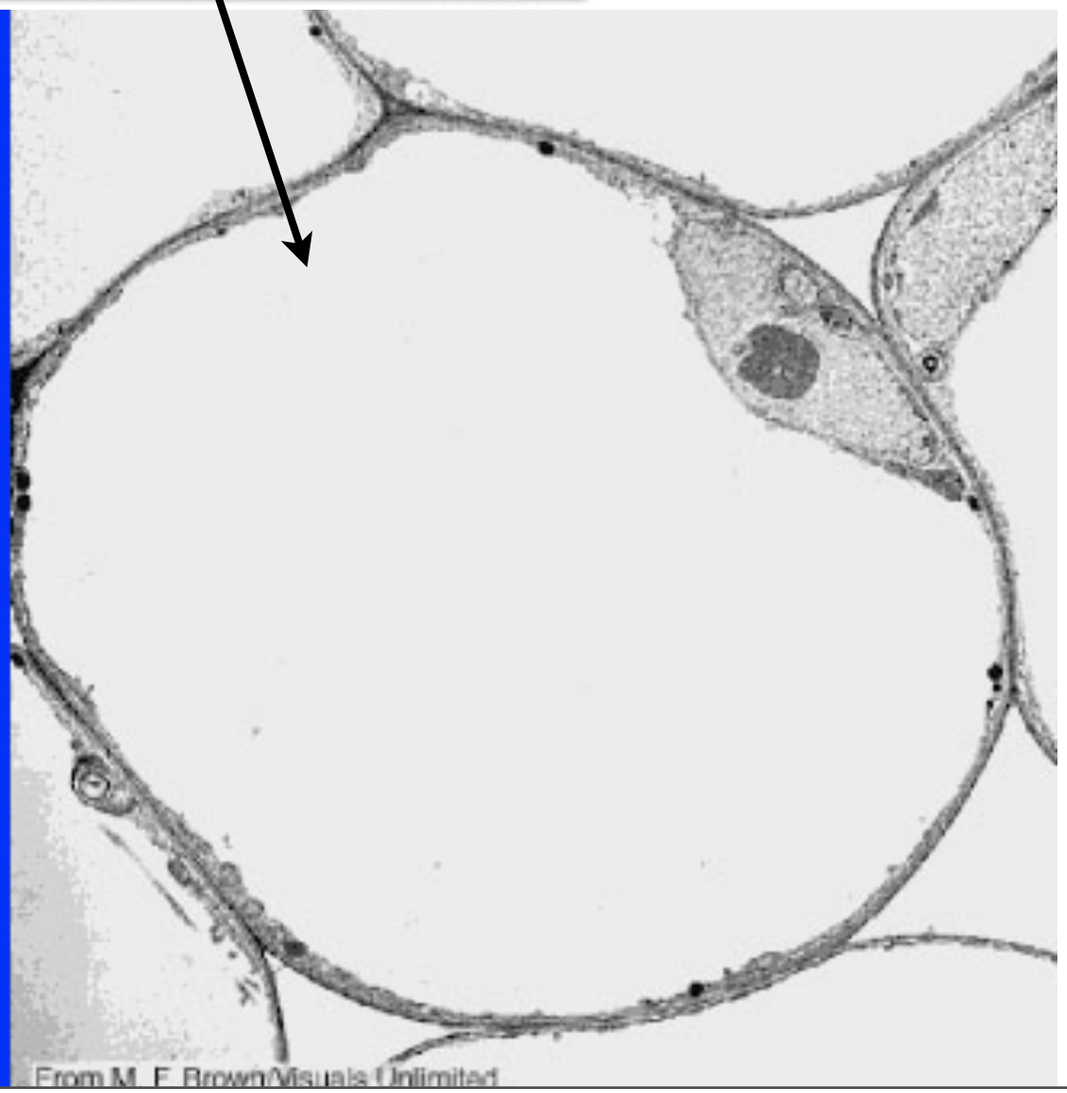

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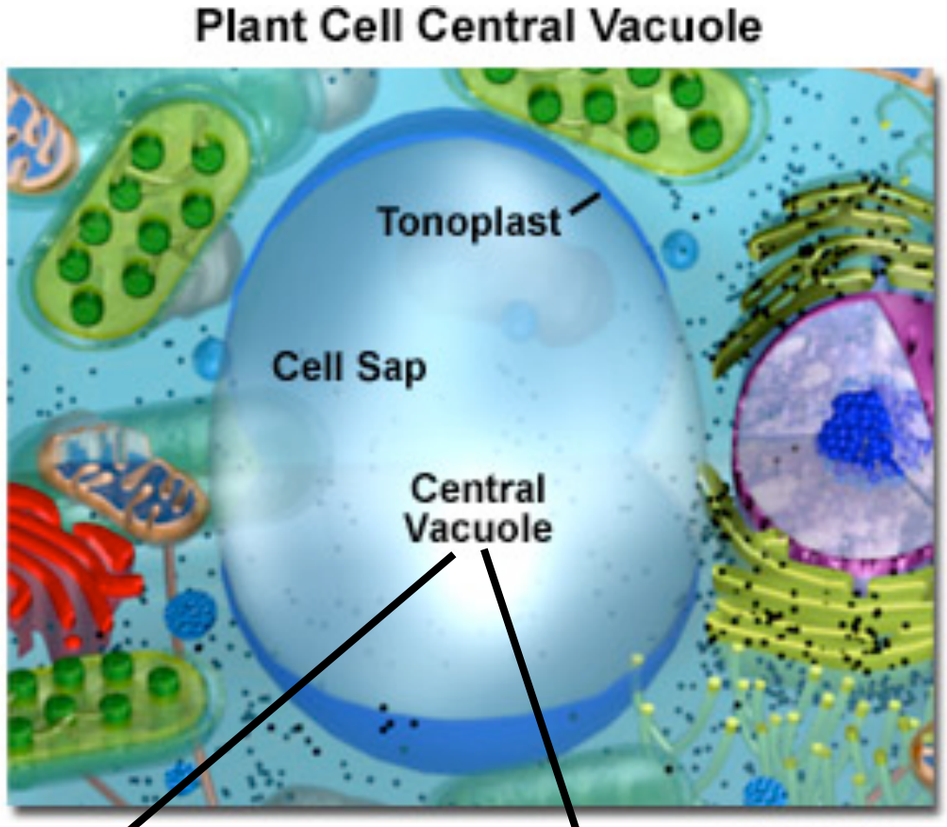
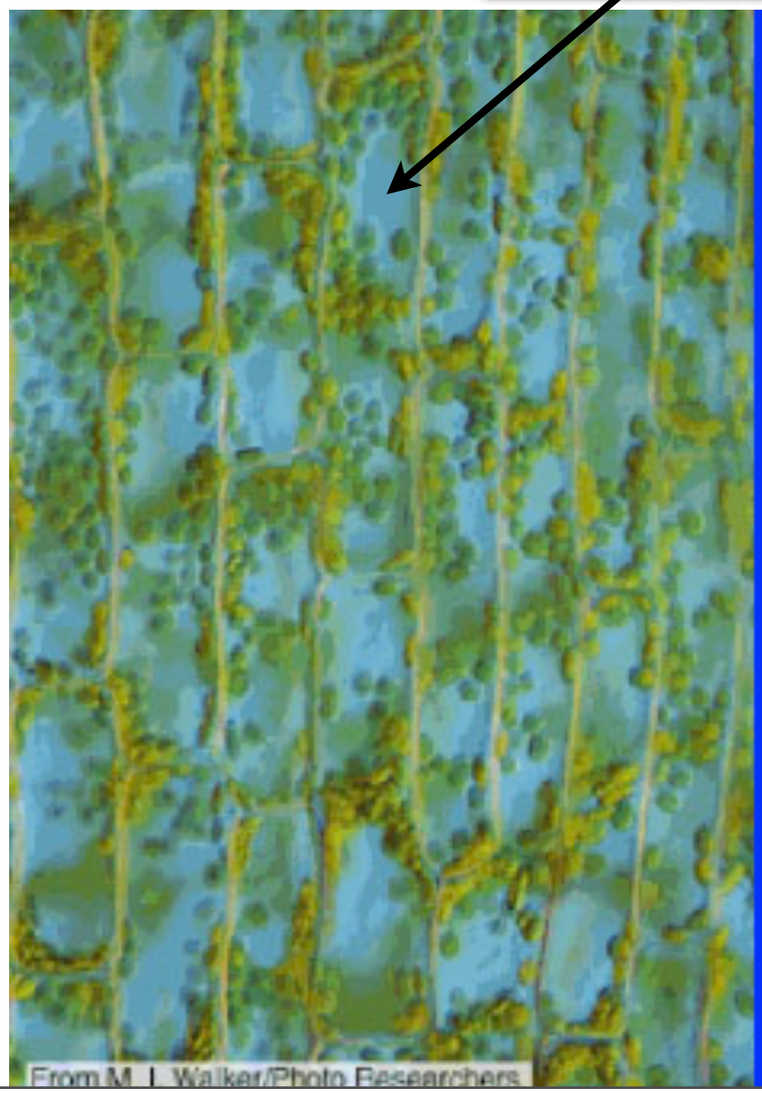
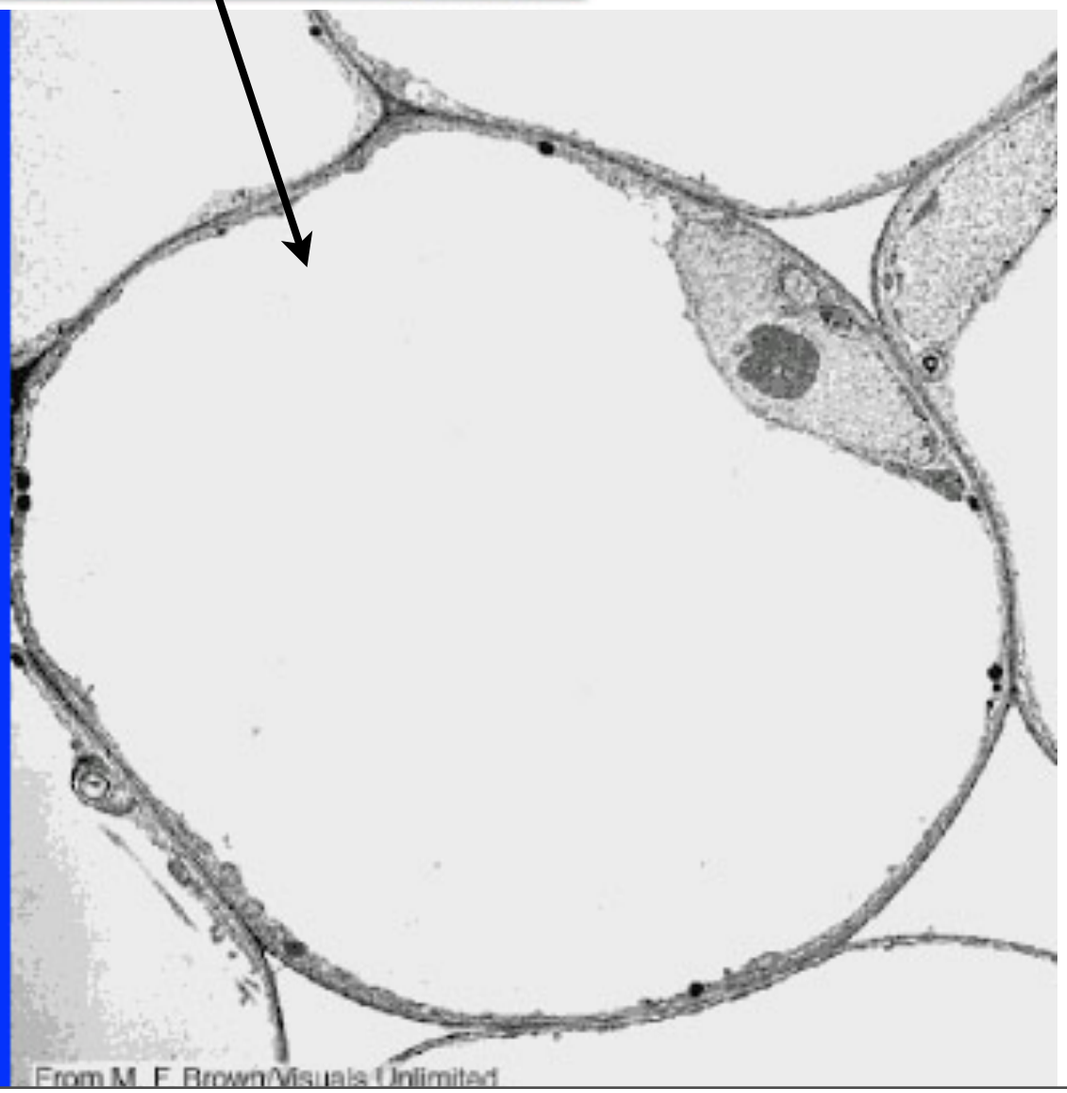


Can account for 50-70% of Cell Volume

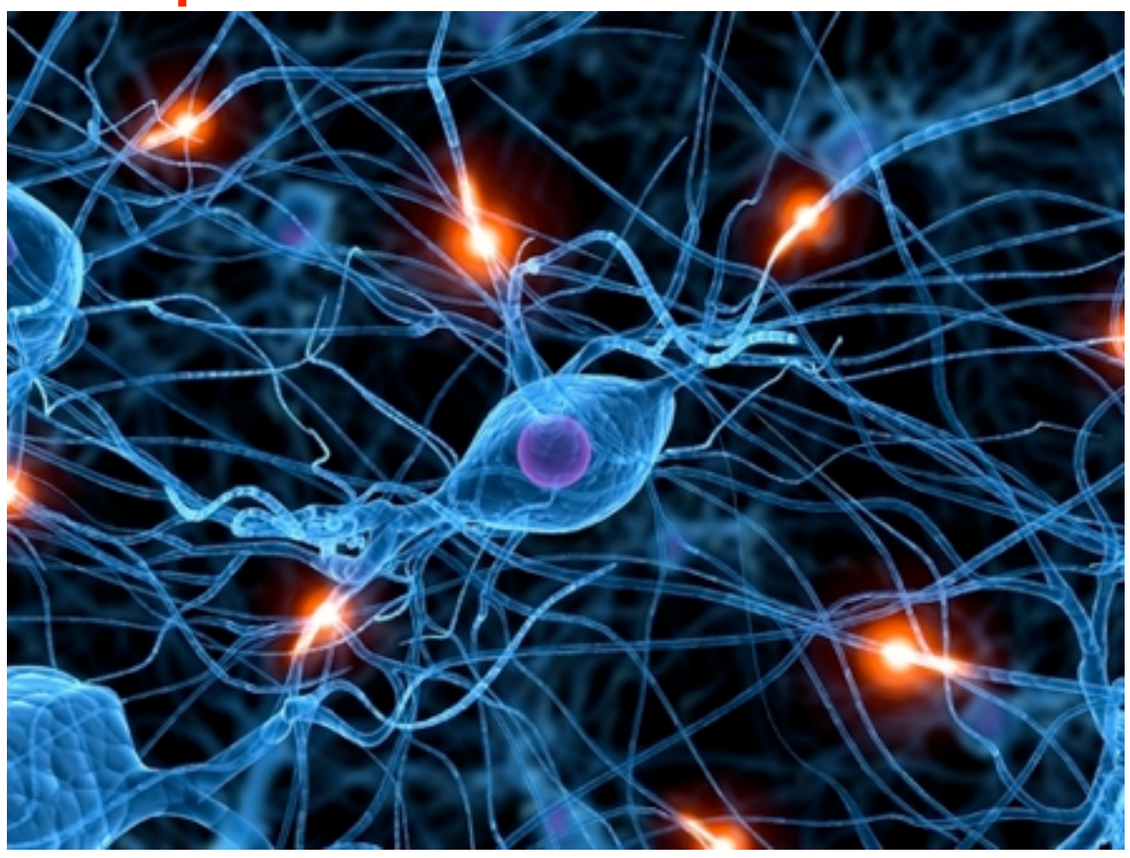




Tour of the Cell

Main Idea: In Eukaryotic cells the mitochondria and chloroplasts are the organelles that convert energy into forms that the cell can use to do work.

Main Idea: The mitochondria and chloroplasts also have similar evolutionary origins.



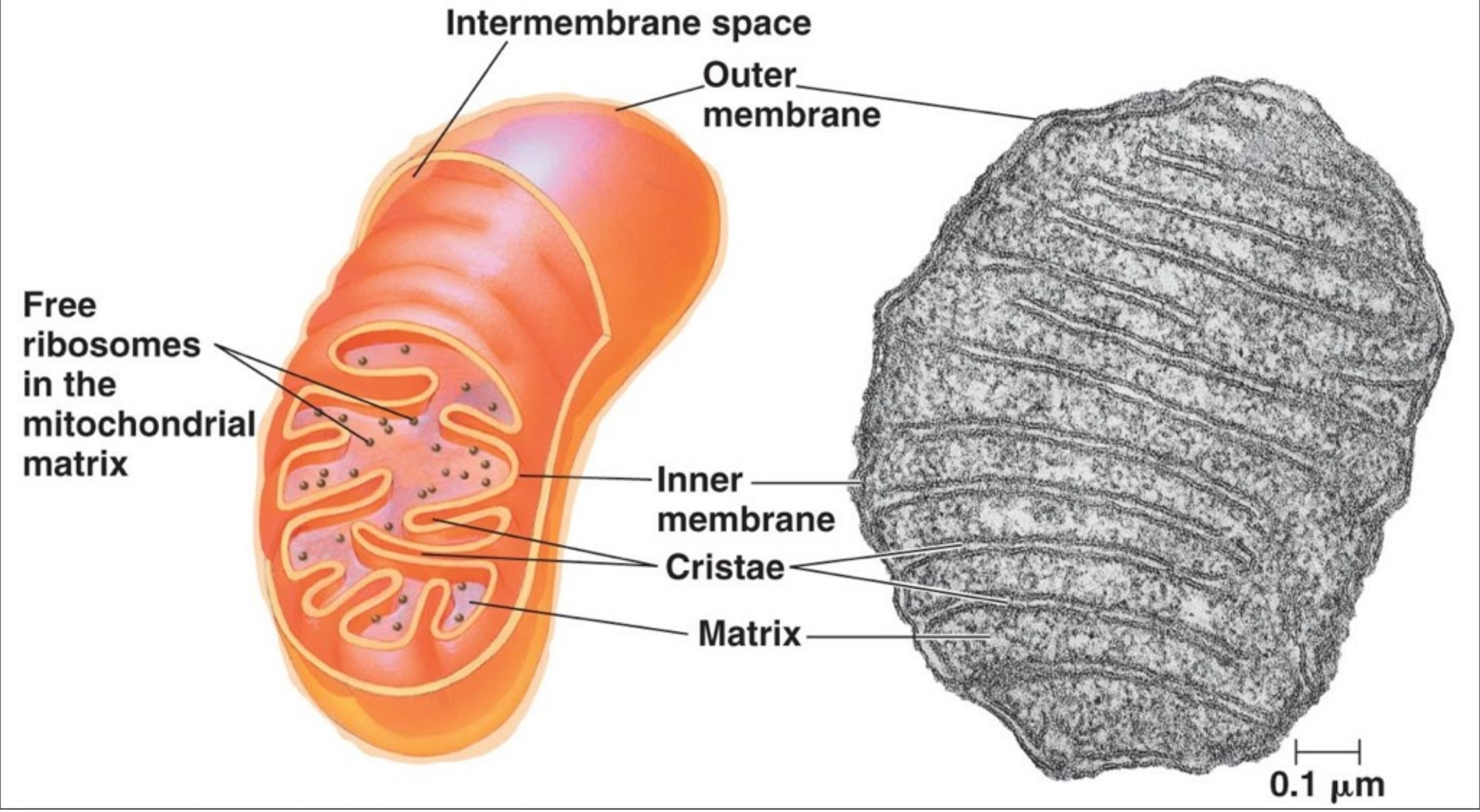
MITOCHONDRIA AND CHLOROPLASTS CHANGE ENERGY FROM ONE FORM TO ANOTHER

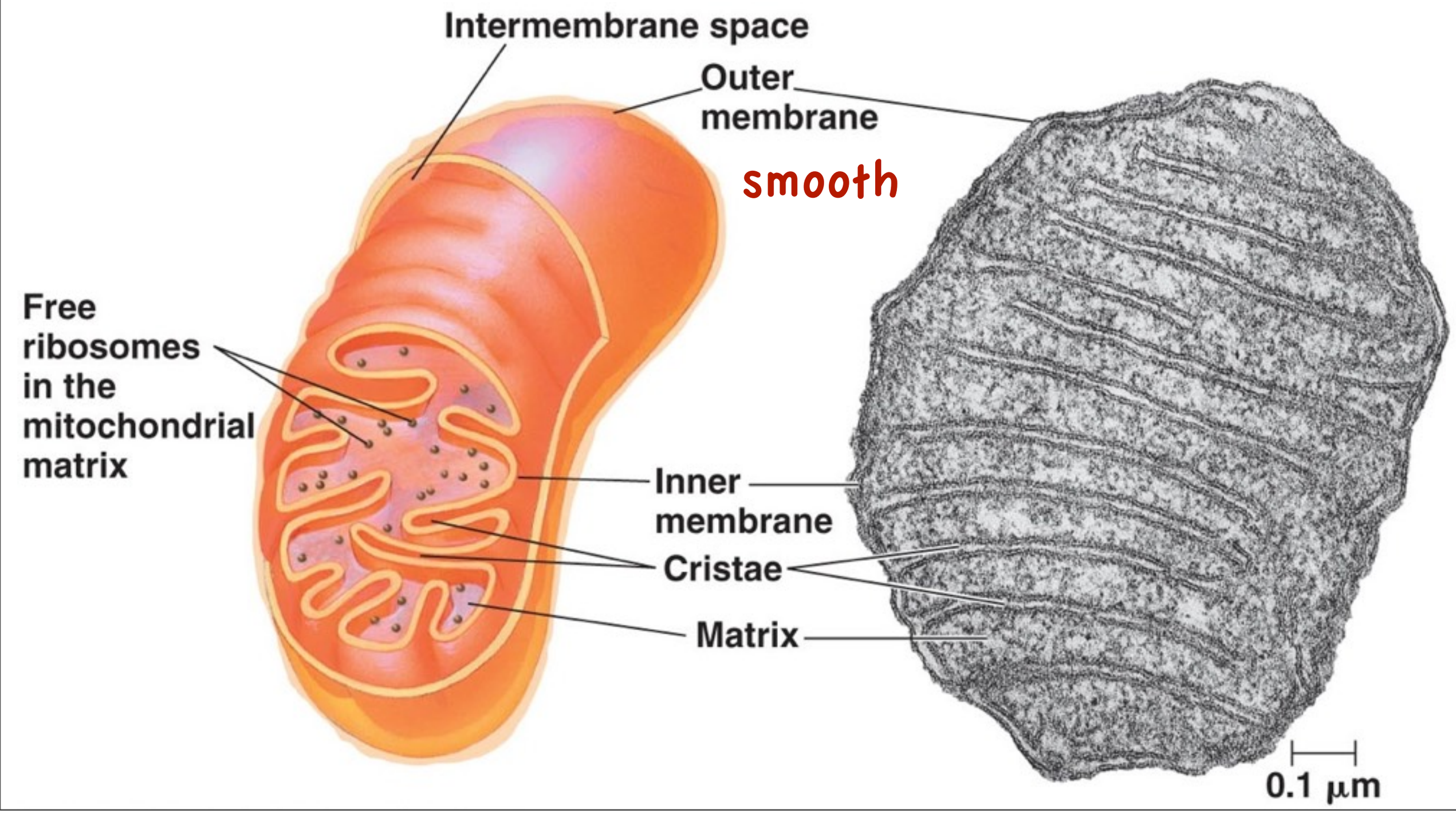
- ***Chloroplasts*** **use solar energy to build sugars from carbon dioxide and water.**
- ***Mitochondria*** **use the stored chemical energy in macromolecules such as sugars and fats to generate ATP (cellular fuel).**

