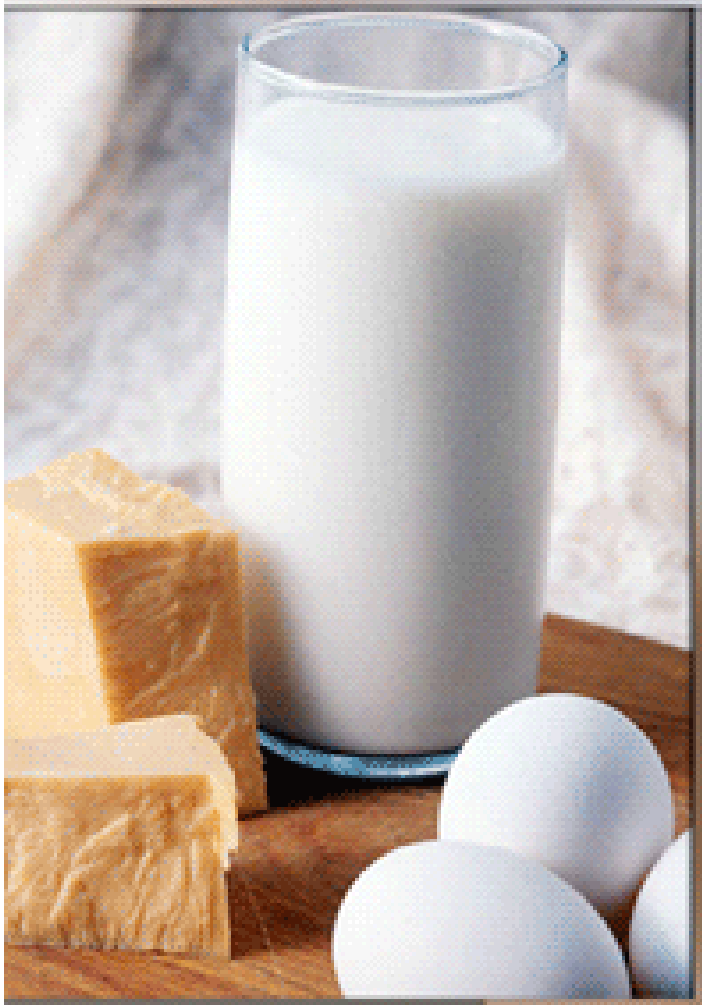
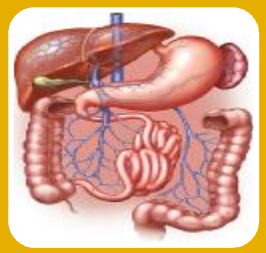


Chapter 9

MATERIAL EXCHANGE IN ANIMAL BODY

Circulation

Gas Exchange



Obtaining Nutrients

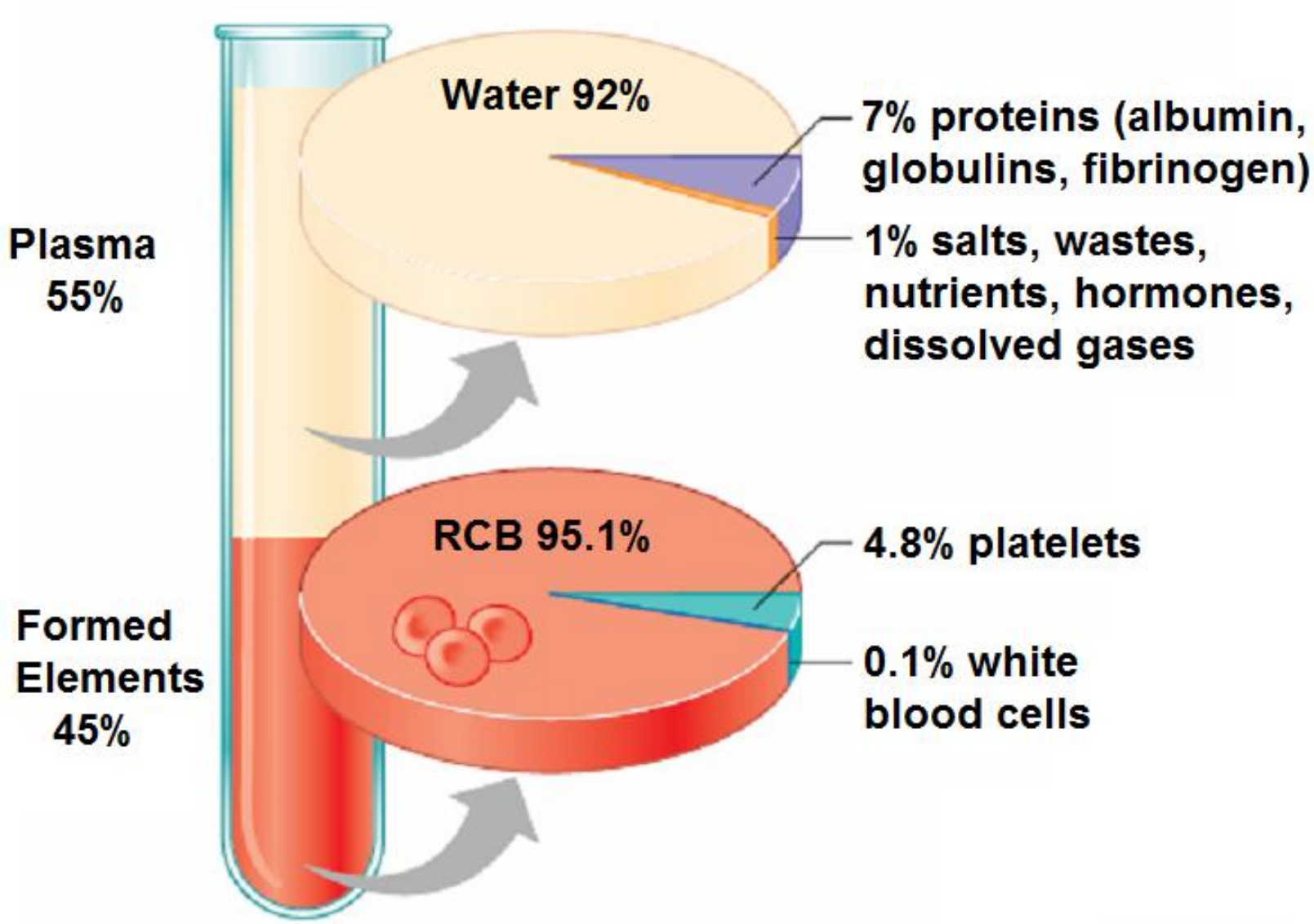
Waste Disposal

Function of Bloods

- Transport of gases, nutrients, and waste products.
- Transport of processed molecules.
- Transport of regulatory molecules.
- Regulation of pH and osmosis.
- Maintenance of body temperature.
- Protection against foreign substances.
- Clot formation.

Blood Compositions

- Blood consists of:
  - A liquid matrix called plasma
  - Formed elements


Water 92%
7% proteins (albumin, globulins, fibrinogen)
1% salts, wastes, nutrients, hormones, dissolved gases
Plasma 55%
RCB 95.1%
4.8% platelets
0.1% white blood cells
Formed Elements 45%