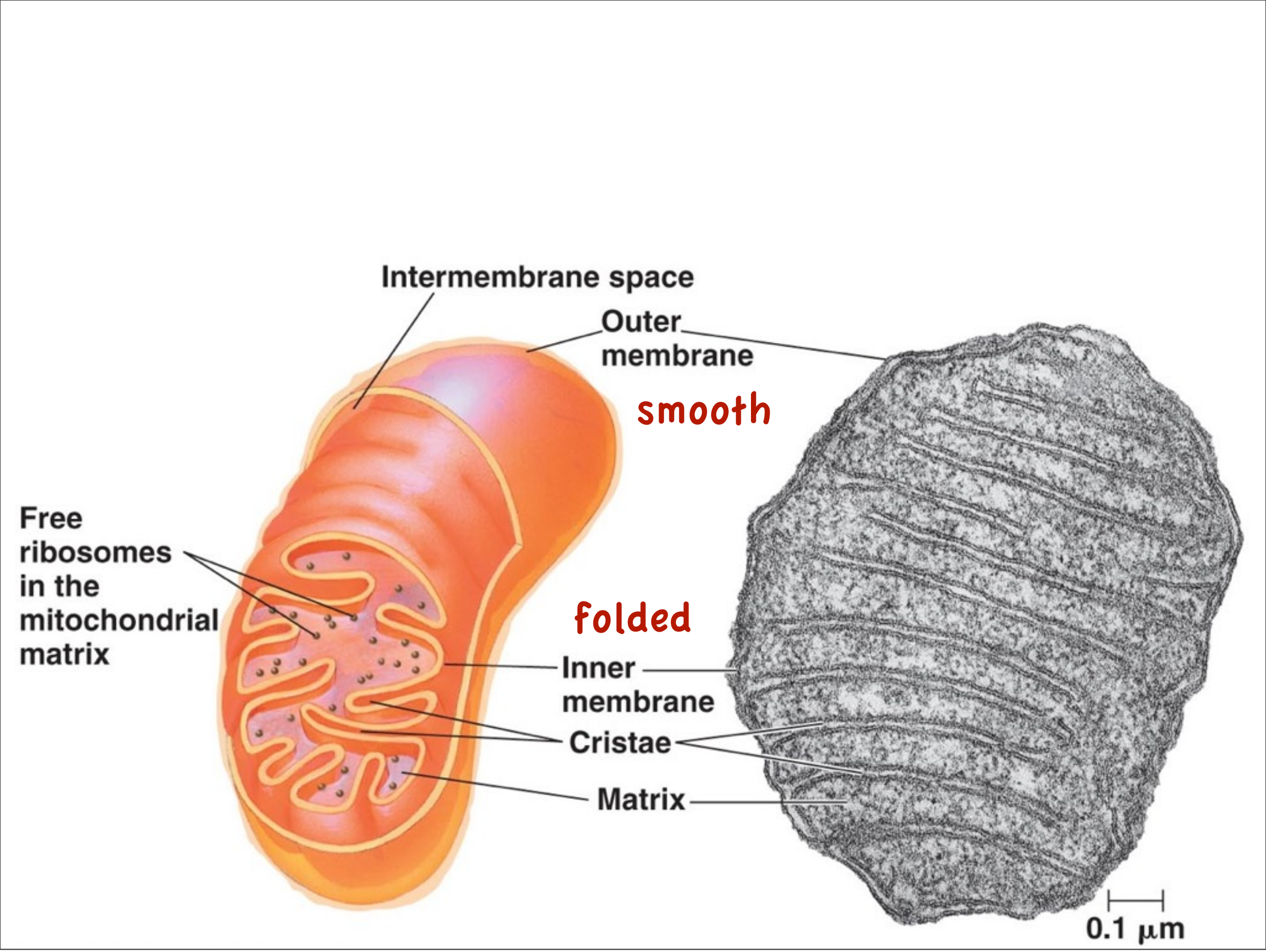
Mitochondria: Chemical Energy Conversion

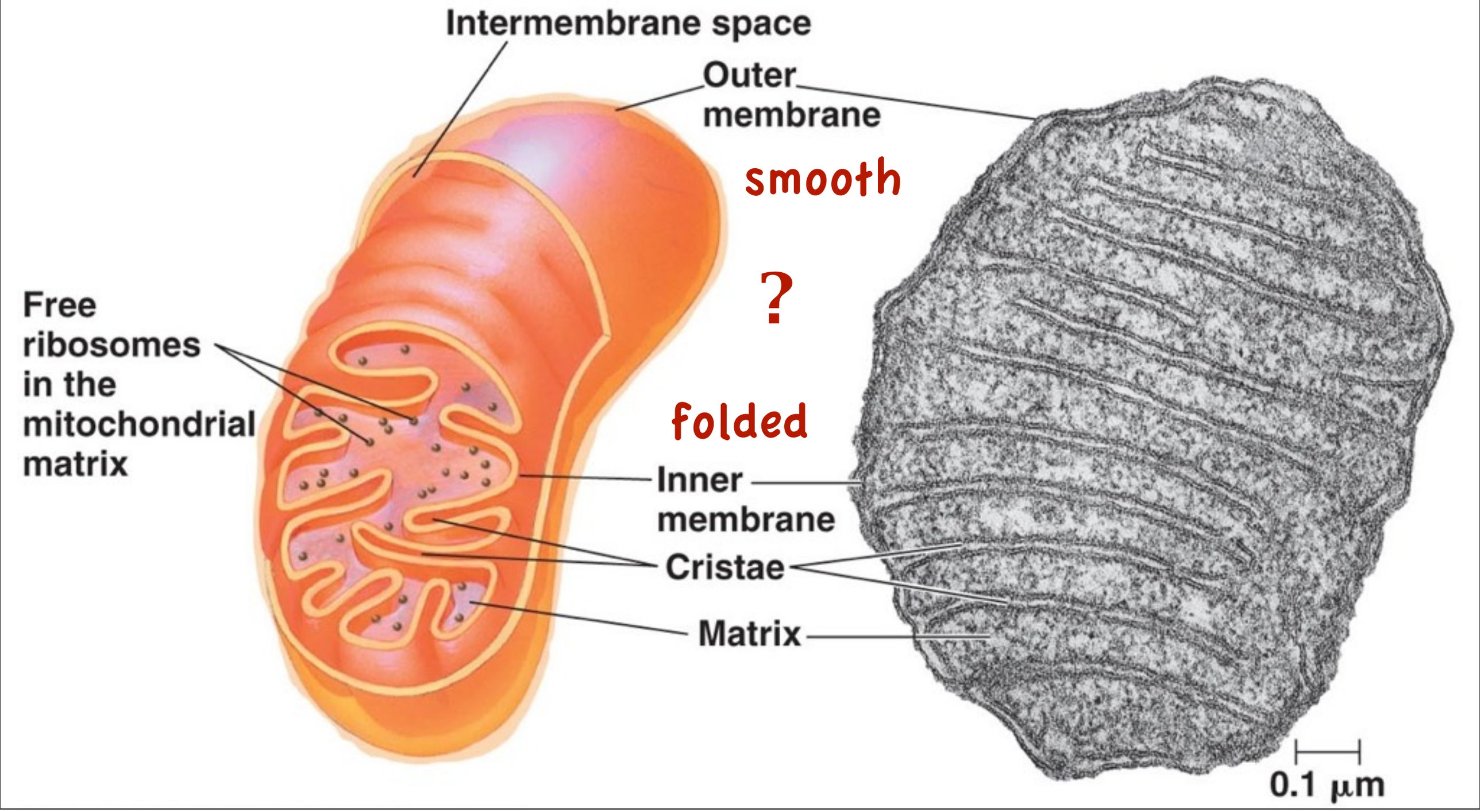
- **Found in nearly all eukaryotic cells**
  - animals, plants, fungi and most protists
- **A cell can have one, but more often has hundreds or thousands**
  - number correlates to metabolic level of the cell
- **Mitochondria are dynamic; they move, they grow and occasionally pinch into two**

Footnote: We will look at this organelle in more detail in the cell respiration unit.

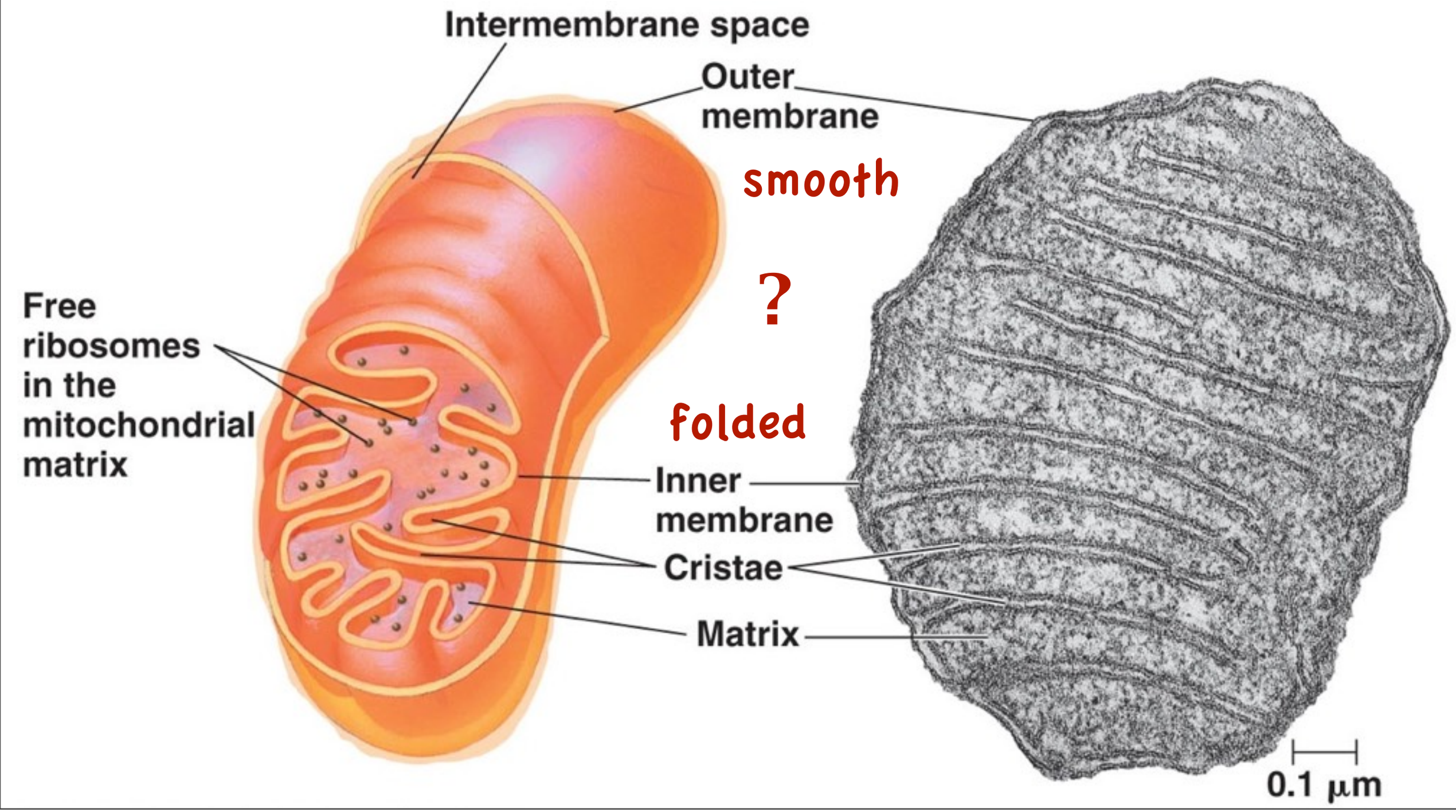

Intermembrane space
Outer membrane
Free ribosomes in the mitochondrial matrix
Inner membrane
Cristae
Matrix
0.1 μm


Intermembrane space
Outer membrane
smooth
Free ribosomes in the mitochondrial matrix
Inner membrane
Cristae
Matrix
0.1 μm


Intermembrane space
Outer membrane
smooth
Free ribosomes in the mitochondrial matrix
folded
Inner membrane
Cristae
Matrix
0.1 µm


Intermembrane space
Outer membrane
smooth
?
folded
Free ribosomes in the mitochondrial matrix
Inner membrane
Cristae
Matrix
0.1 µm

We will learn more about each area and its contents and functions in the cell respiration unit



Chloroplasts: Capture of Light Energy

- **Found in plants and algae**
  - chloroplasts contain a green pigment called chlorophyll
- **Chloroplasts are dynamic; they move, they grow and occasionally pinch into two**
- **Belong to the family of plastids, organelles that manufacture and store compounds. Most contain pigments. (see next slide)**

Footnote: We will look at this organelle in more detail in the cell respiration unit.

Comparing Mitochondria and Chloroplasts

Mitochondria	Chloroplasts
• Converts energy to useable forms.	• Ditto
• Not part of endomembrane system.	• Ditto
• Has double membrane.	• Ditto
• Grows and reproduces.	• Ditto
• Has its own DNA and ribosomes.	• Ditto
• Semi-autonomous.	• Ditto
• Site for cell respiration	• Site for photosynthesis
• Found in both animal and plant cells	• Found in plant cells and eukaryotic algae

Peroxisomes: Oxidation

- **A Specialized Metabolic Compartment**
- **Removes hydrogen ions(H^+) from substrates and transfers them to oxygen (O_2) thus producing hydrogen peroxide (H_2O_2)**
  - some break down fatty acids to be used in cell respiration
  - in the liver they detoxify alcohol & poisons
- Hydrogen peroxide (H_2O_2) is itself toxic BUT there are enzymes in the peroxisomes that convert H_2O_2 back to water
- **Yet another great example of the importance of compartmentalization!**

Comparing Animal and Plant Cells

Animal Cells

- Lysosomes
- Centrioles
- Flagella
- Gap Junctions

Plant Cells

- Chloroplasts
- Central Vacuoles
- Cell wall
- Plasmodesmata

Most cell organelles and structures are shared by both cell types

Essential knowledge 4.B.2: Cooperative interactions within organisms promote efficiency in the use of energy and matter.

2. Within multicellular organisms, specialization of organs contributes to the overall functioning of the organism.

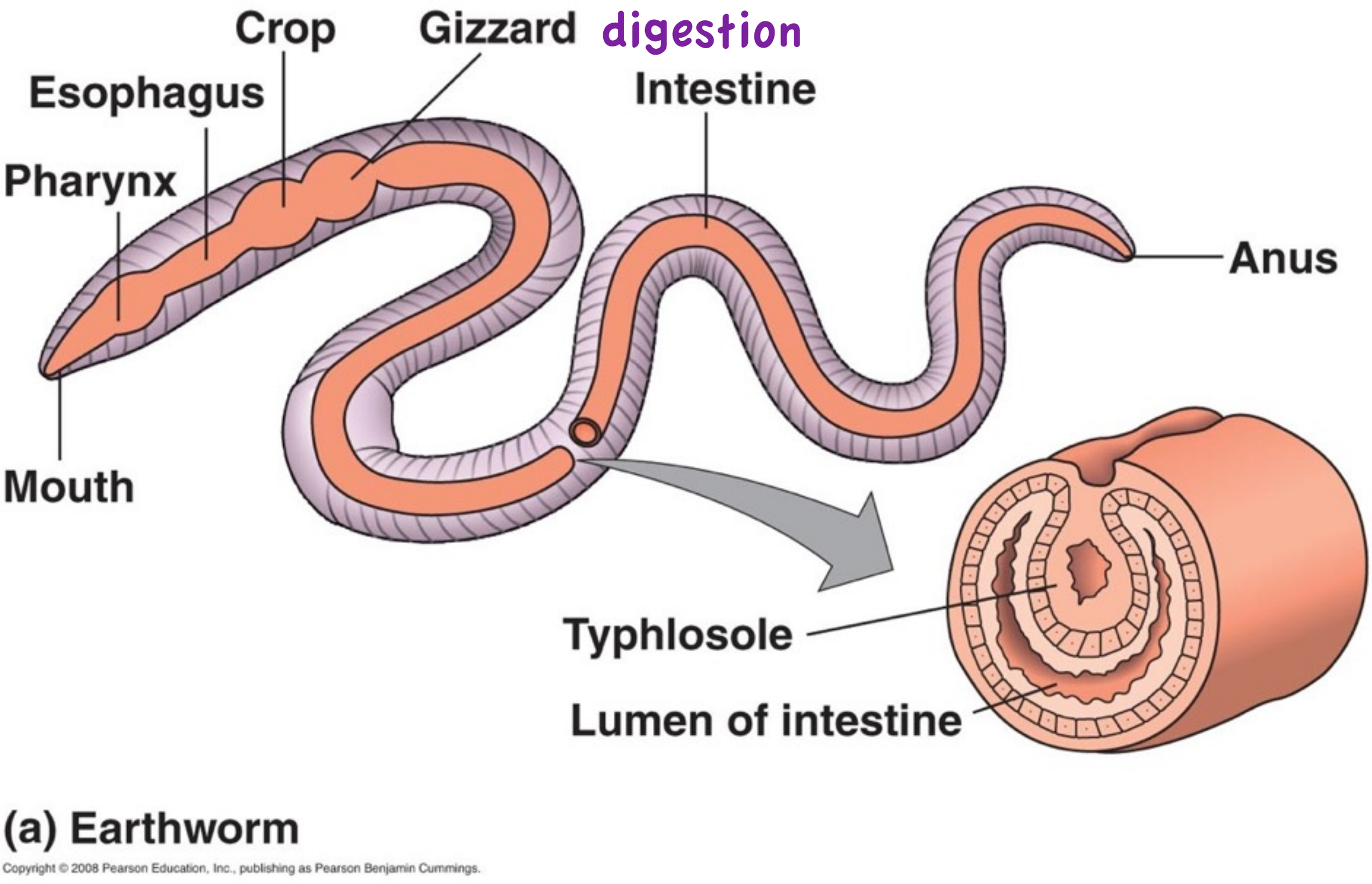
To foster student understanding of this concept, instructors can choose an illustrative example such as:

1 Exchange of gases
2 Circulation of fluids
3 Digestion of food
4 Excretion of wastes

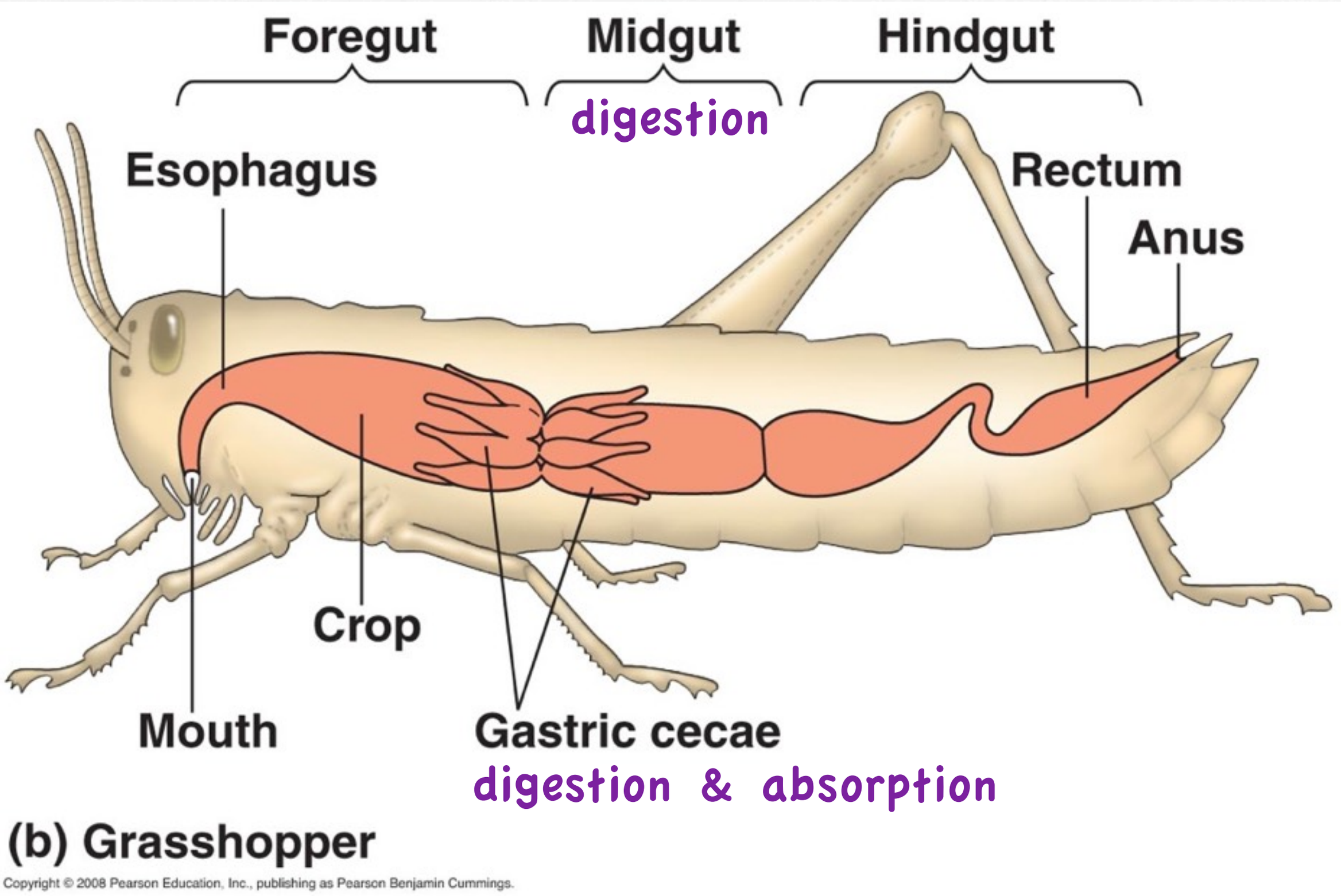
To foster student understanding of this concept, instructors can choose an illustrative example such as:

Digestion of food

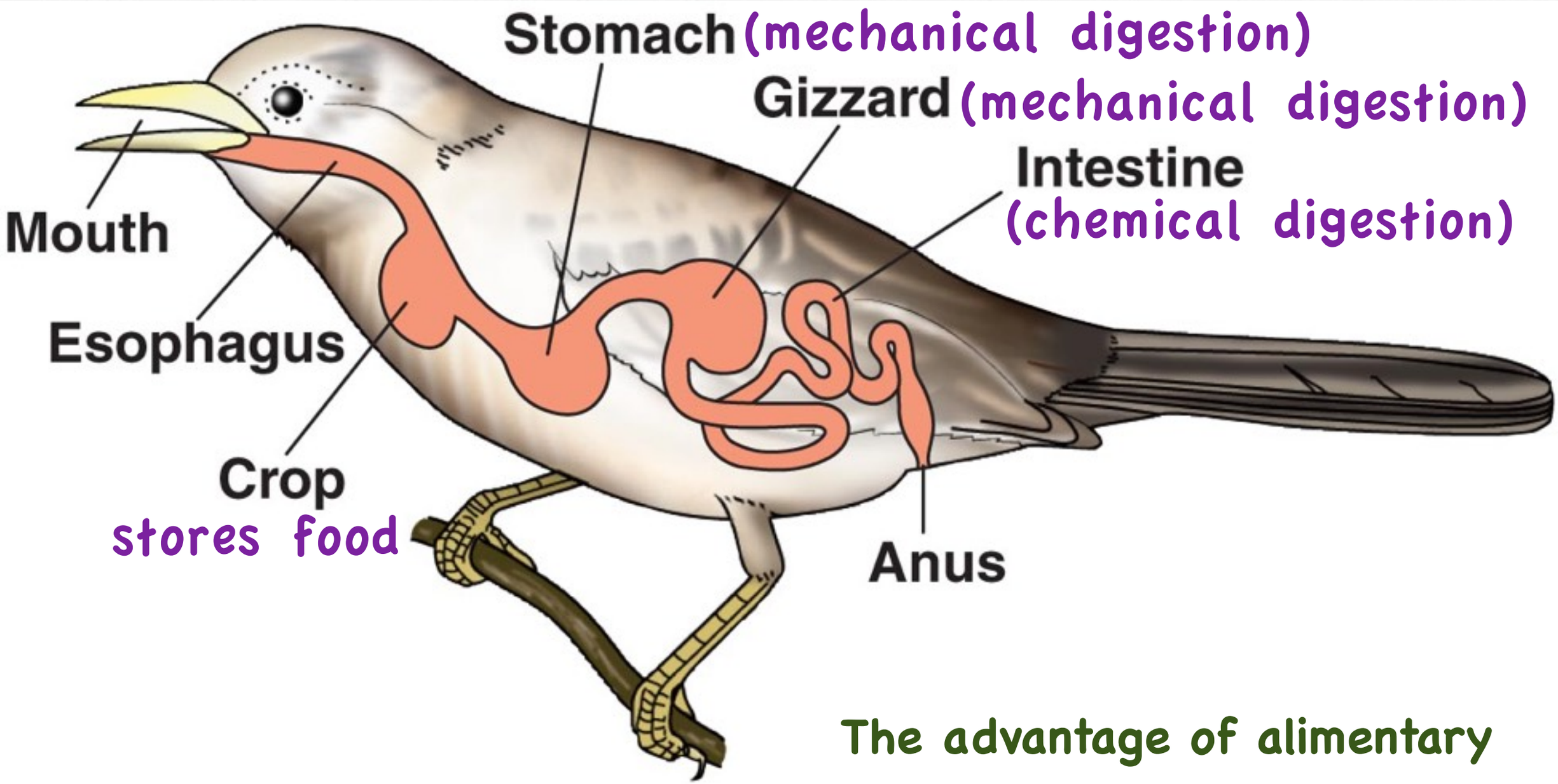
digestion



(a) Earthworm

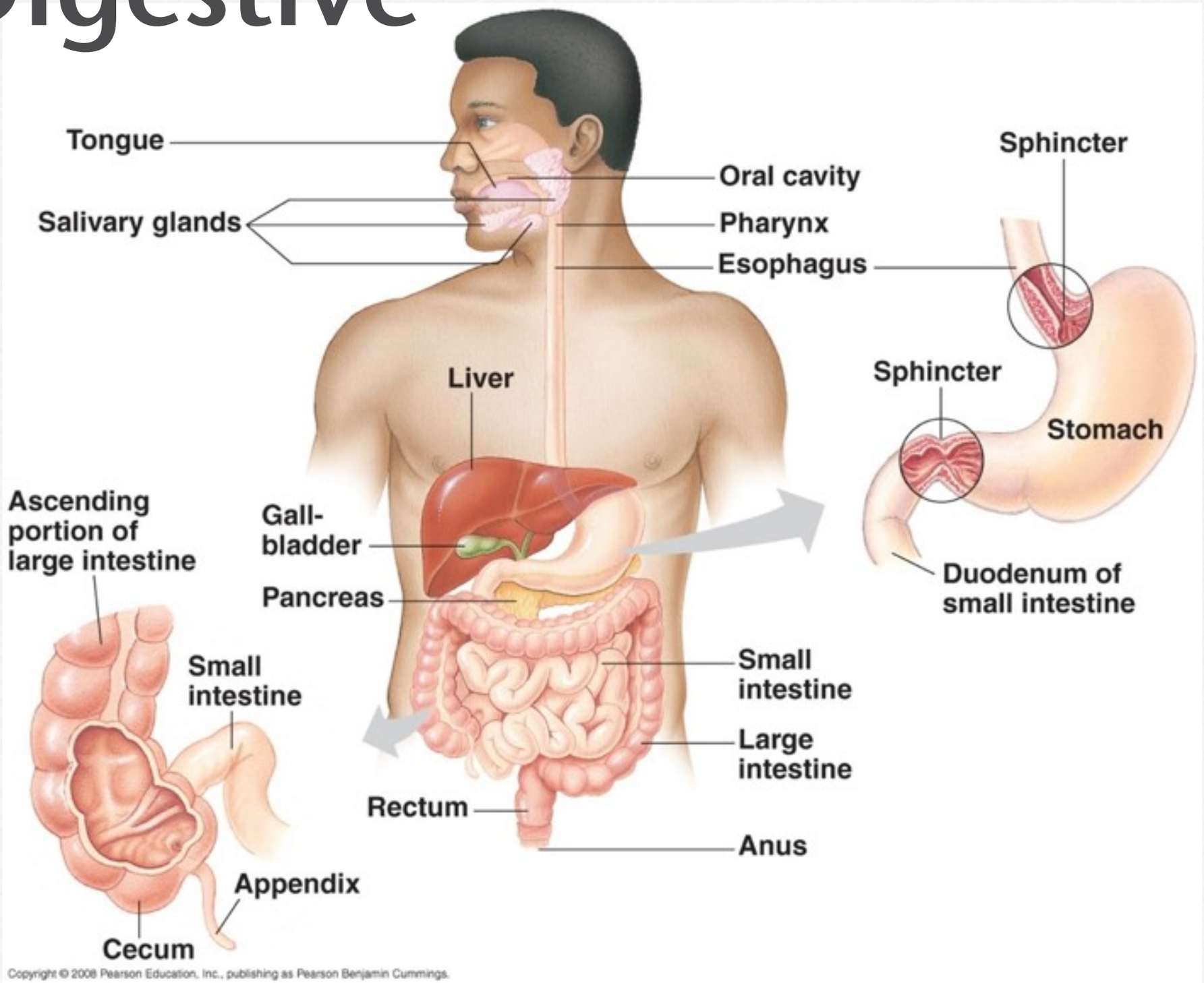


(b) Grasshopper



The advantage of alimentary canals is specialization and food can be digested while an earlier meal is being absorbed

HumanDigestive System

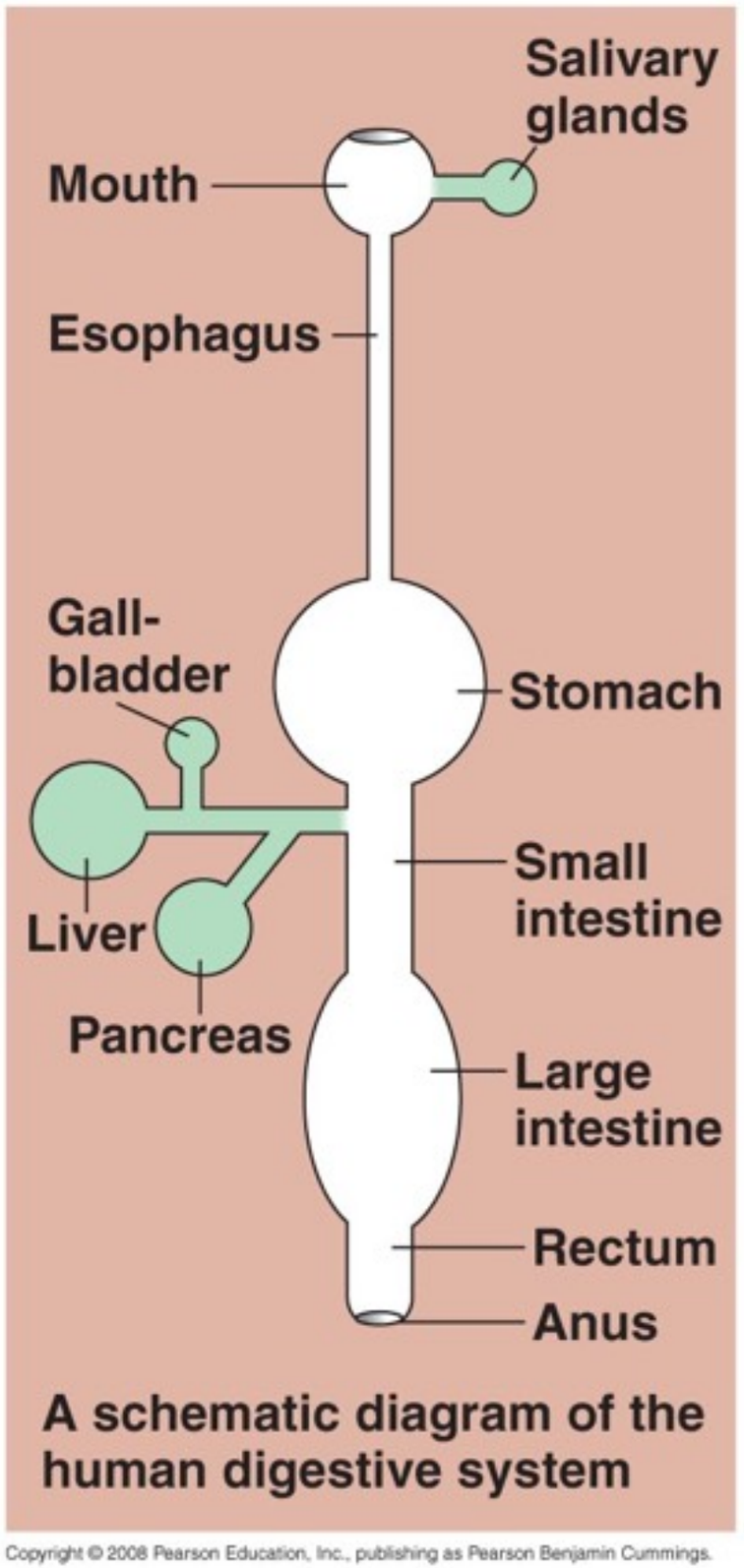


mechanical digestion

stores bile

makes bile
detoxifies

digestive enzymes



A schematic diagram of the human digestive system

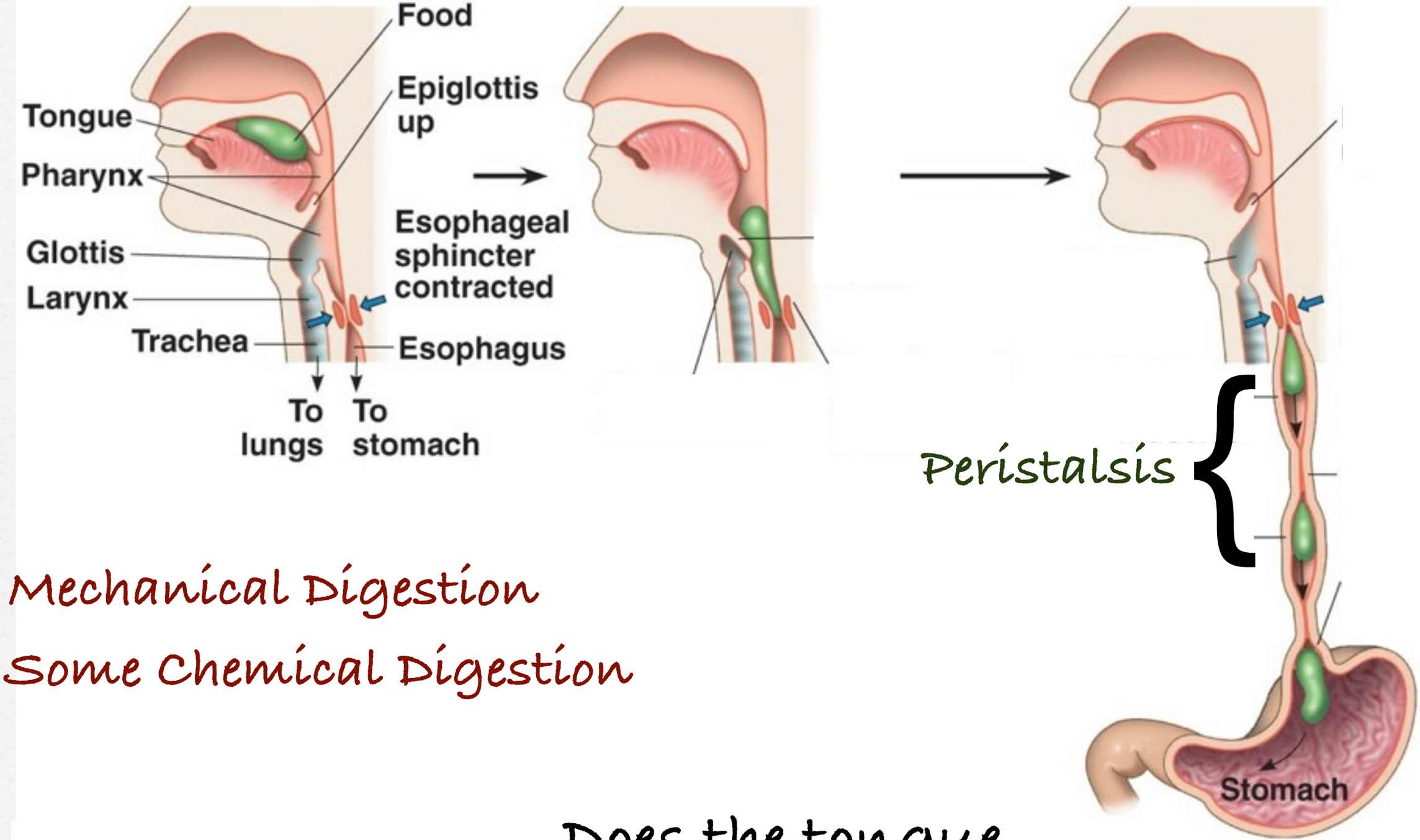
starts chemical digestion

food storage
mechanical digestion

chemical digestion
absorption

absorption

waste storage



Mechanical Digestion

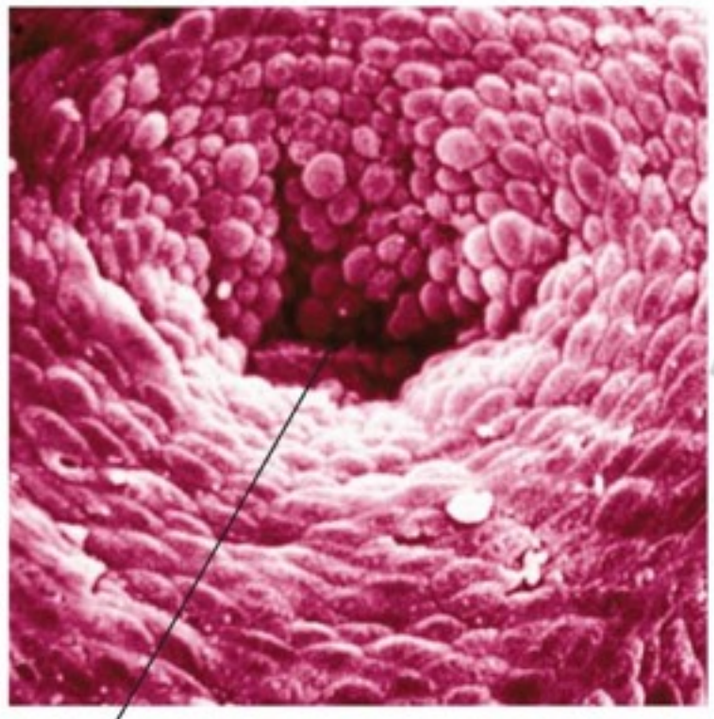
Some Chemical Digestion

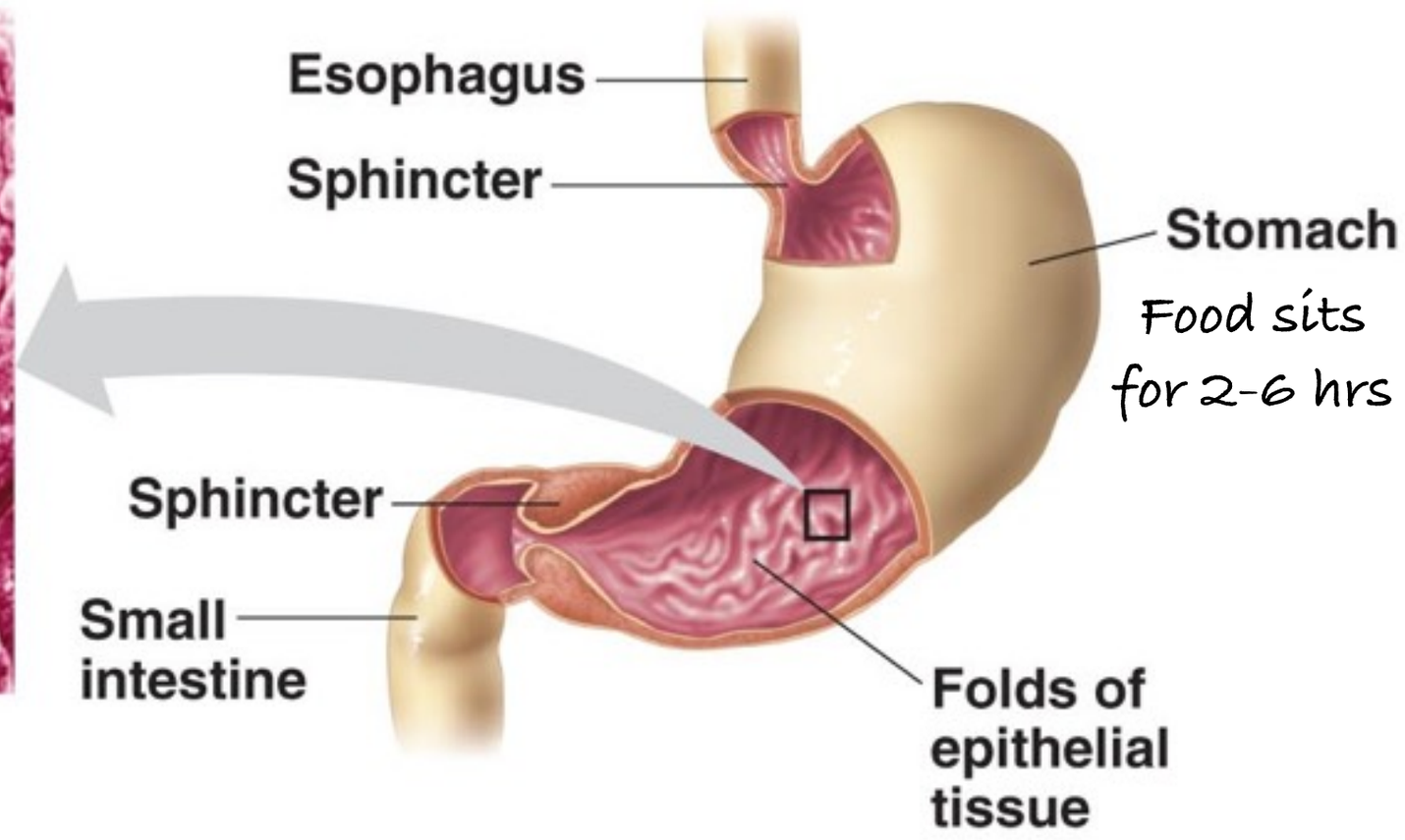
Does the tongue have any function?

Mainly Storage

Chemical Digestion

Some Mechanical Digestion



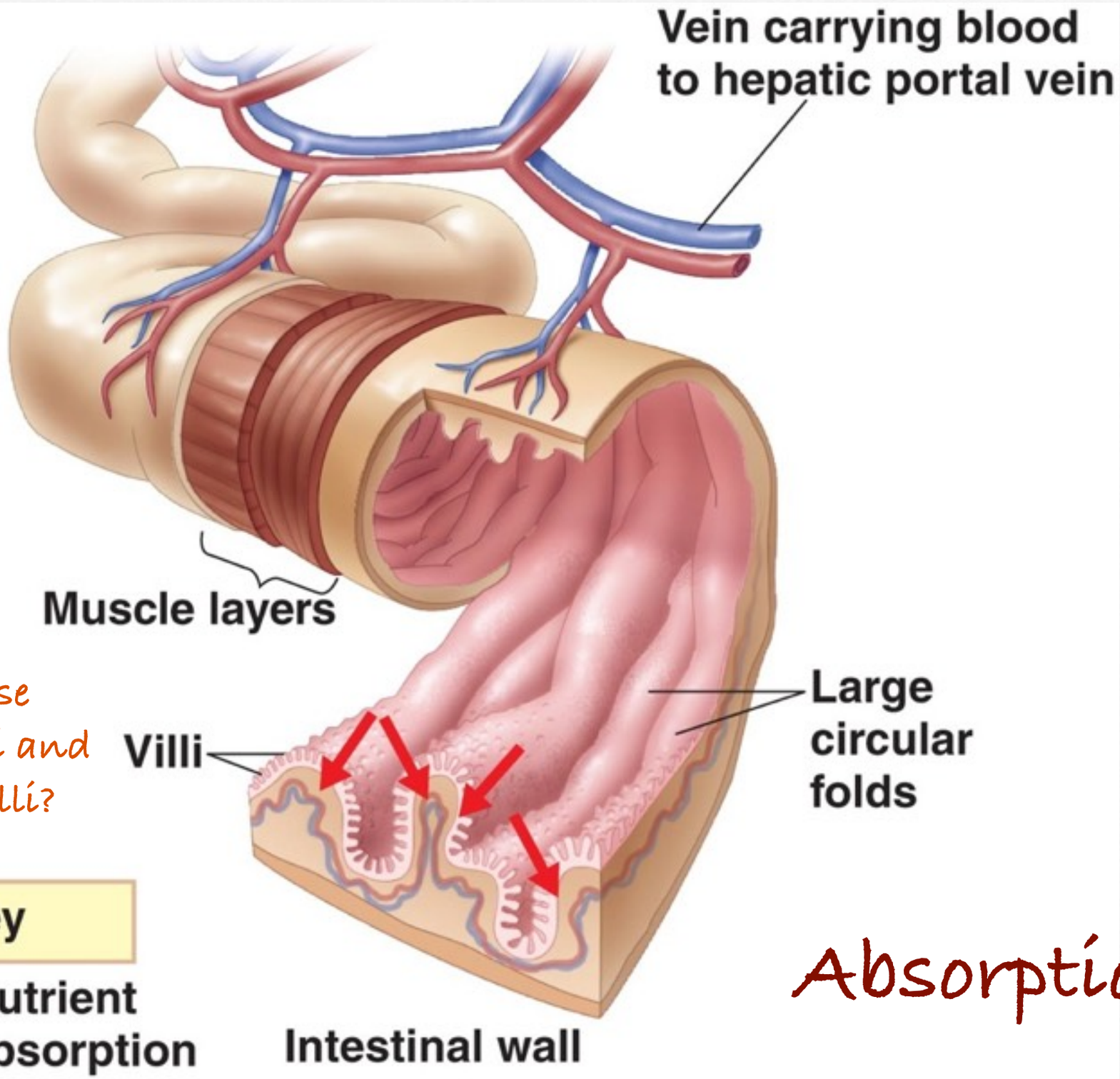


Very acidic...Why?

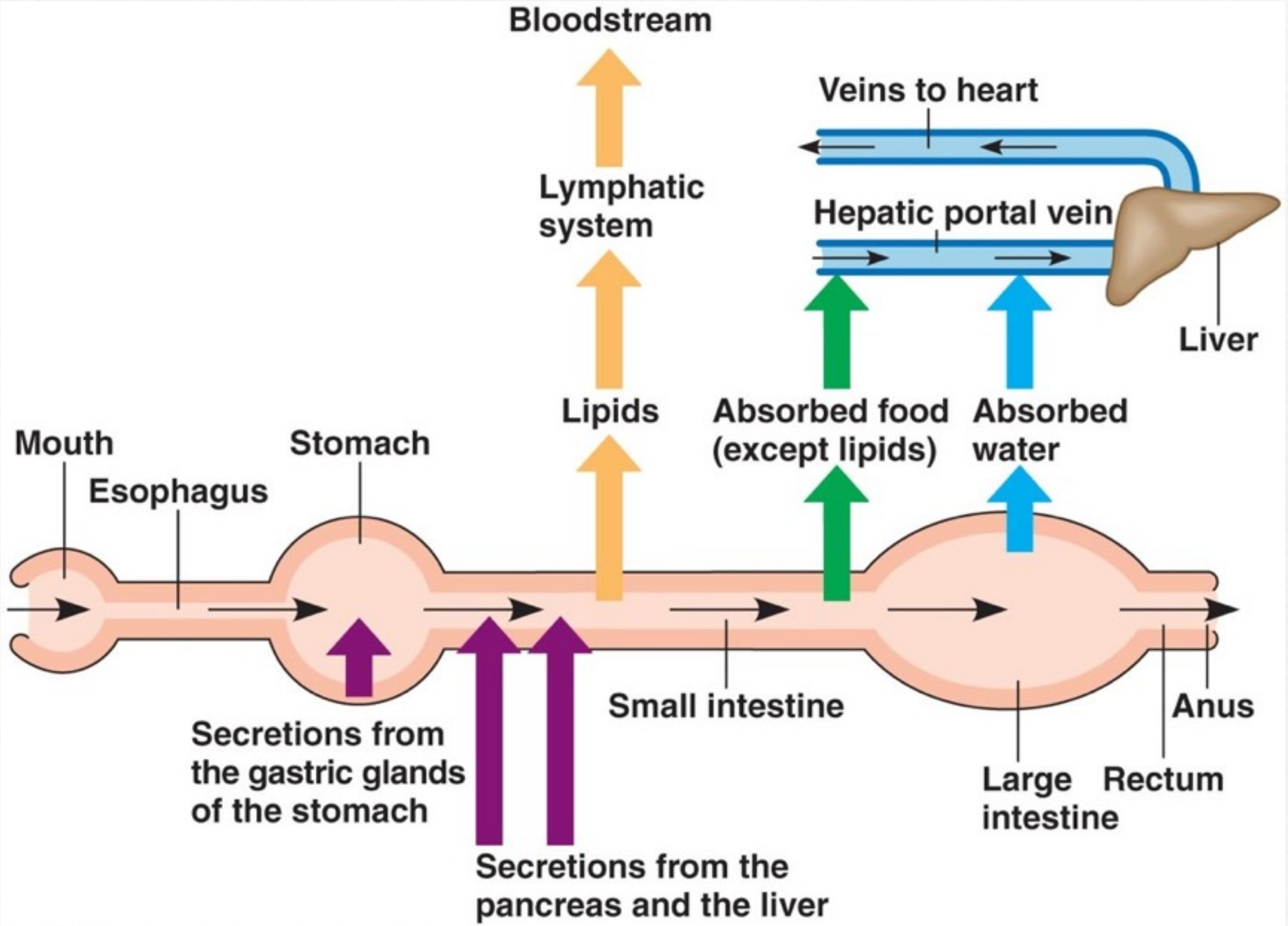
Chemical Digestion

over 20 feet long

What is the purpose behind the folds, villi and the unseen microvilli?