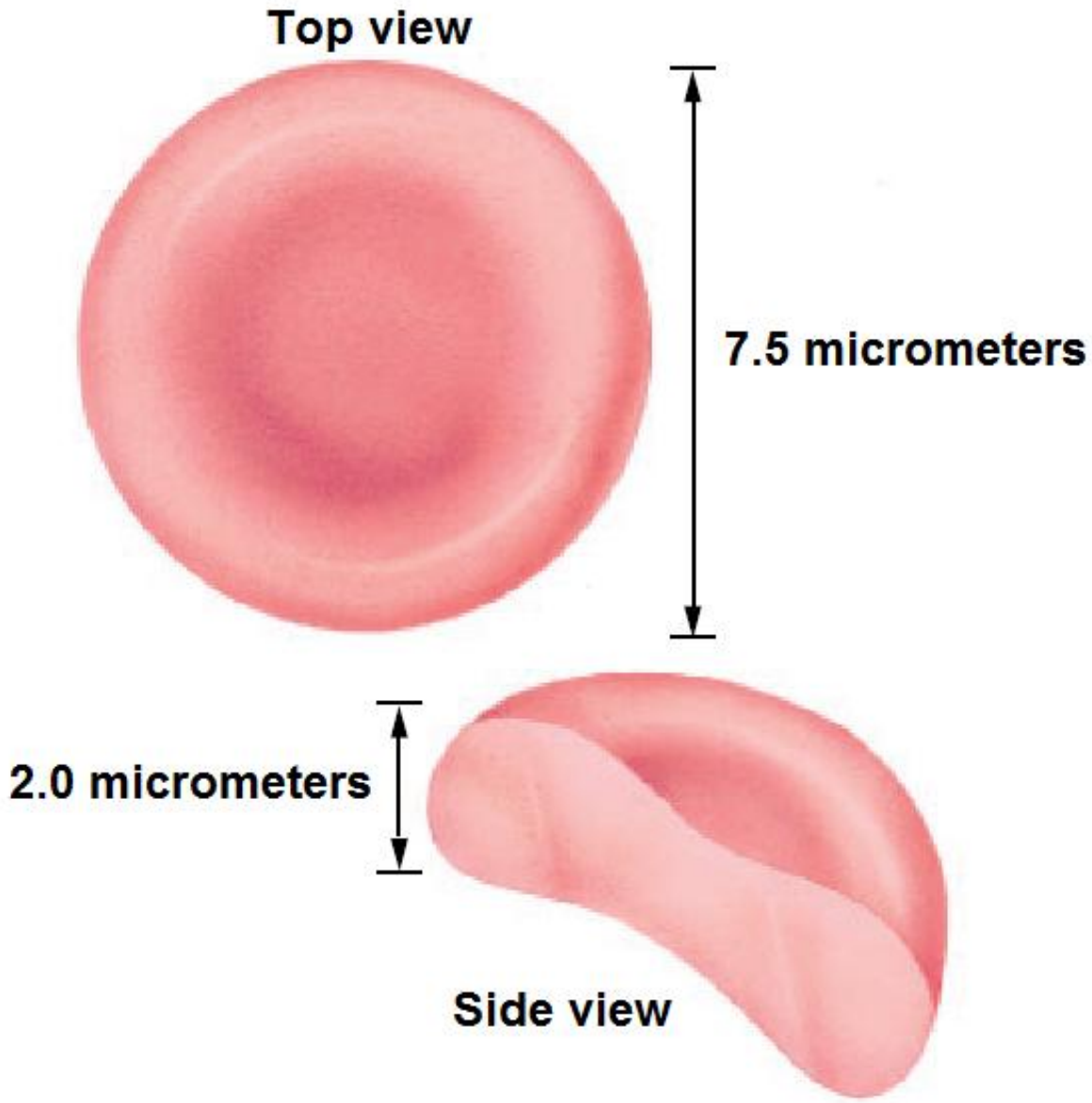
Plasma

Constituents	Major functions
Water	Solvent for carrying other substances
Ions (blood electrolytes) Sodium Potassium Calcium Magnesium Chloride Bicarbonate	Osmotic balance, pH buffering, and regulation of membrane permeability.
Plasma Proteins Albumin Fibrinogen Globulin	Osmotic balance, pH buffering Clotting Defence
Substances transported by blood Nutrients (Glucose, Fatty acids, Vitamins) Waste products of metabolism Respiratory gases (O2 and CO2) Hormones	