Absorption



To foster student understanding of this concept, instructors can choose an illustrative example such as:

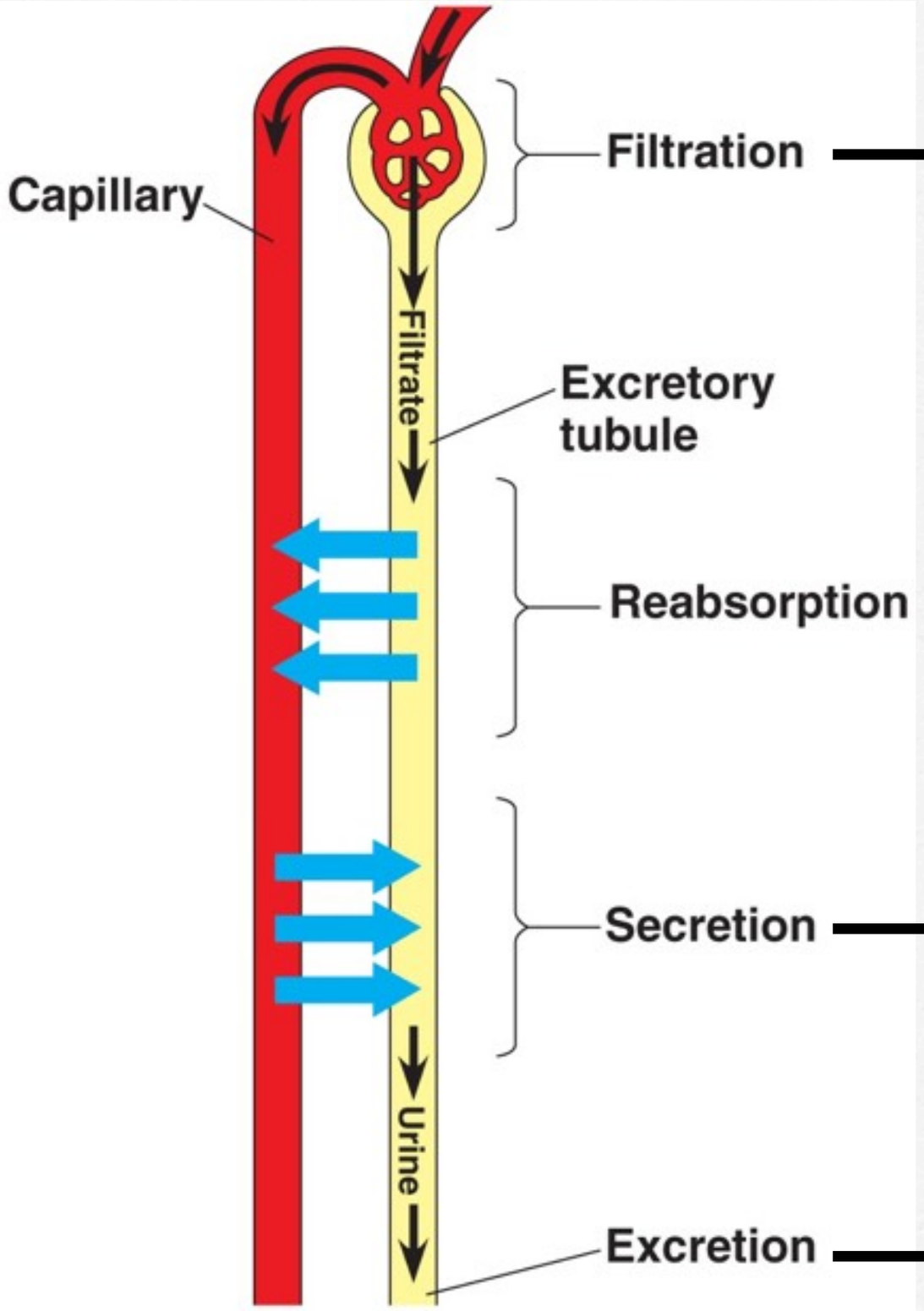
Excretion of Waste

Excretory Systems

- ALL water balance relies on the regulation of solute movement between internal fluids and external environments.
- Most of this movement in multicellular organisms is handled by excretory systems.
- These systems not balance water and solute concentrations but also excrete harmful wastes.

Excretion: The Process

- Animals produce a fluid waste called urine through 4 basic steps:
  - Filtration
  - Reabsorption
  - Secretion
  - Excretion

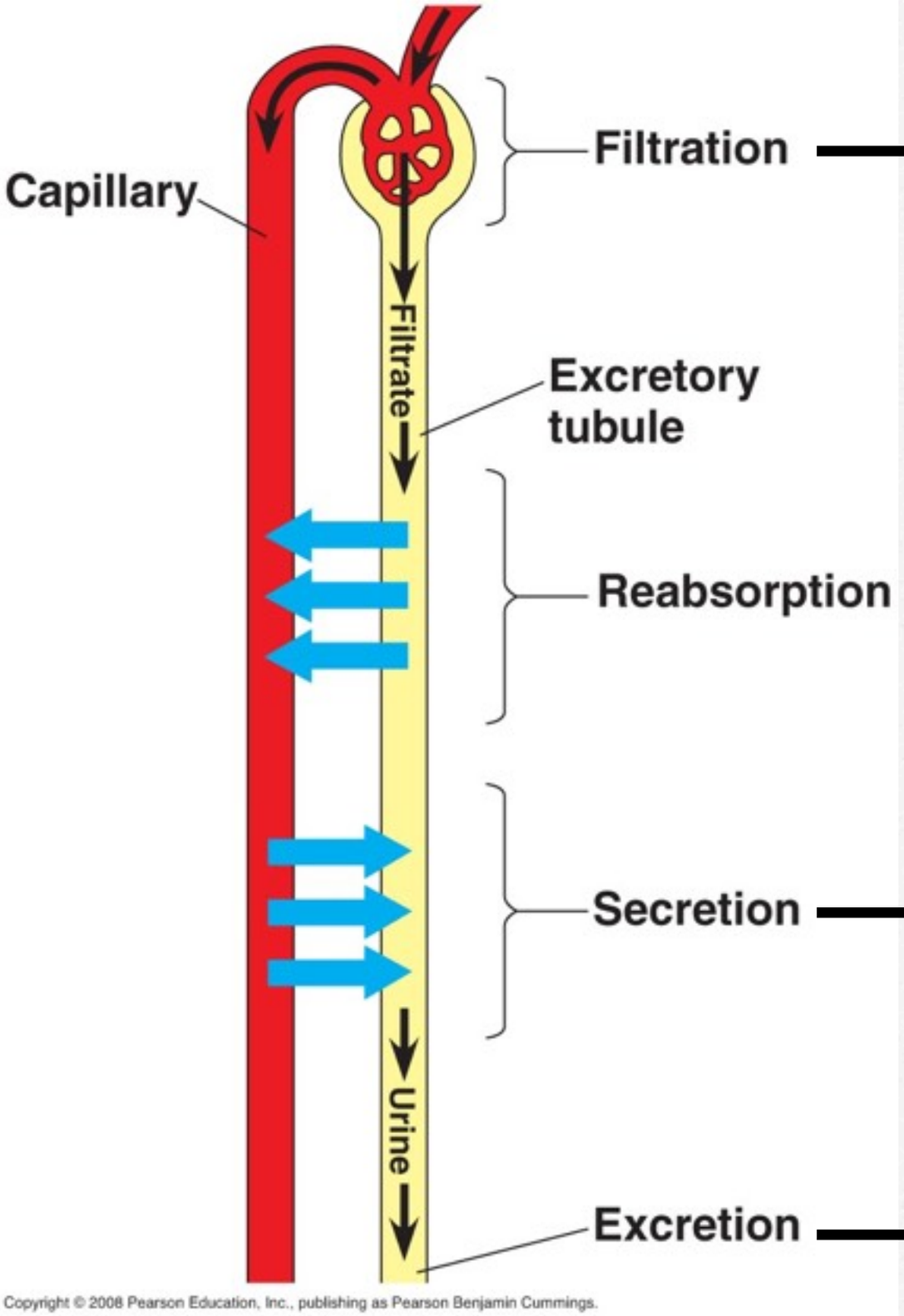


Water and solutes are forced out of the blood

Reclaims valuable substances from filtrate

Excessive solutes and toxins are removed from the blood

The altered filtrate leaves body as urine



water, salts, sugars, amino acids, nitrogenous waste, etc

water, certain salts, glucose, amino acids, vitamins, hormones

additional solutes and waste

water and nitrogenous waste, etc

Diverse Excretory Systems

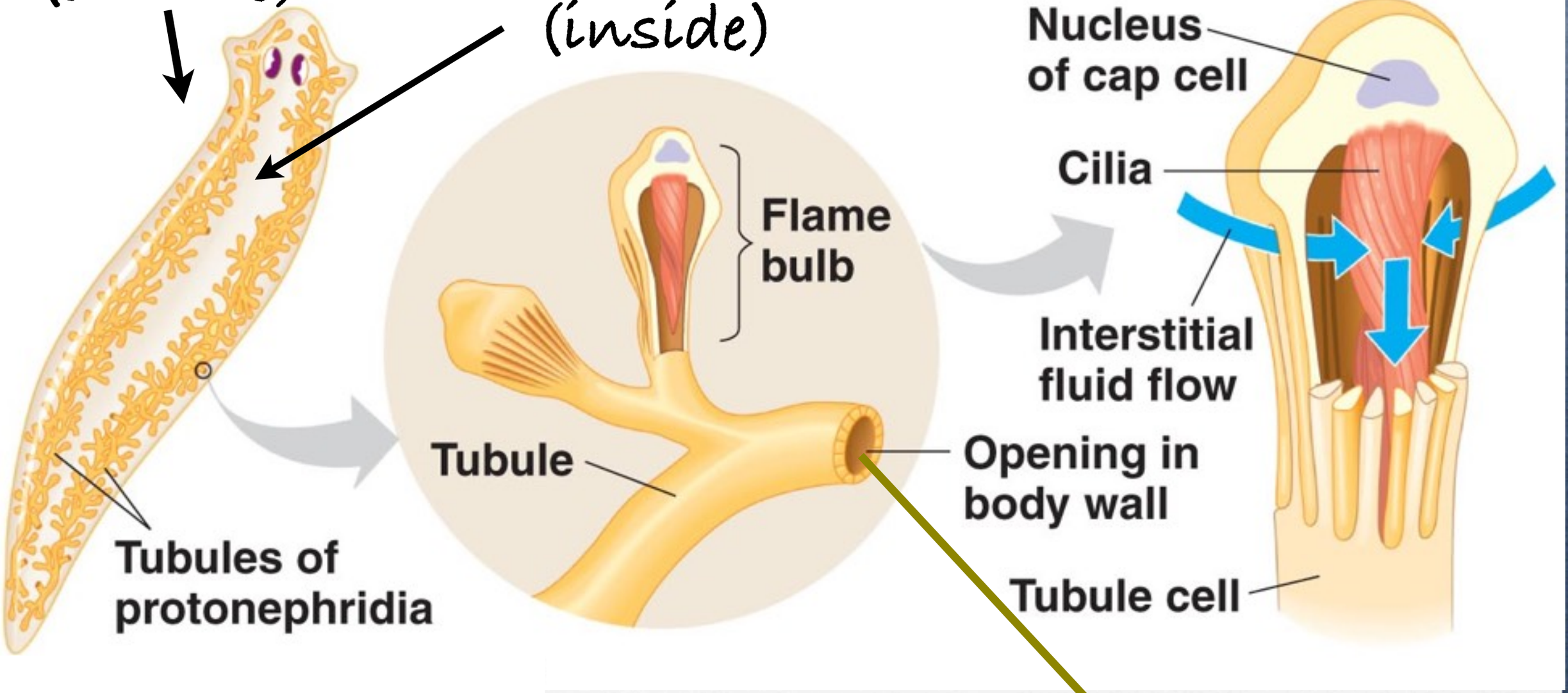
- Although structures vary among animals the functions remain the same-control solute concentration and balance water uptake and output.
  - Protonephridia-flatworms
  - Metanephridia-earthworms
  - Malphigian Tubules-insects (grasshoppers)
  - Kidneys-vertebrates (humans)

Protonephridia

- **Serve to regulate water!**
- Waste removal occurs across the body surface or waste is moved into the gastrovascular cavity where leaves through the mouth
- Freshwater flatworms produce dilute urine to counteract the constant influx of water

Hypoosmotic (outside)

Hyperosmotic (inside)

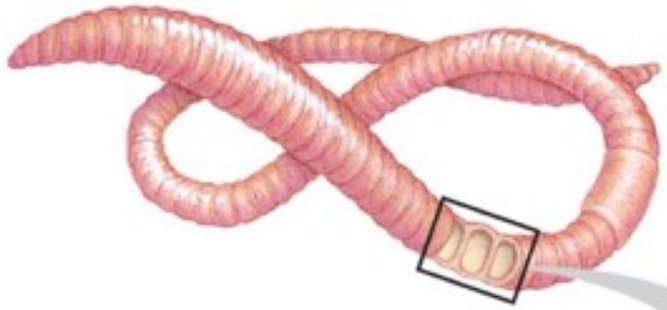


This system is used for osmoregulation, not waste removal

LOW SOLUTE URINE

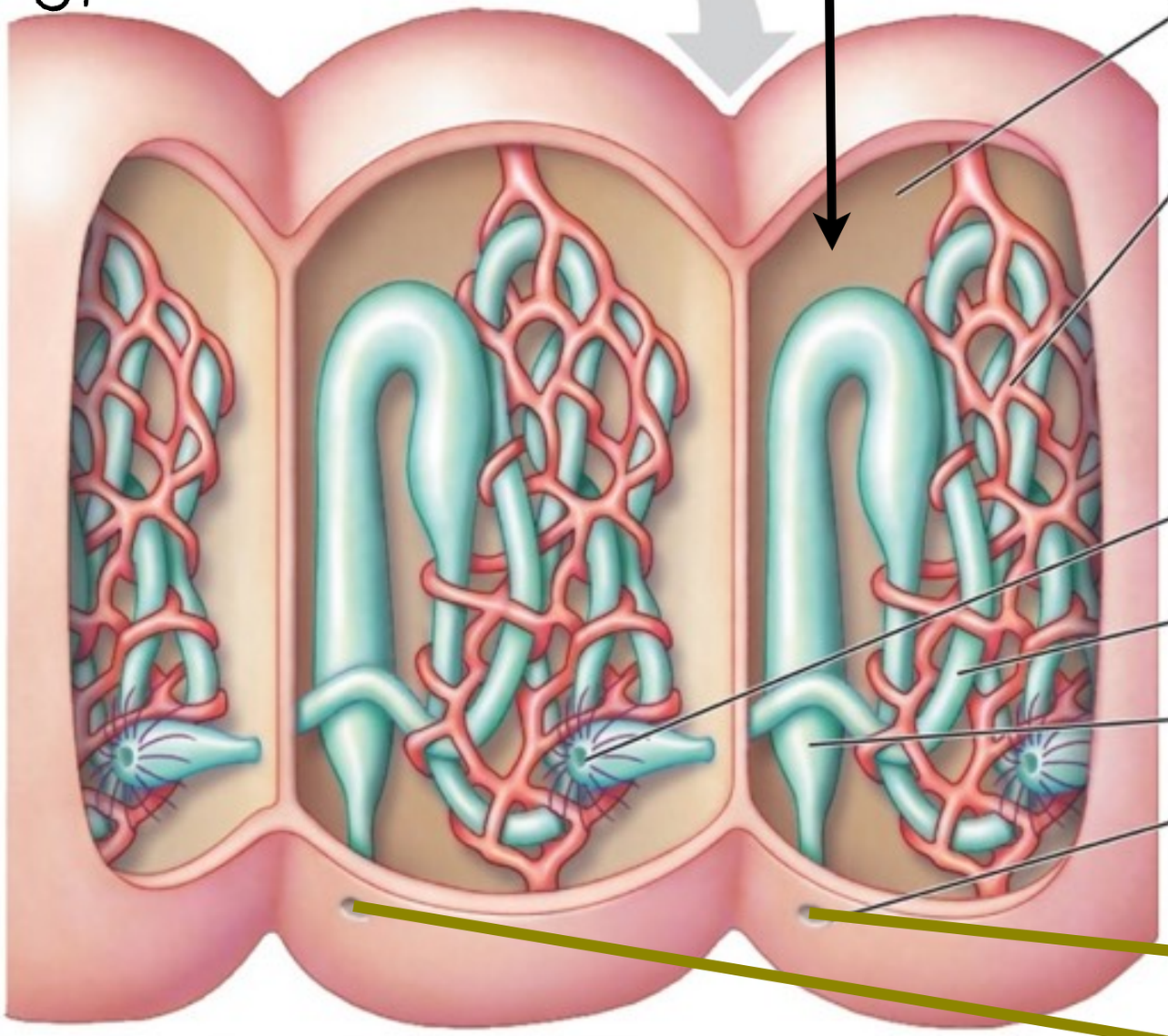
Metanephridia

- **Serve to regulate water and eliminate waste!**
- Waste moves into and remains in the collecting tubule and is eventually excreted to the outside
- Earthworms inhabit moist soils and thus produce dilute urine to counteract the constant influx of water



Hyperosmotic (inside)

Hypoosmotic (outside)



Coelom

Capillary network → Reabsorbs most solutes ("good ones")

Components of a metanephridium:

Internal opening → Collects fluid from coelom

Collecting tubule

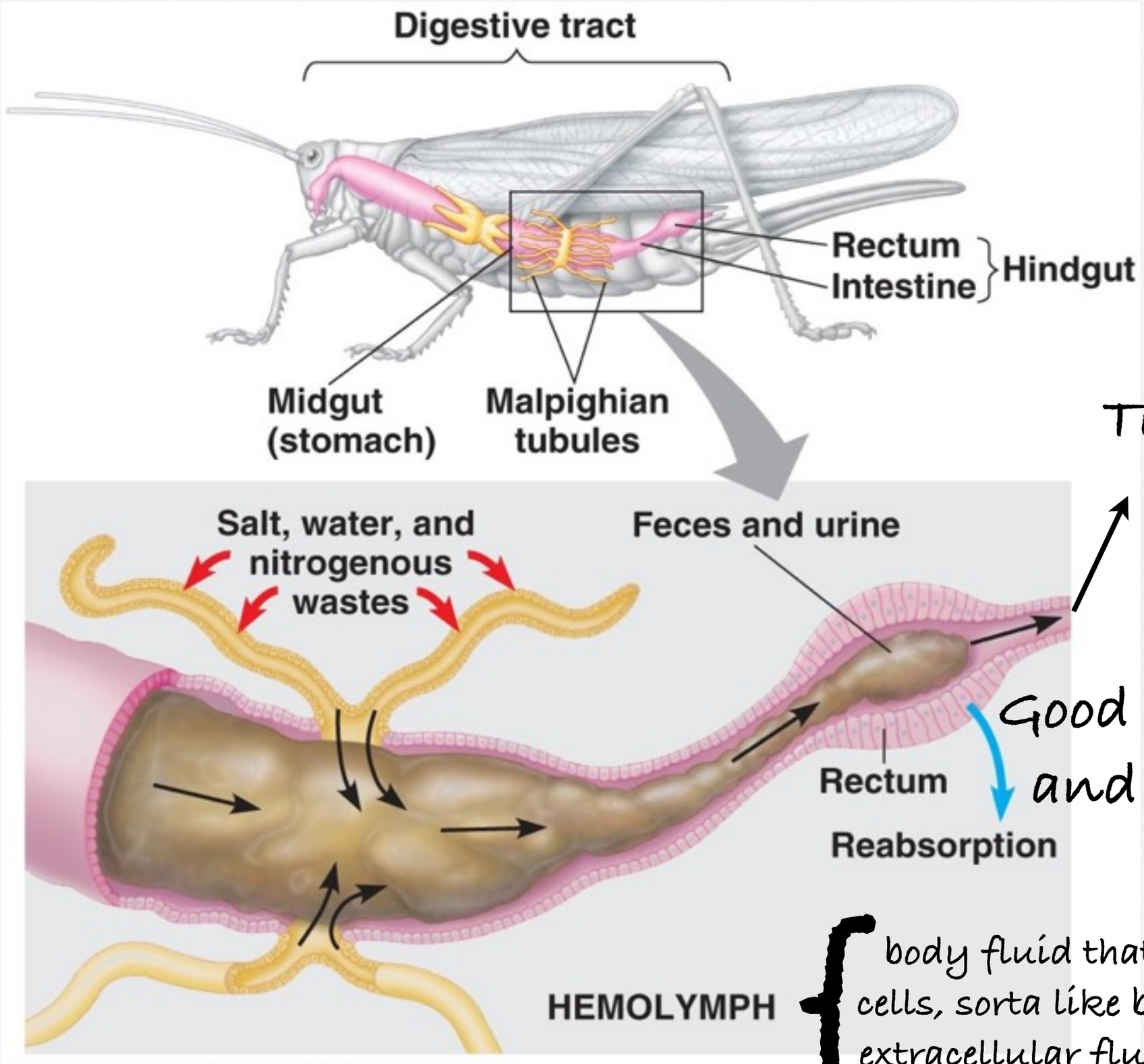
Bladder

External opening

Low Solute Urine & Nitrogenous waste

Malpighian Tubules

- **Serve to regulate water and eliminate waste!**
- Nitrogenous waste is actually moved into the (gastrovascular cavity) rectum where it is eliminated along with the feces
- Insects live in hyperosmotic environments and must therefore conserve water, producing non-soluble nitrogenous waste saves water



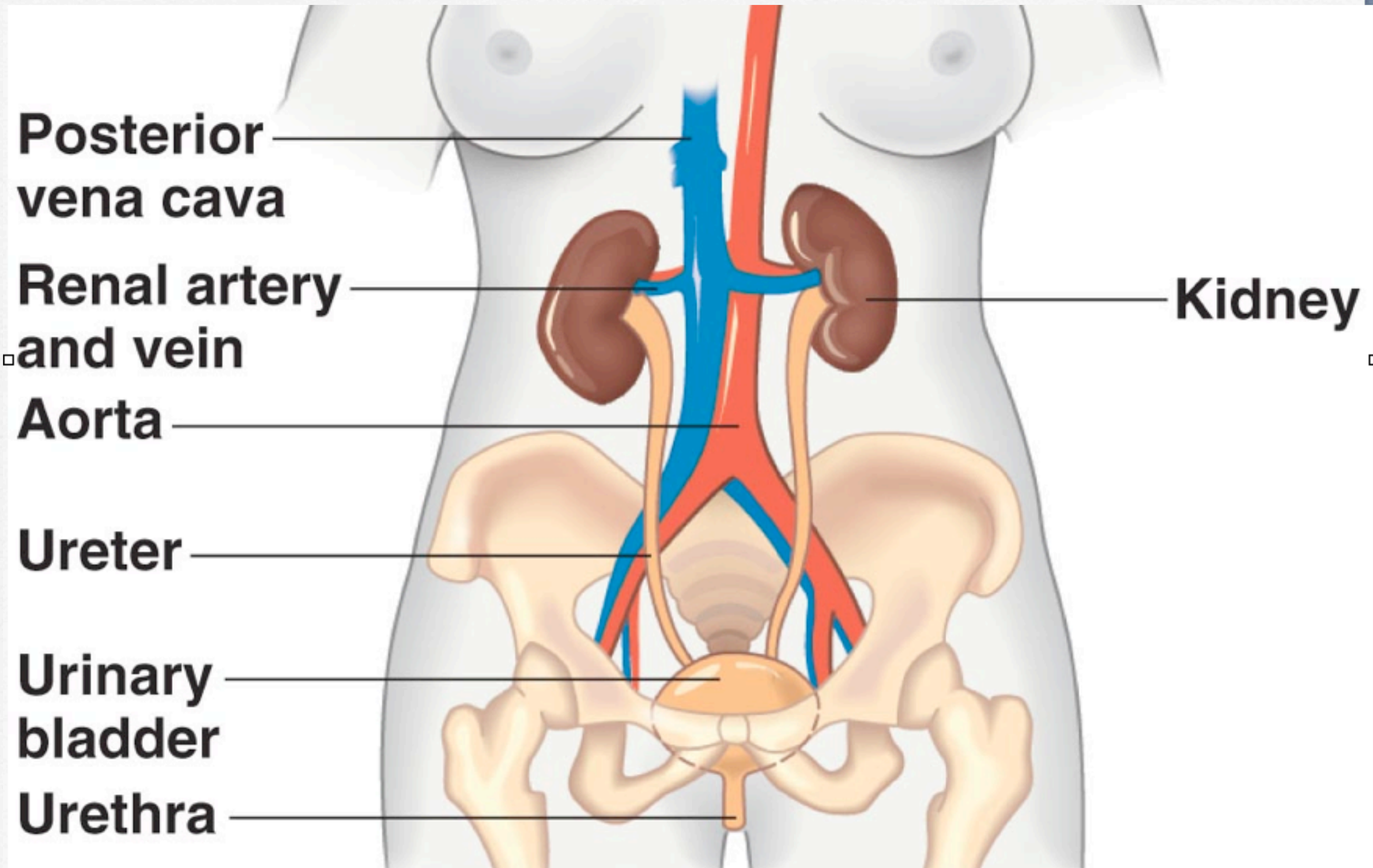
Text

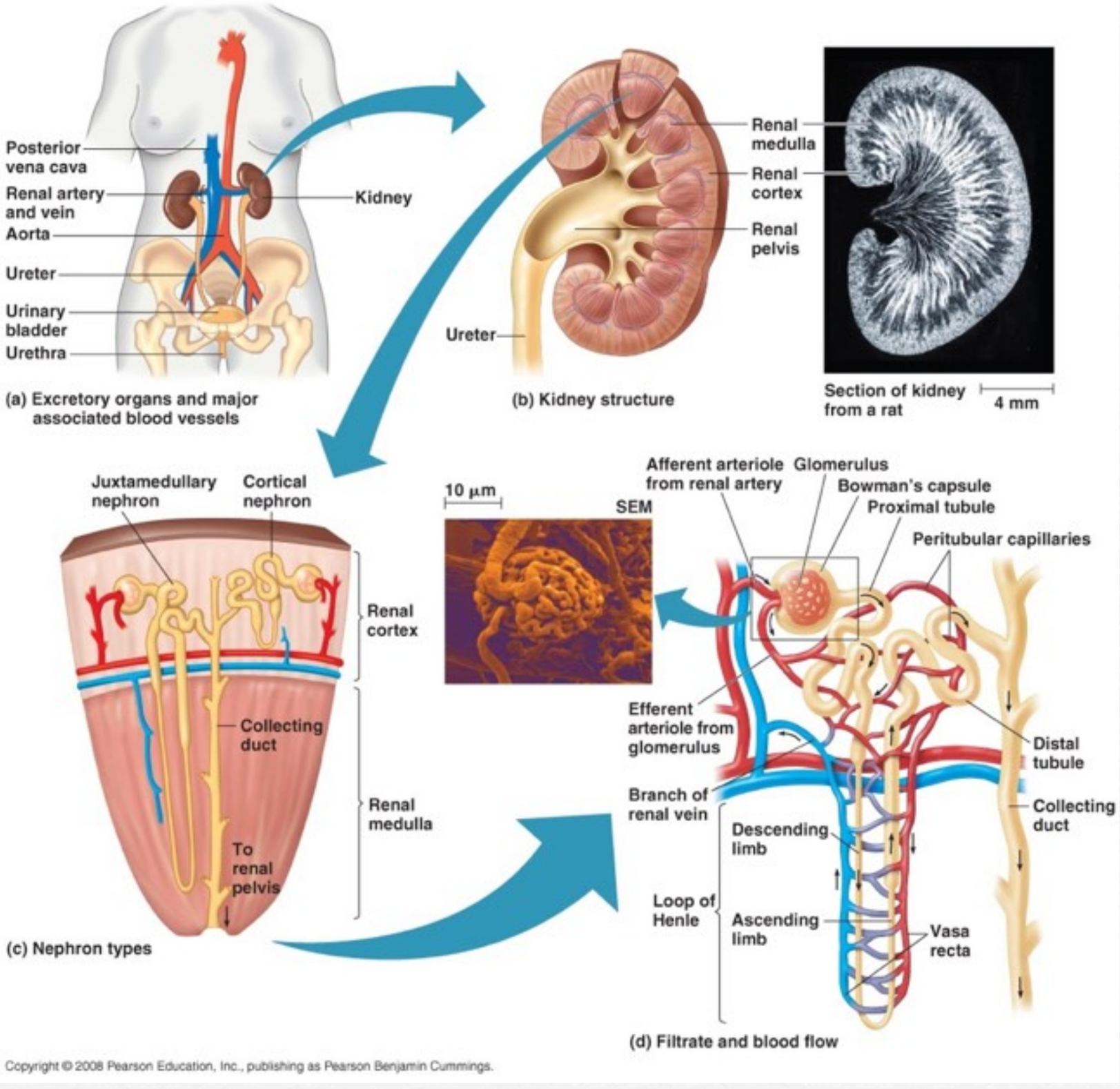
Good Solutes and Water

{ body fluid that bathes cells, sorta like blood and extracellular fluid combo

Mammalian Excretory System

- **Serve to regulate water and eliminate waste!**
- Nitrogenous waste is soluble and leaves in the urine
- Mammalian kidneys have the ability to produce dilute or concentrated urine depending the environmental circumstances


Posterior vena cava
Renal artery and vein
Aorta
Ureter
Urinary bladder
Urethra
Kidney



Mammalian kidneys filter blood

↓

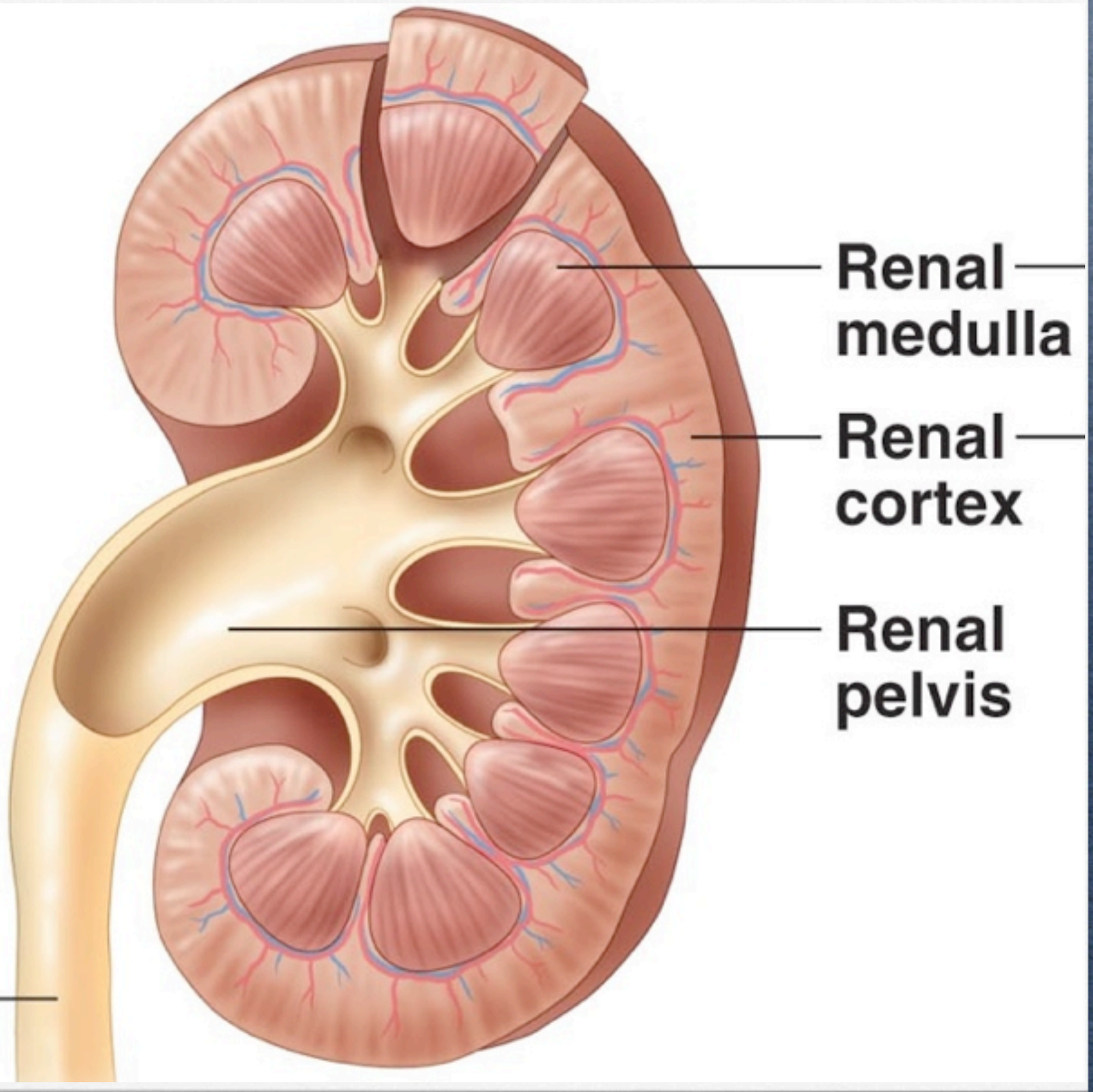
"Good stuff" is put back into blood

↓

"Bad stuff" stays and leaves in urine

↓

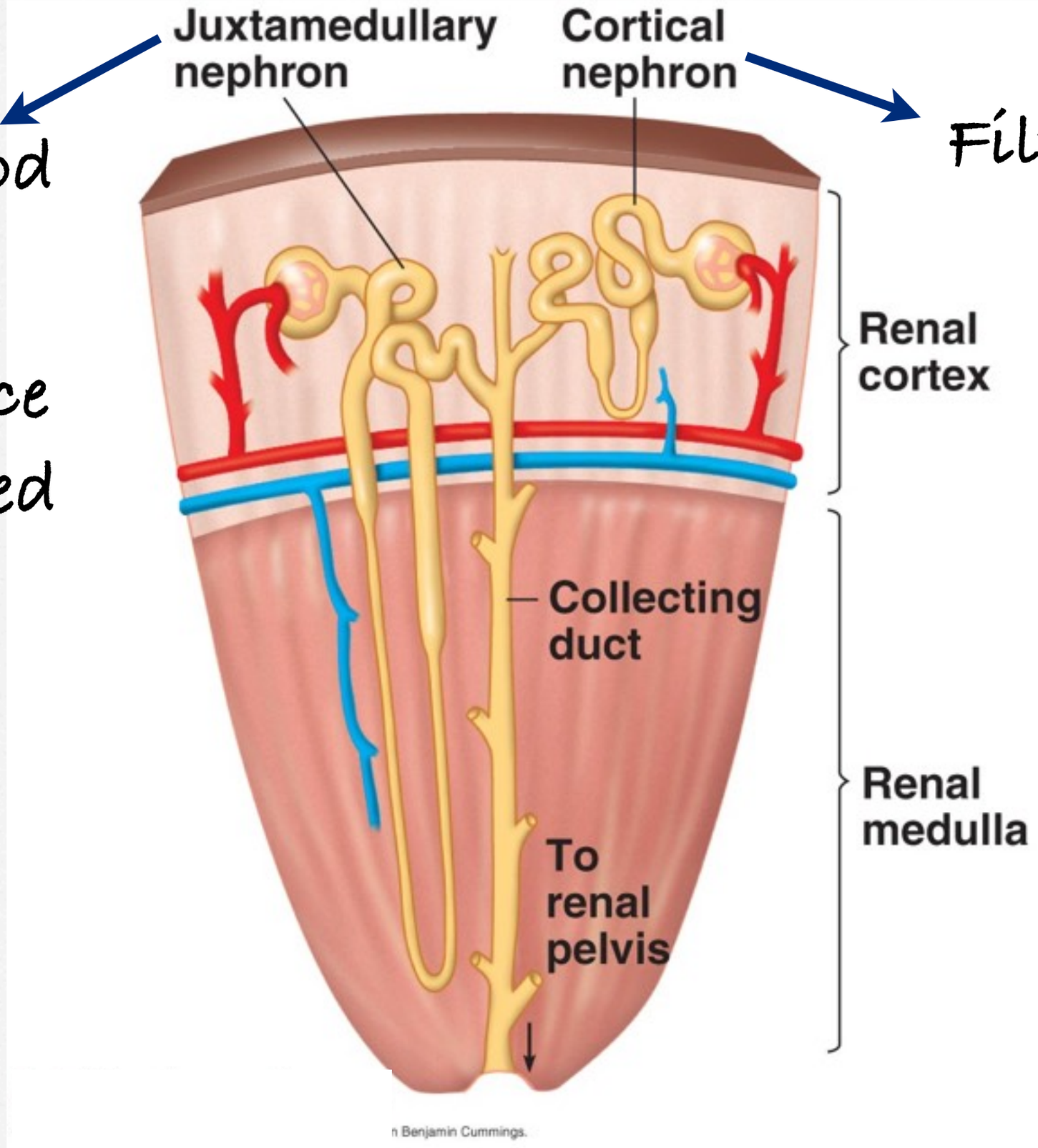
The concentration of urine will vary with the needs of the organism



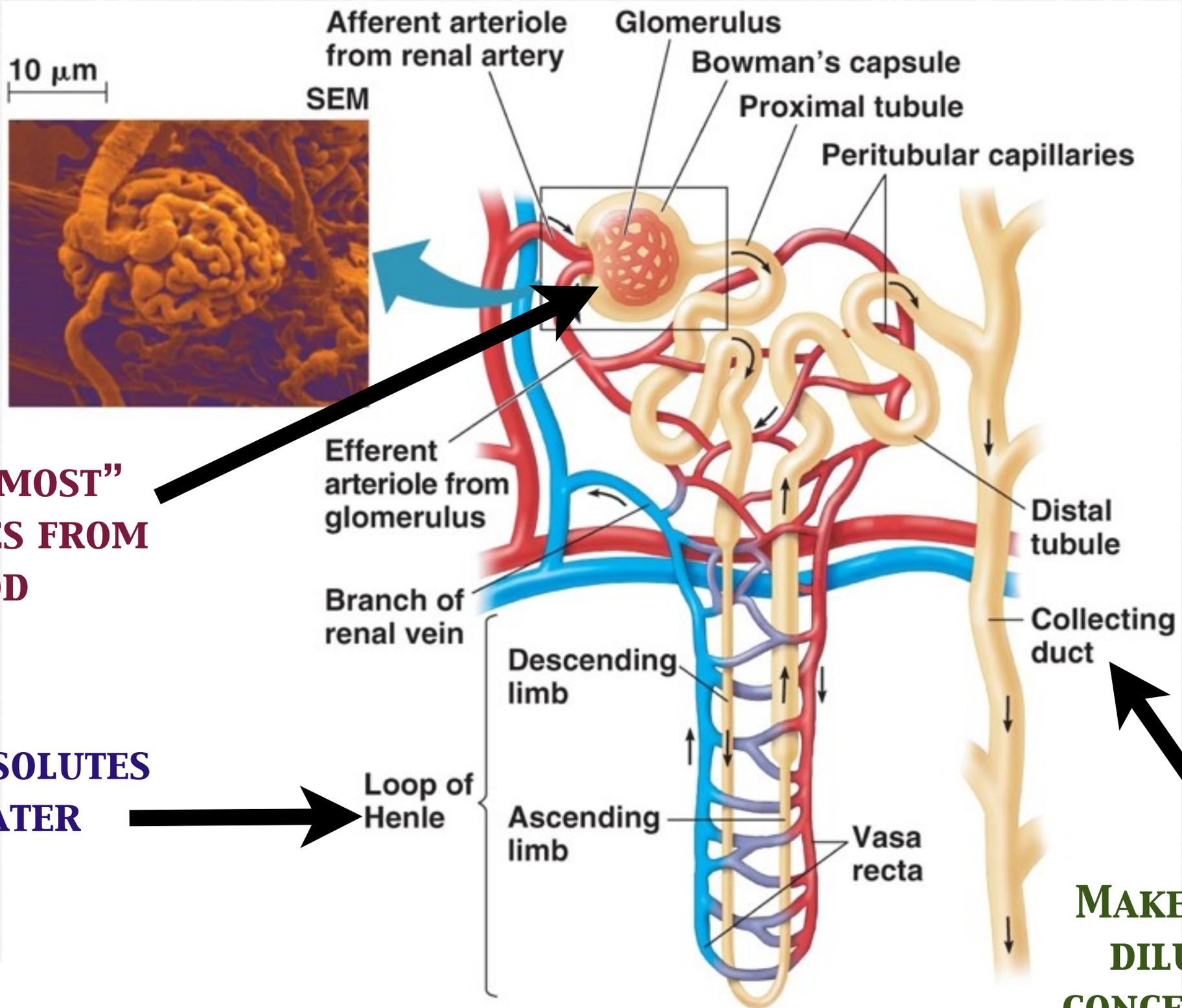
Filters Blood

and

Can produce concentrated urine



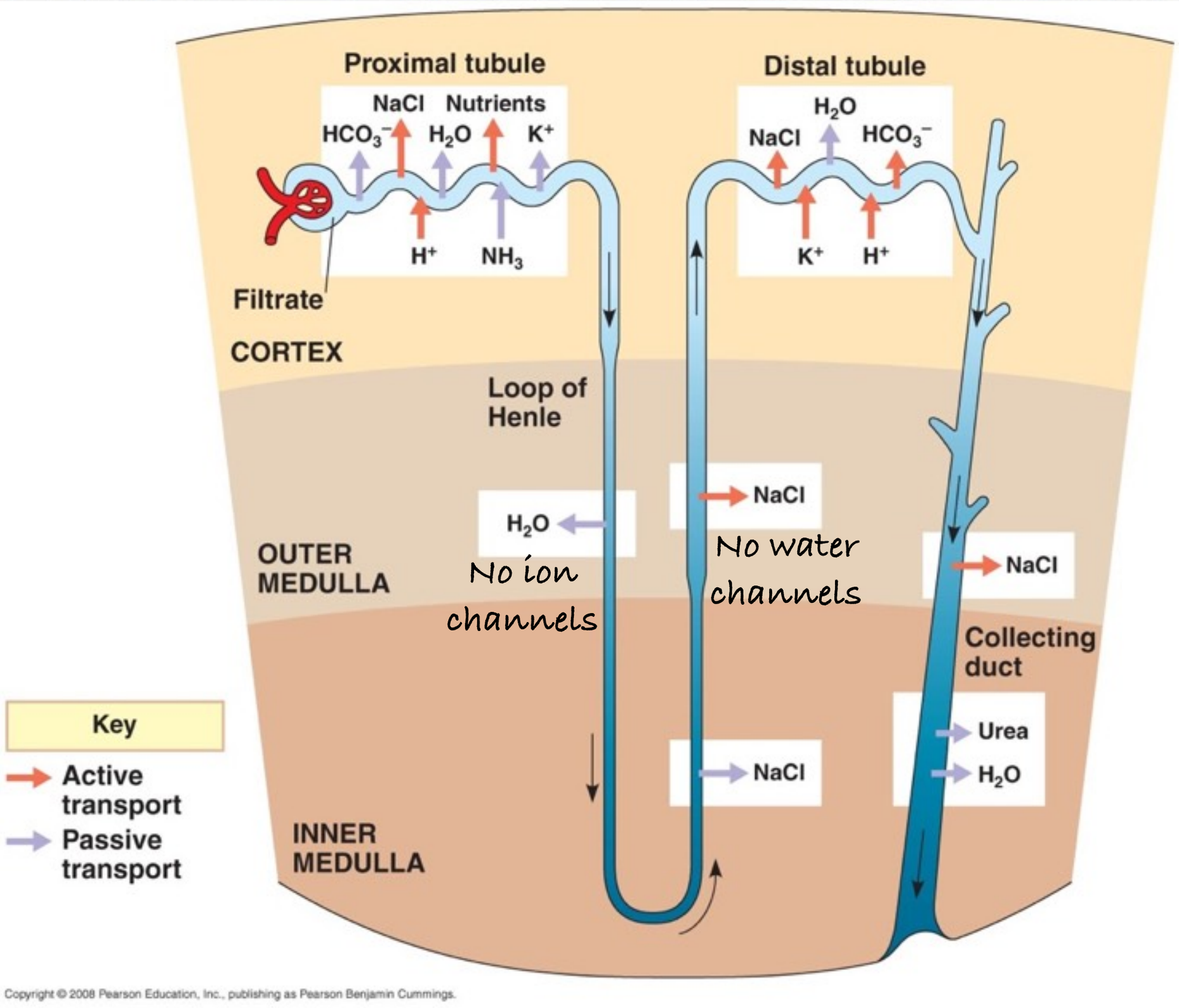
Filters Blood

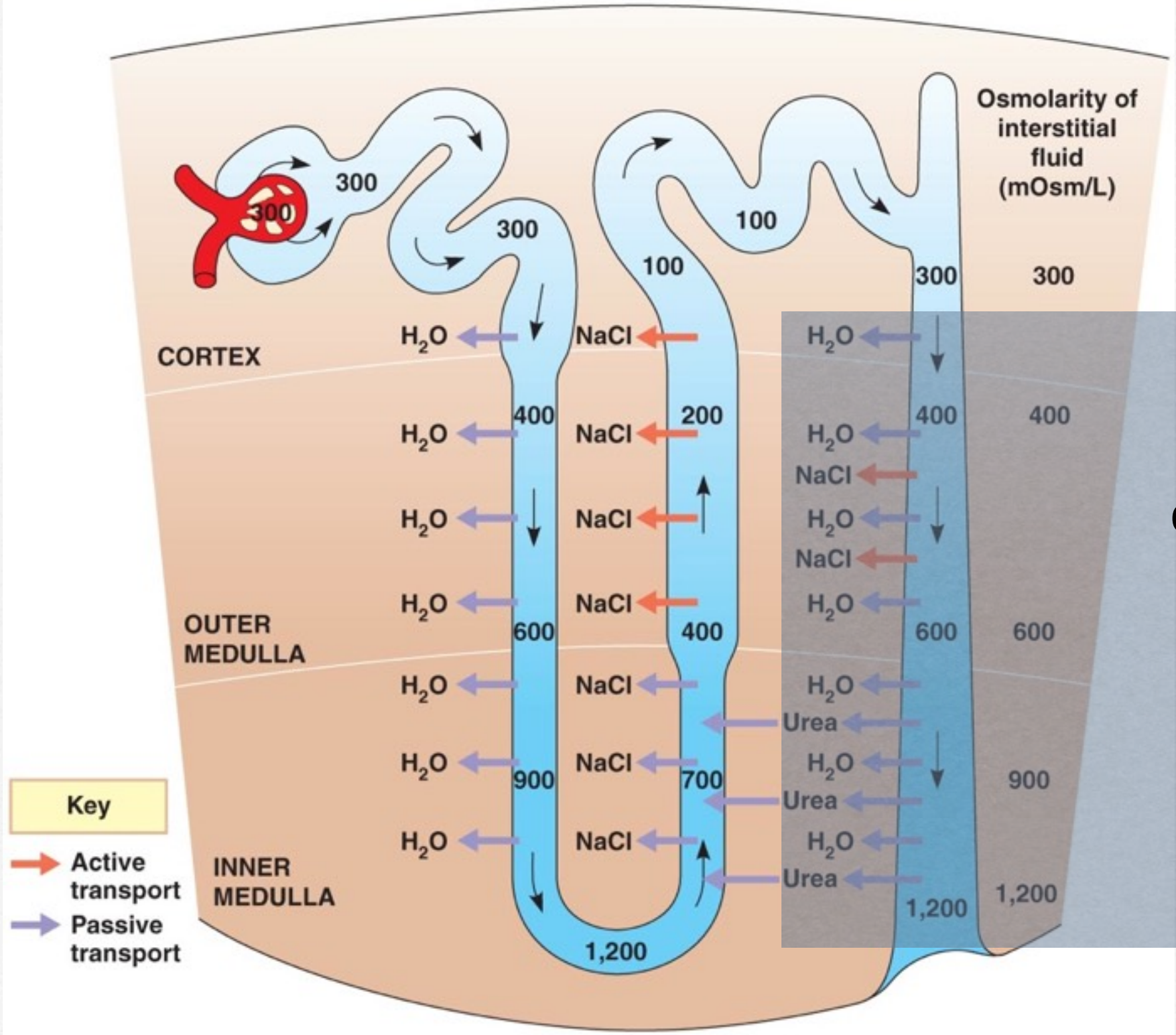


FILTERS "MOST" SUBSTANCES FROM BLOOD

RECLAIMS SOLUTES AND WATER

MAKES URINE DILUTE OR CONCENTRATED





THESE CHANNELS ARE UNDER HORMONAL CONTROL SO THAT THE BODY CAN REGULATE ITS WATER NEEDS

To foster student understanding of this concept, instructors can choose an illustrative example such as:

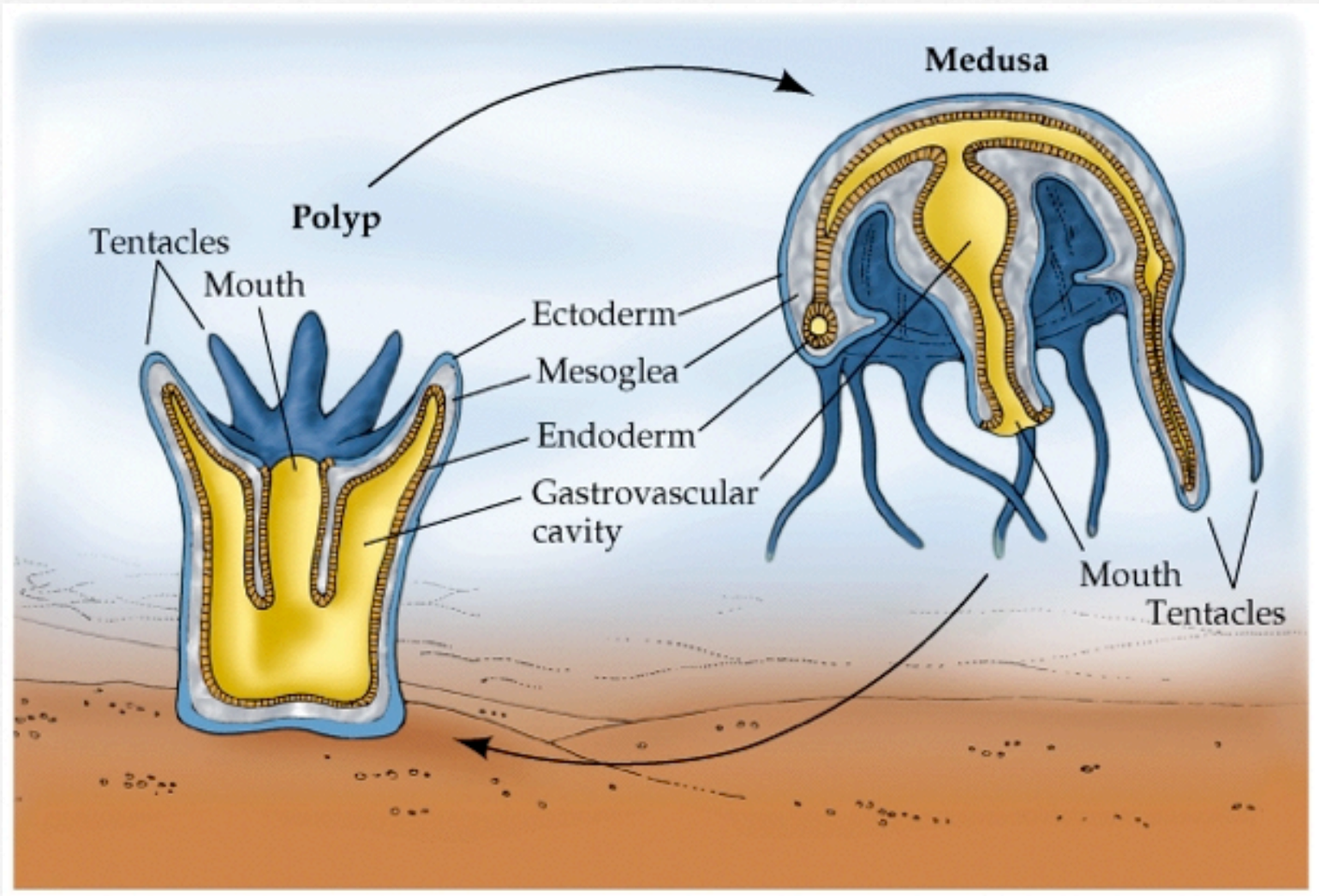
Circulation of Fluids

Circulatory Systems

-Link Exchange Surfaces

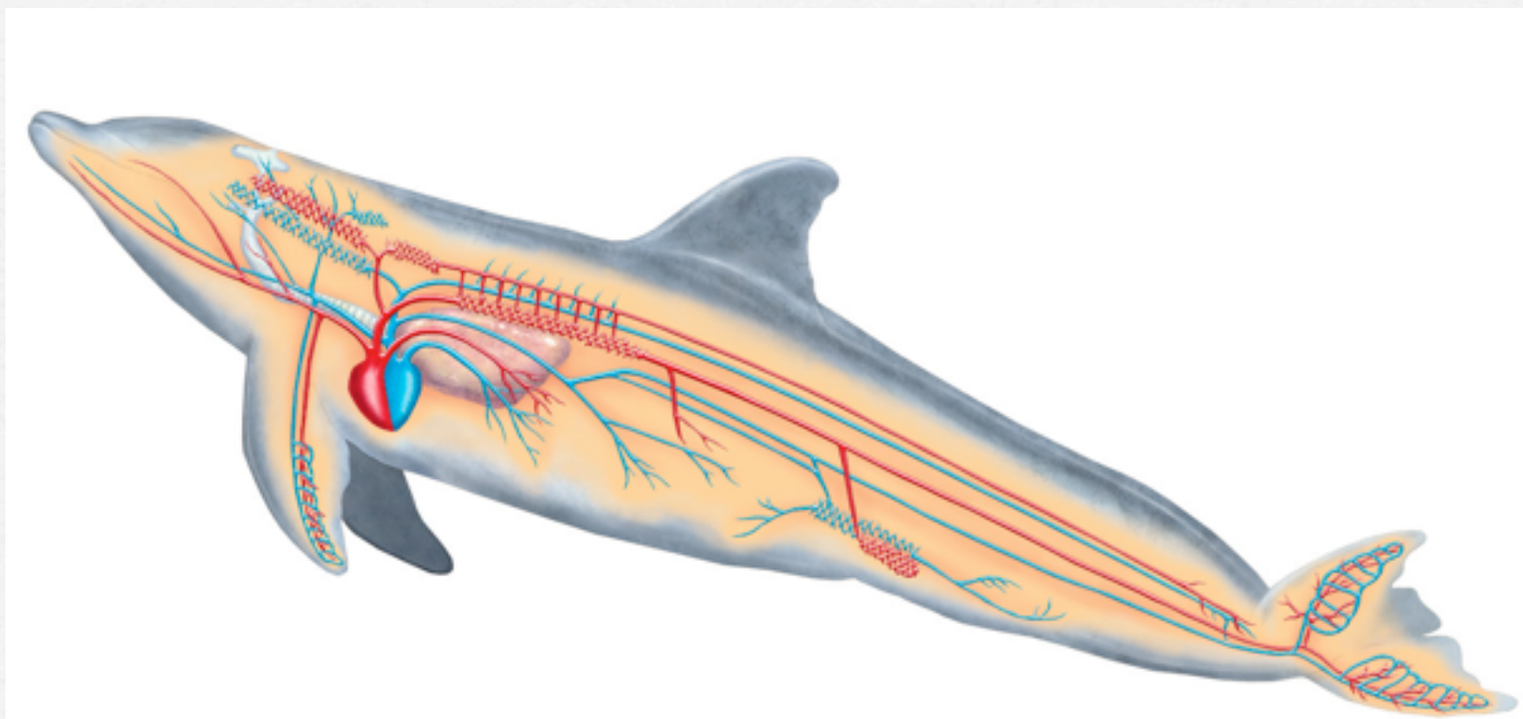
- Recall: Diffusion is slow!
    - (ex. 100 seconds to go 1mm)
- Since gases diffuse, this puts a significant constraint on the body plan of any animal.
- Natural selection has resulted in TWO general solutions.

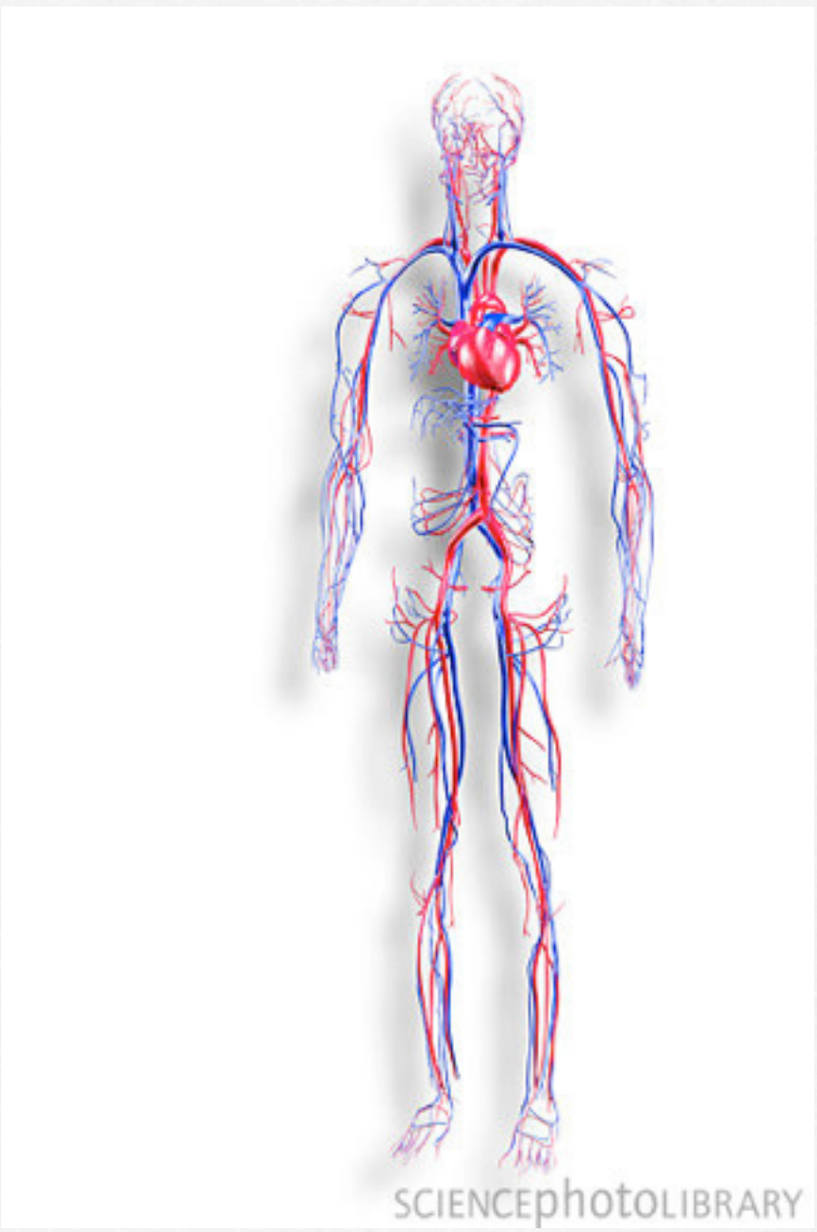
- **Solution One:** A body size and shape that keeps all or most cells in direct contact with the environment.
  - seen only in certain invertebrates and flatworms



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

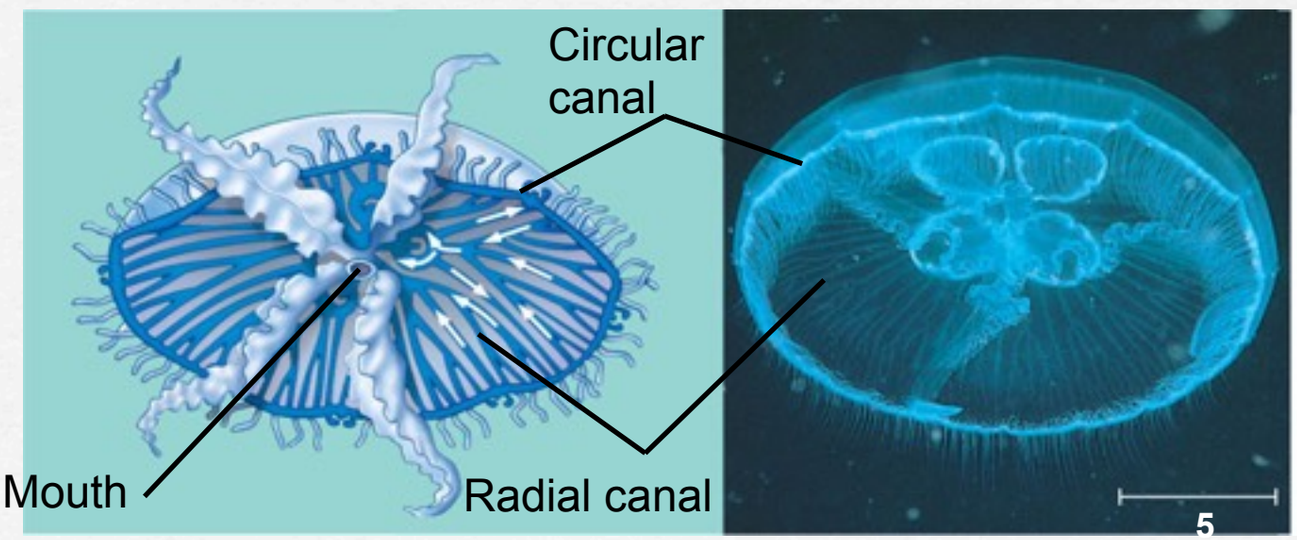
- found in all other animals





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.

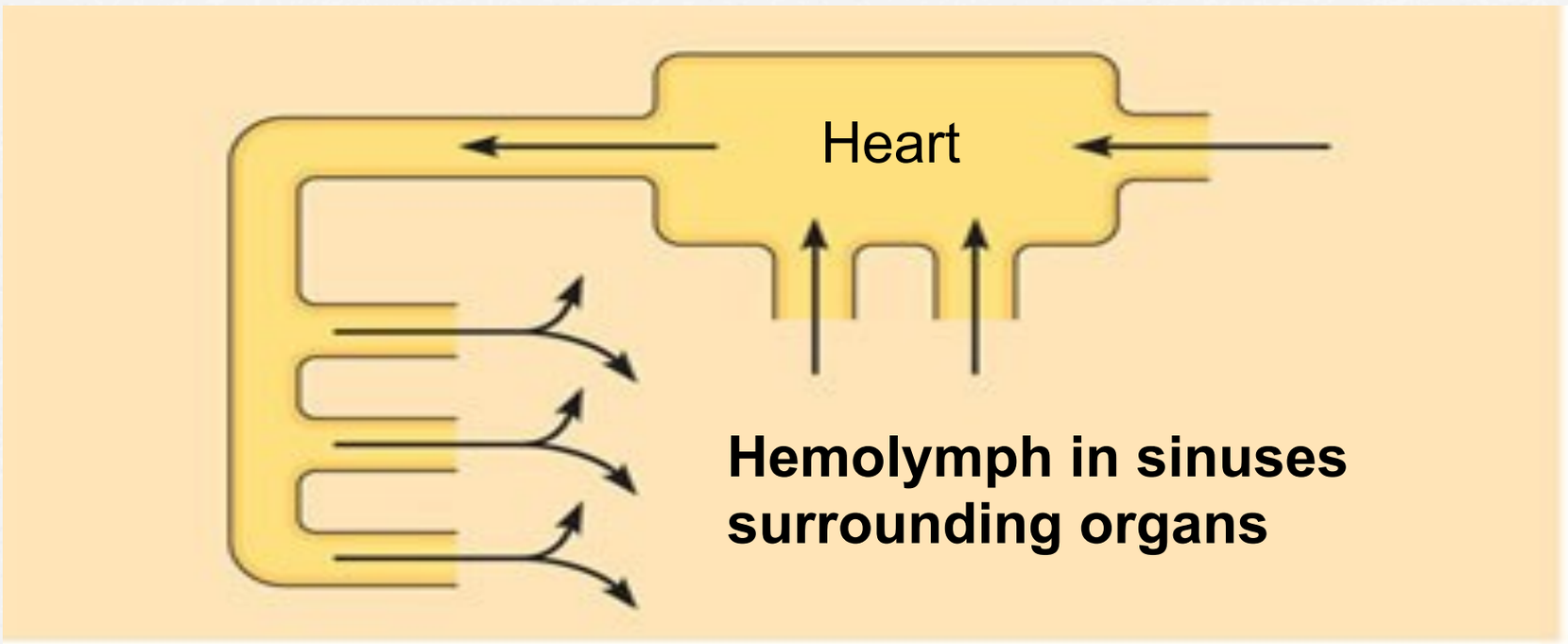
General Properties of Circulatory Systems

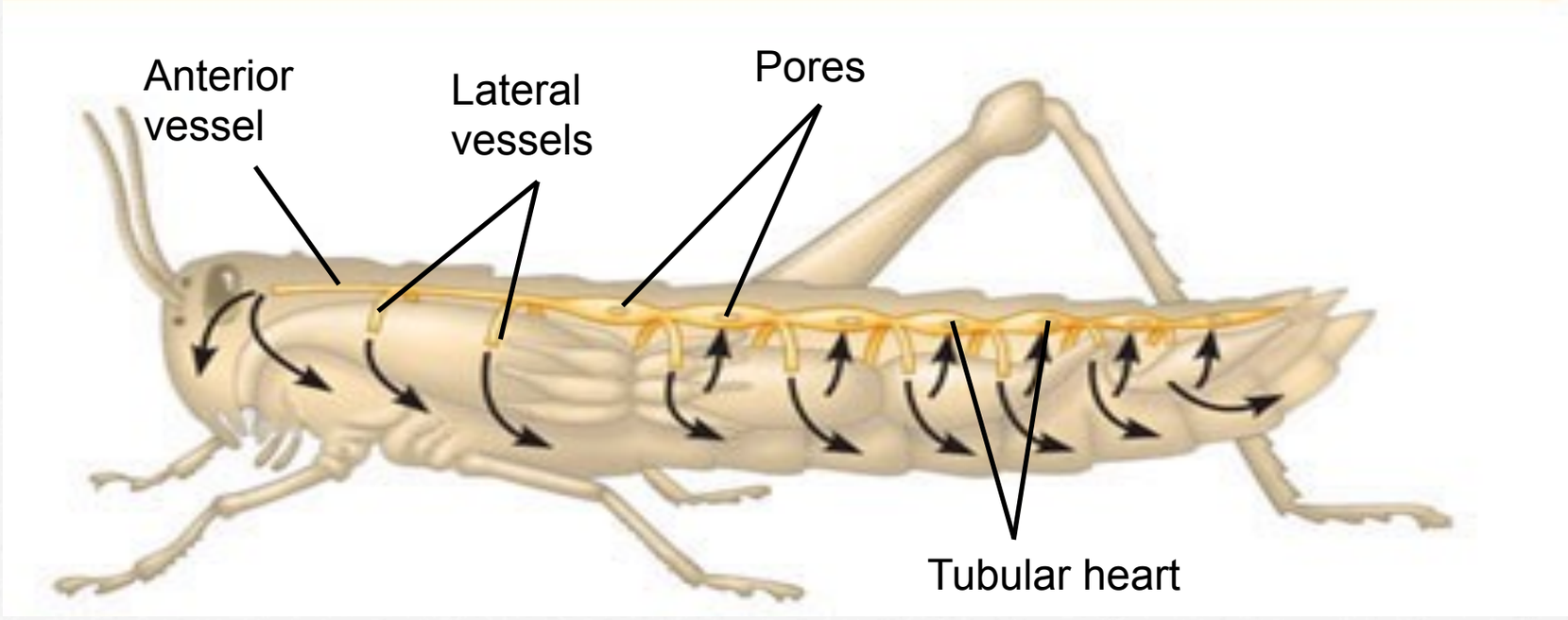
- **A circulatory system has three basic components:**
  - **a fluid, vessels, a pump(s)**
- By moving fluid through the body the circulatory system connects the aqueous surroundings of the cells to the organs that exchange gases (or absorb nutrients, or eliminate waste)
- Several basic types of systems 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

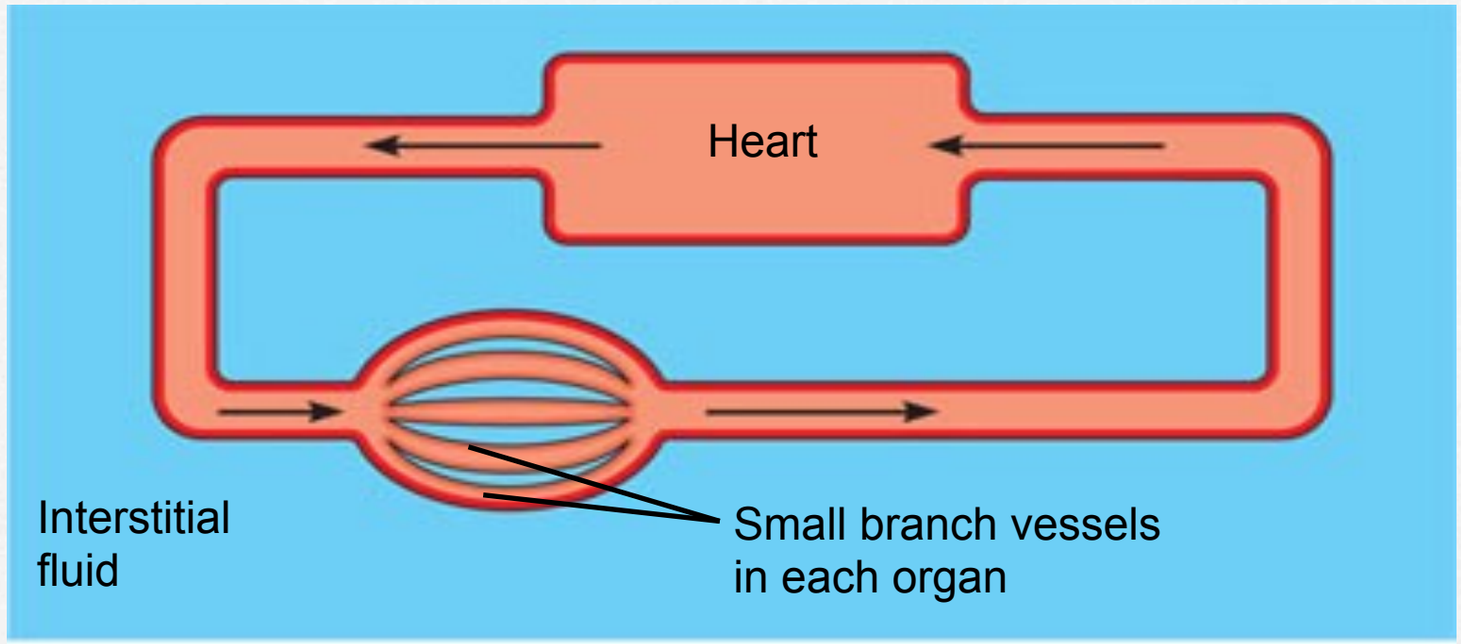


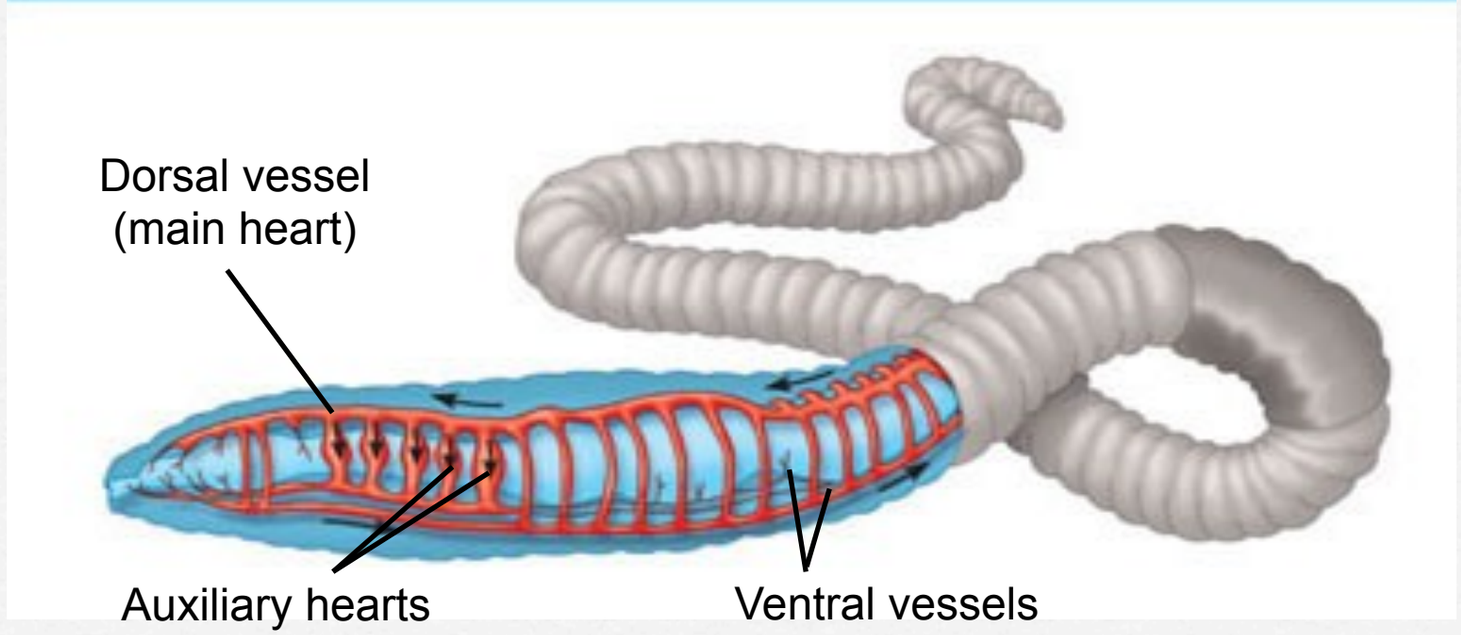


Open & Closed Circulatory Systems

- **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

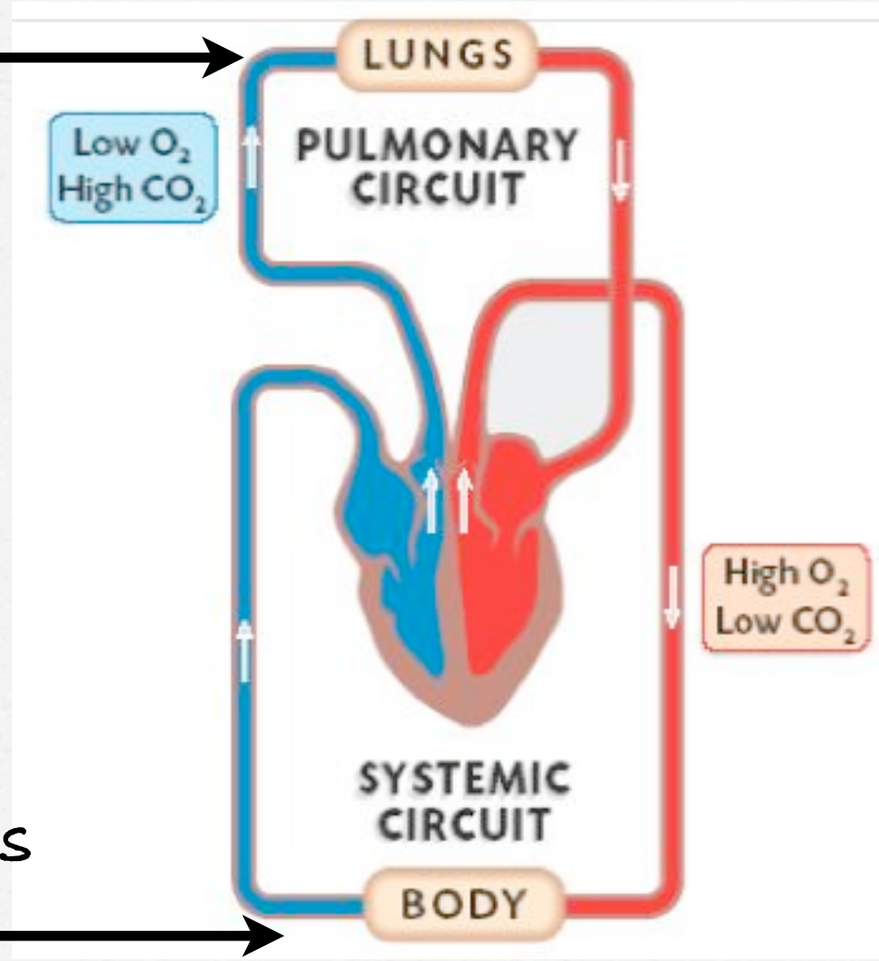
- **Recall a circulatory system has three basic components:**
  - **a fluid, vessels, a pump(s)**
- **The fluid-blood-**fluid component and a cellular component. Although many substances are found within the blood for this unit you only need to remember that oxygen and carbon dioxide are transported 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.

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

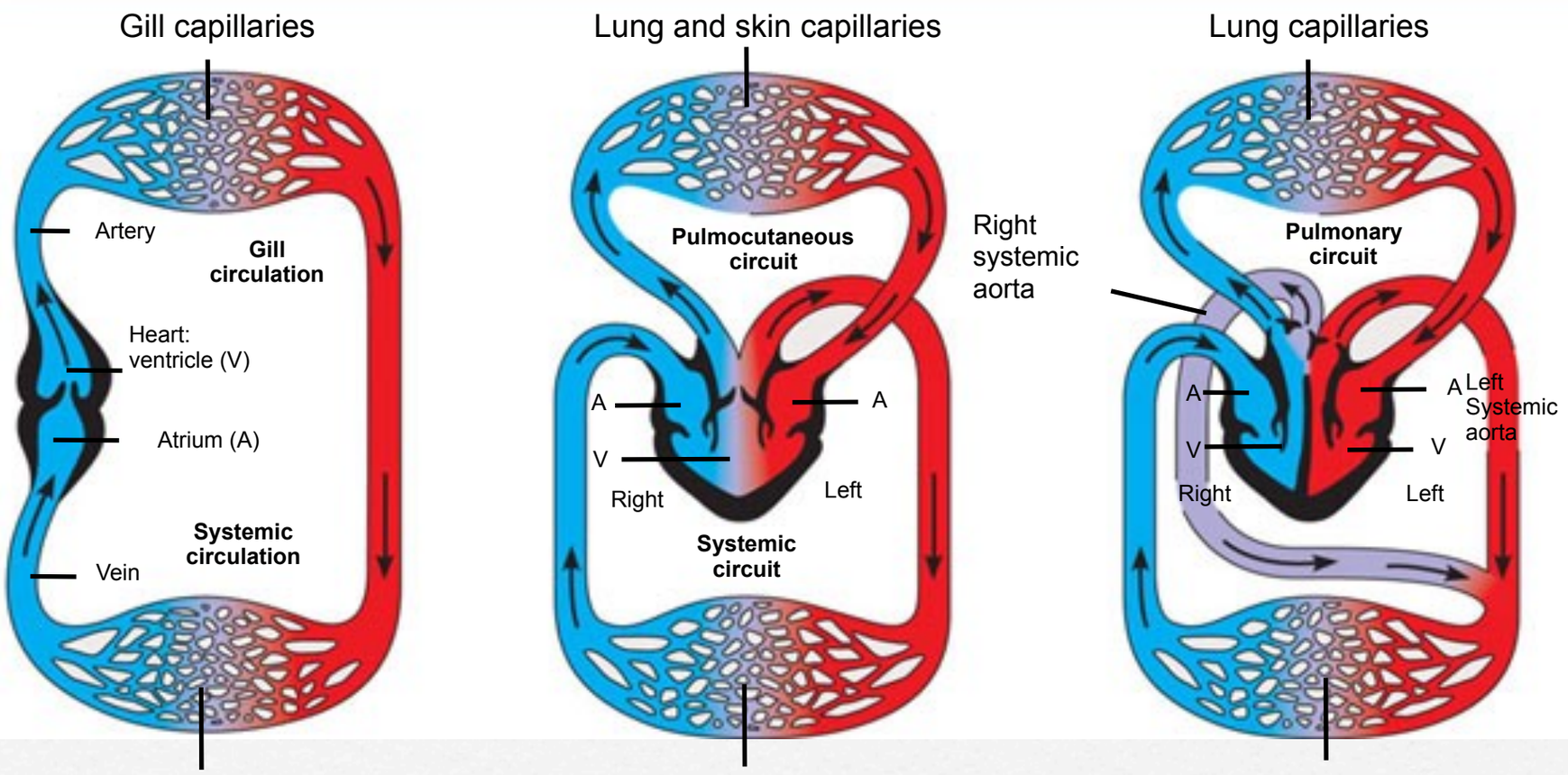


Carbon dioxide diffuses into blood, oxygen diffuses out of blood

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

Vertebrate Circulatory Systems

FISHES	AMPHIBIANS	REPTILES (EXCEPT BIRDS)	MAMMALS AND BIRDS



“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.

To foster student understanding of this concept, instructors can choose an illustrative example such as:

Gas Exchange

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*

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

- 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!**

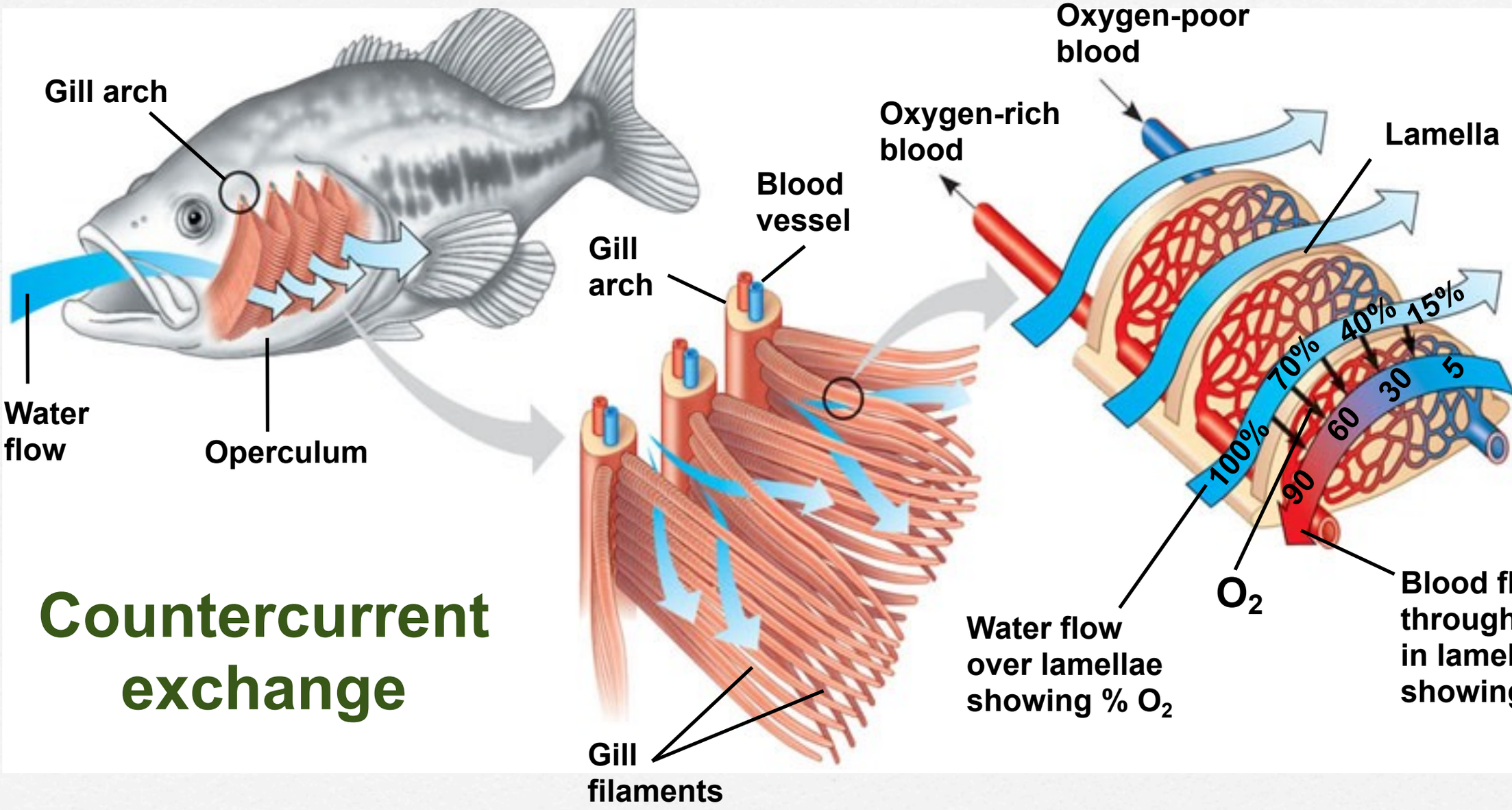
Gills in Aquatic Animals

- 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 (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.)



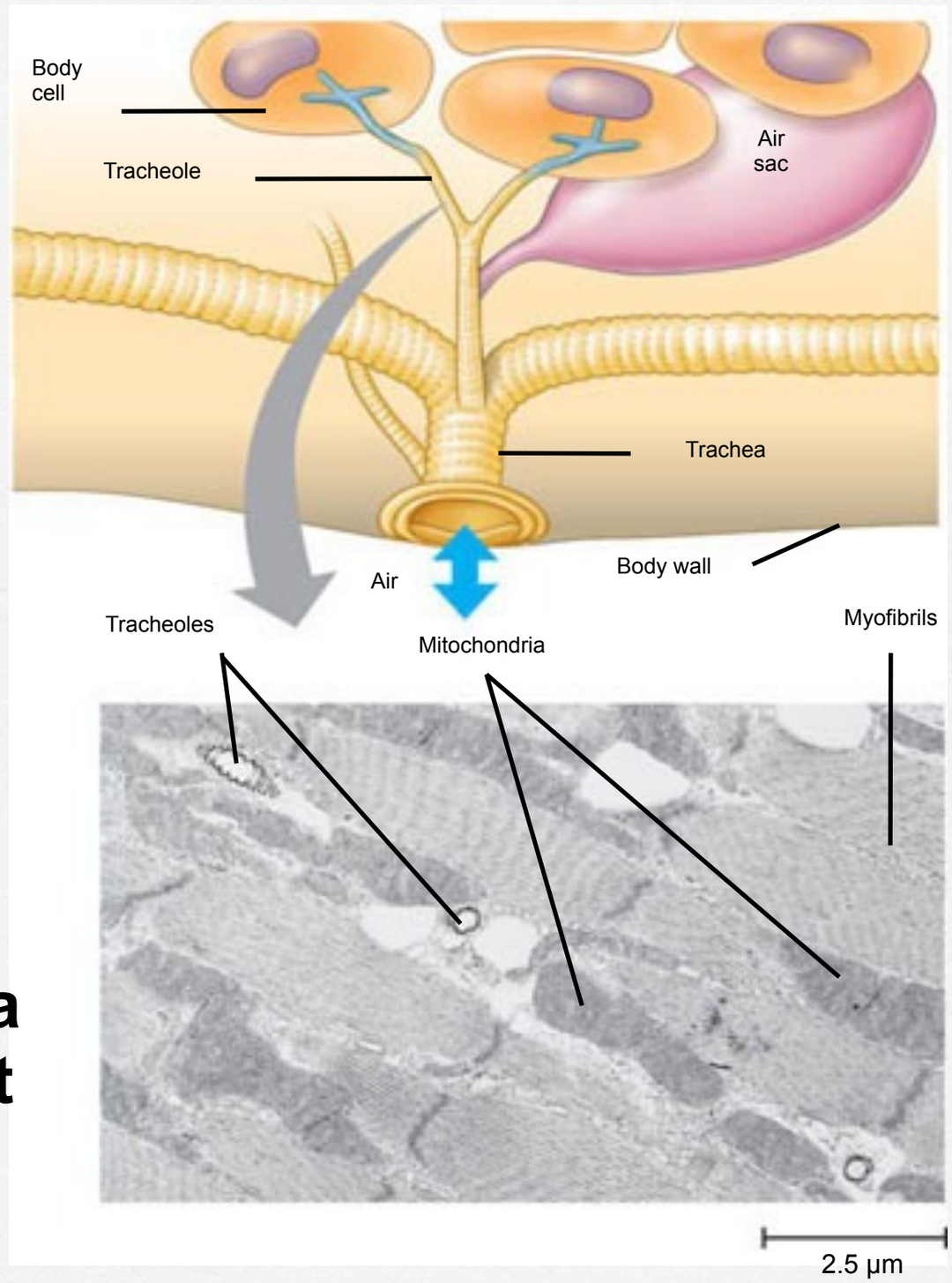
Countercurrent exchange

Higher oxygen gradient is maintained along entire length of capillary

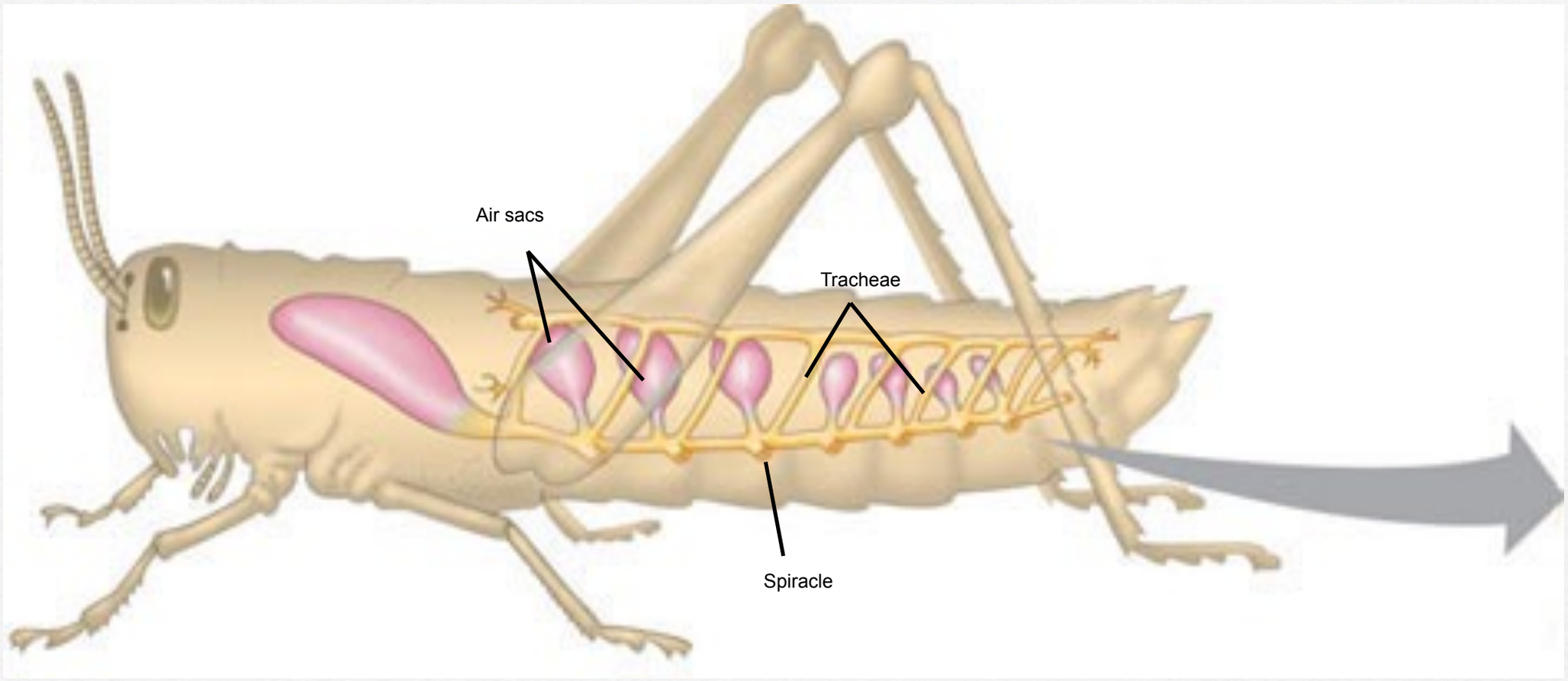
Tracheal Systems in Insects

- 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.

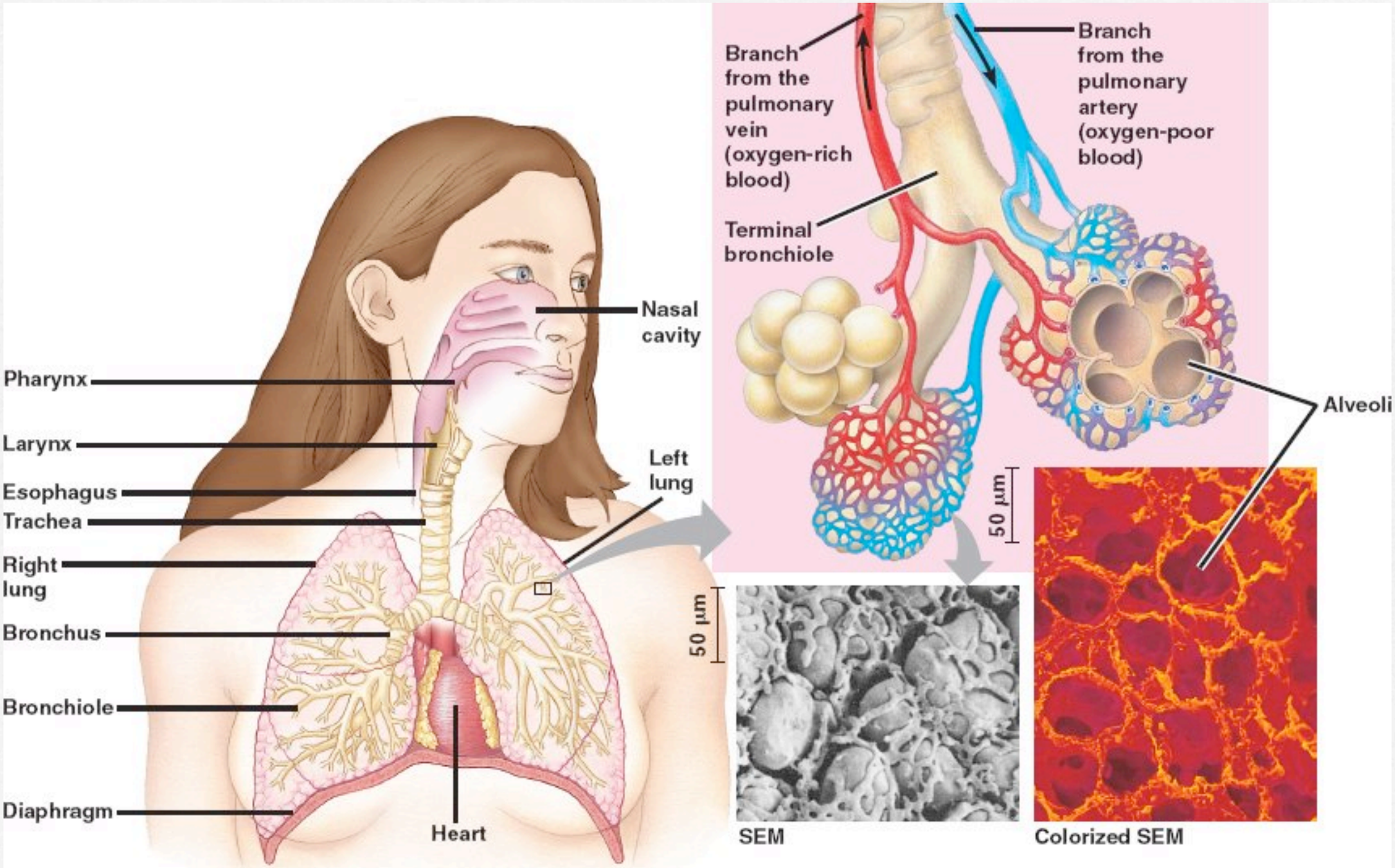


(a) The respiratory system of an insect consists of branched internal tubes that deliver air directly to body cells. Rings of chitin reinforce the largest tubes, called tracheae, keeping them from collapsing. Enlarged portions of tracheae form air sacs near organs that require a large supply of oxygen. 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



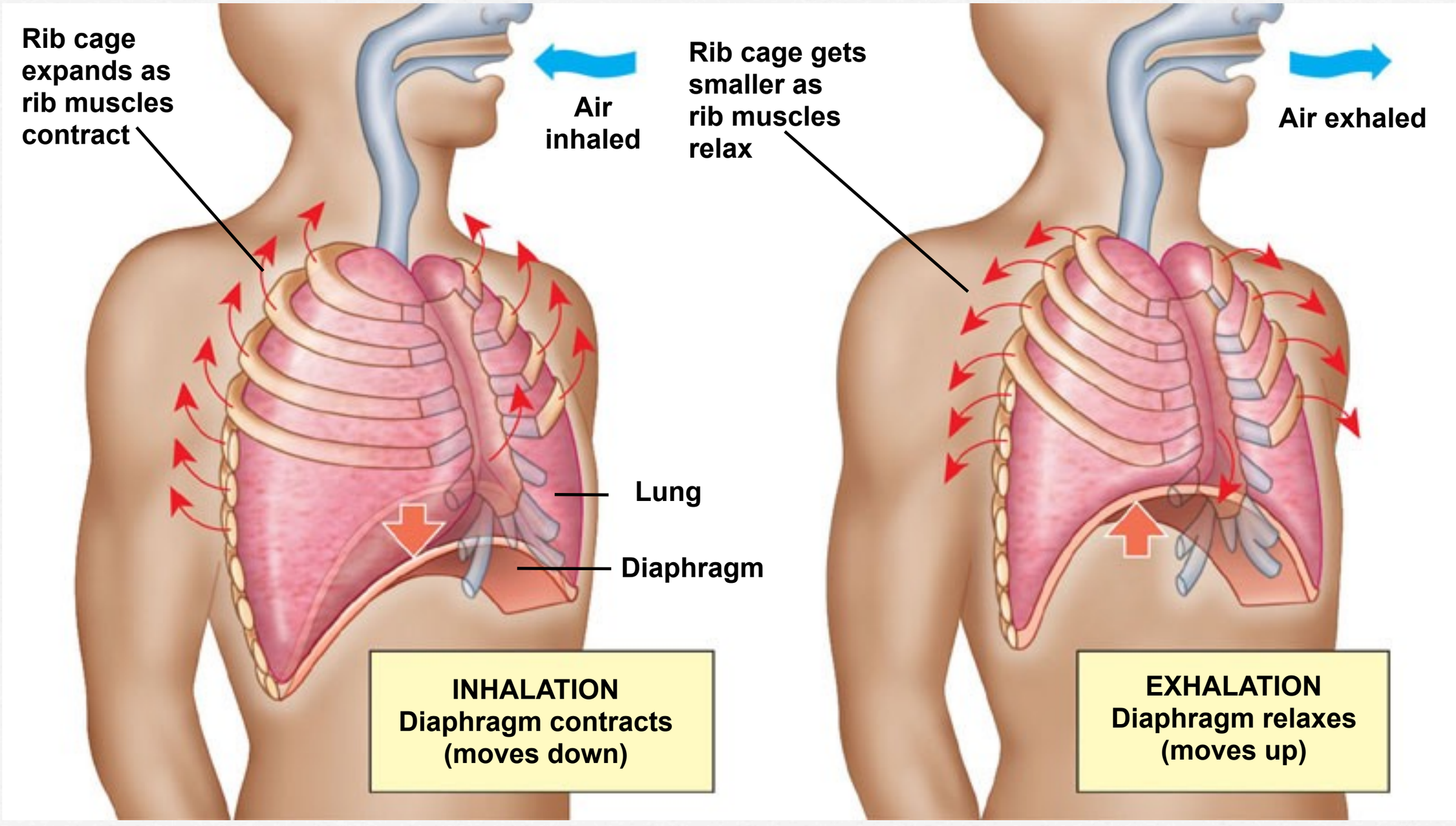
Breathing Ventilates the Lungs

- **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

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

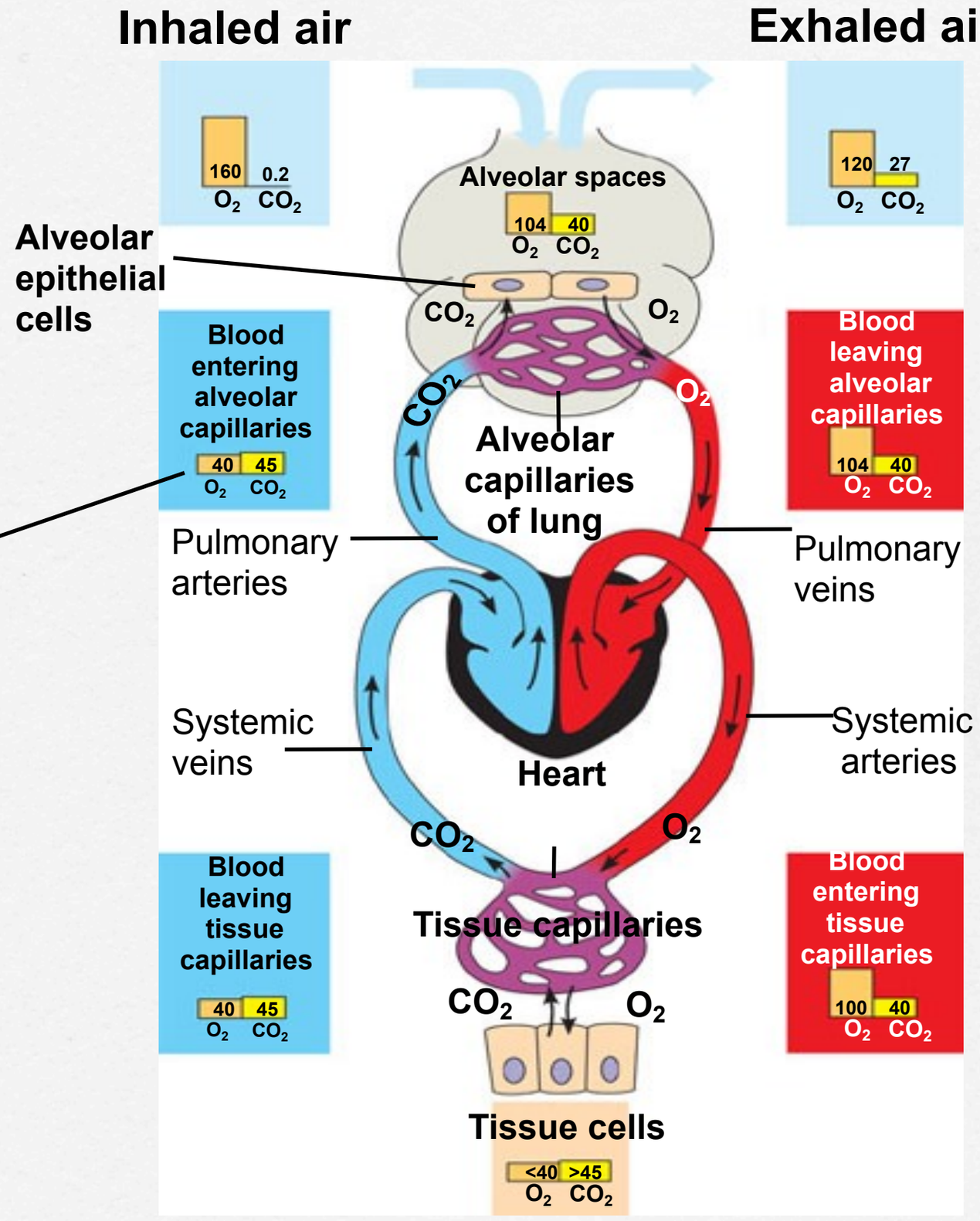
- High metabolic demands of many animals necessitate large quantities of O_2 and CO_2.
- Respiratory pigments facilitate this exchange through their interaction with O_2 and CO_2.

Coordination of Circulation and Gas Exchange

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

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*.**

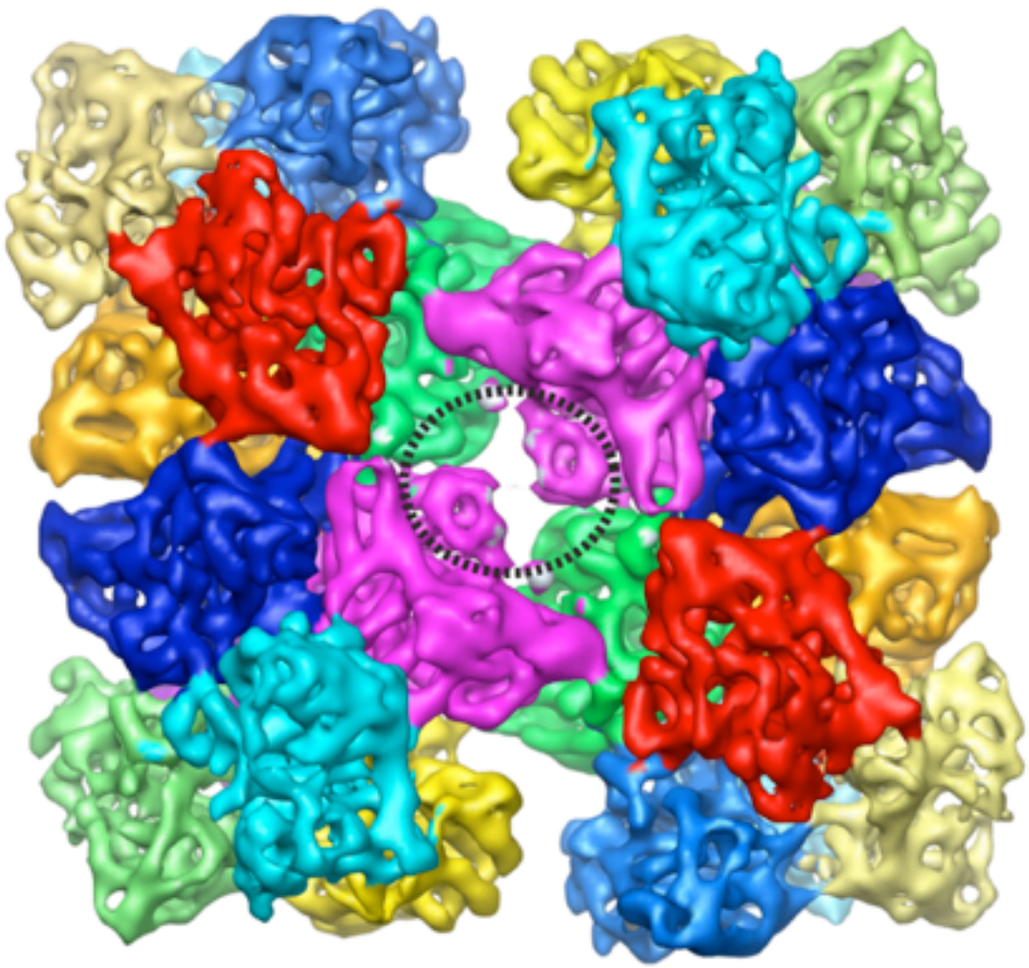
Respiratory Pigments

- ***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.**

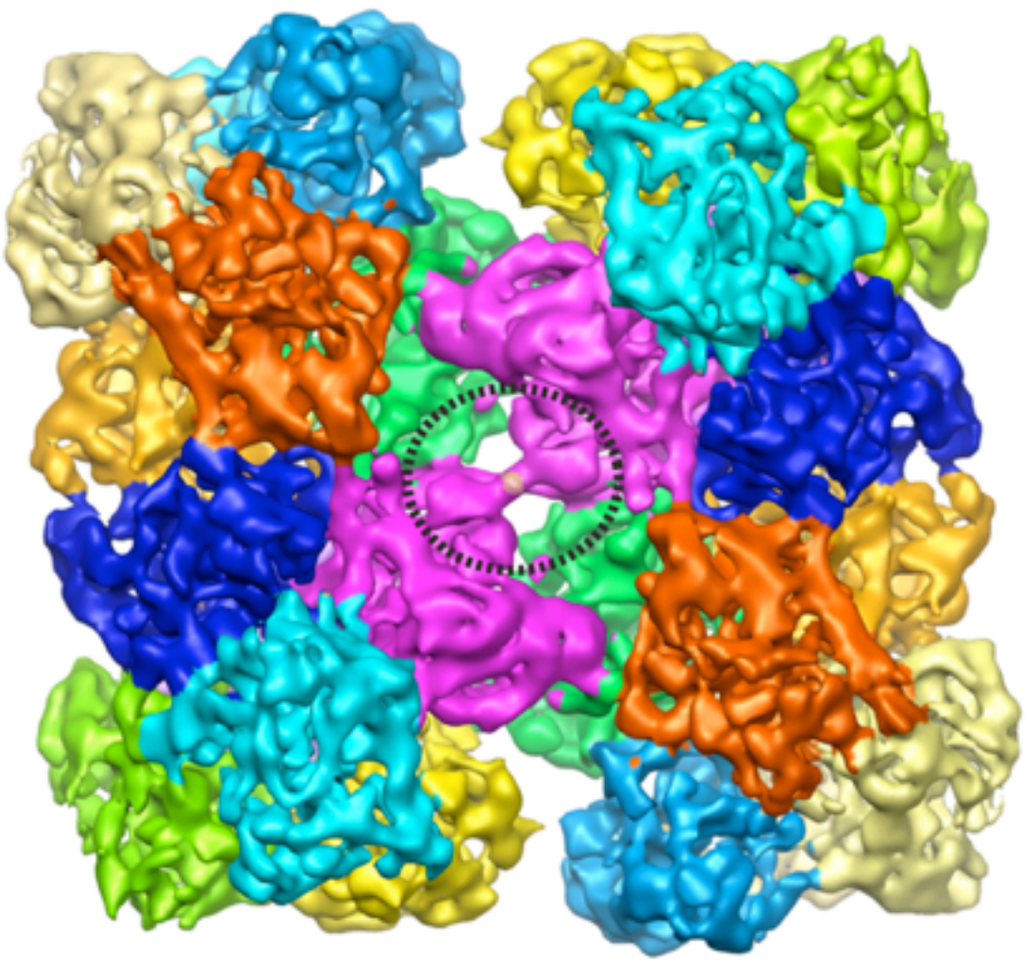
Respiratory Pigments

- ***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

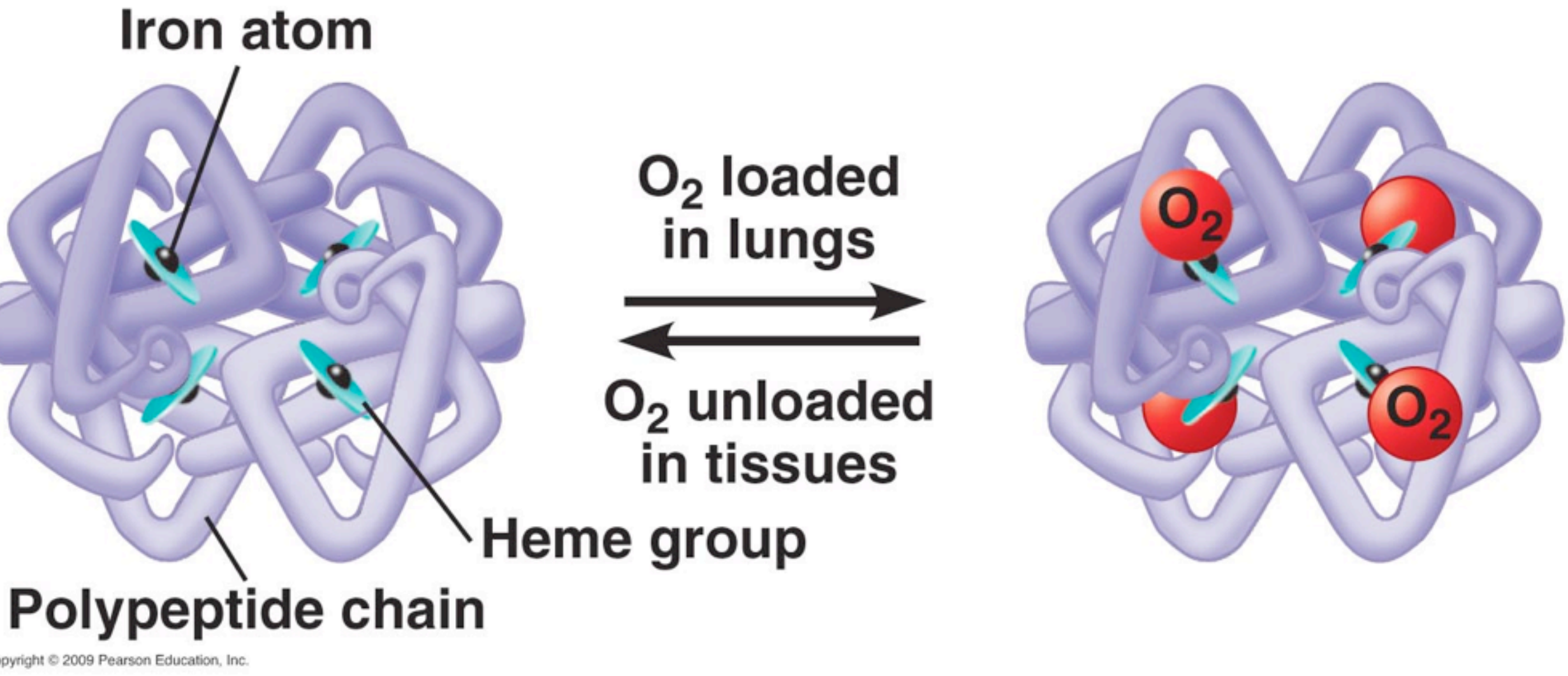


Resting state at 6.8 Å



Activated state at 8 Å

Hemoglobin



Essential knowledge 4.B.2: Cooperative interactions within organisms promote efficiency in the use of energy and matter.

3. Interactions among cells of a population of unicellular organisms can be similar to those of multicellular organisms, and these interactions lead to increased efficiency and utilization of energy and matter.

To foster student understanding of this concept, instructors can choose an illustrative example such as:

1 Bacterial community in the rumen of animals

2 Bacterial community in and around deep sea vents

#2. Cellulose Digestion in Ruminants (herbivores and bacteria)

Overview

- **Herbivores** have an established mutualistic relationship with **anaerobic bacteria** (some yeast and fungi as well) that lives in its digestive tract. These anaerobic bacteria possess the enzyme *celulase* necessary to chemically digest cellulose

- **Termites** have an established mutualistic relationship with a **protist** (some yeast and fungi as well) that lives in its digestive tract. These protists possess the enzyme *cellulase* necessary to chemically digest cellulose.

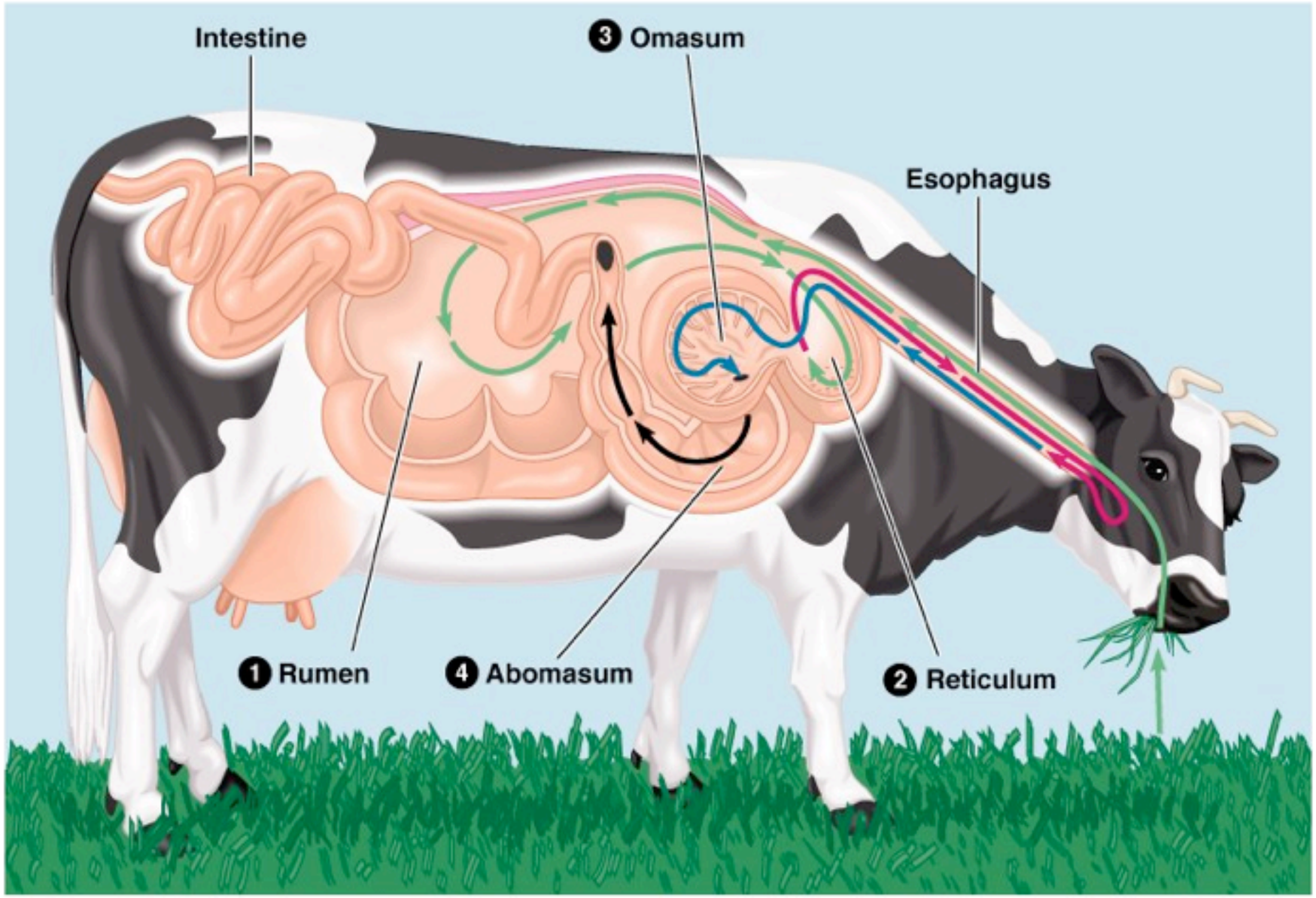
- Many animals, like humans can not digest cellulose which will as a result simply pass through our digestive tracts. This is what we call fiber and diets high in fiber may reduce the risk of colon cancers.

- In Abrahamic religions, a distinction between clean and unclean animals approximately falls according to whether the animal ruminates. The Law of Moses in the Bible allowed only the eating of animals that had cloven hooves and "that chew the cud", a stipulation preserved to this day in the Jewish laws of Kashrut. (source wikipedia)

- **The verb *to ruminate* has been extended metaphorically to mean *to ponder thoughtfully* or *to meditate* on some topic. Similarly, ideas may be *chewed on* or *digested*. *Chew the (one's) cud* is to reflect or meditate. (wikipedia)**

- **Methane has 23 times the warming potential of carbon dioxide and its production by ruminants may contribute to a greenhouse effect or climate change. Methane production by animals, principally ruminants, is estimated 15-20% global production of methane. The rumen is the major site of methane production in ruminants. (wikipedia)**

What do the microorganisms get from this relationship?



Learning Objectives:

LO 4.18 The student is able to use representations and models to analyze how cooperative interactions within organisms promote efficiency in the use of energy and matter. [See SP 1.4]