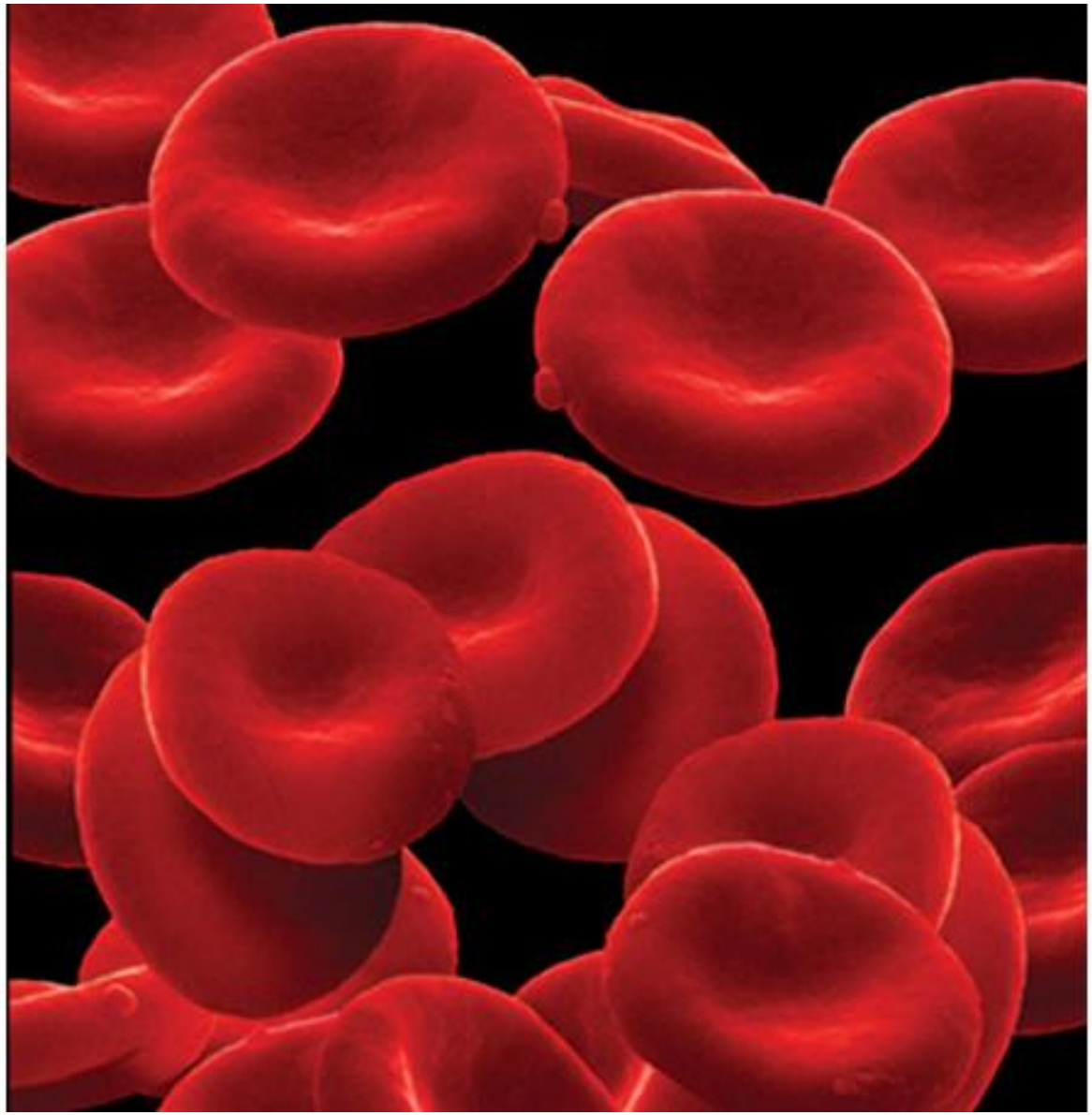
Red Blood Cells

- Red blood cells, or erythrocytes
  - are by far the most numerous type of blood cell
- Males have about 5.4 million red blood cells per microliter of blood
- Females have about 4.8 million/μL

Shape and Dimensions of a RCB



SEM of RCBs



White Blood Cells

- White blood cells, or **leukocytes**, are clear or whitish-colored cells that lack hemoglobin but have a nucleus.
- White blood cells:
  - protect the body against invading microorganisms
  - remove dead cells and debris from the body

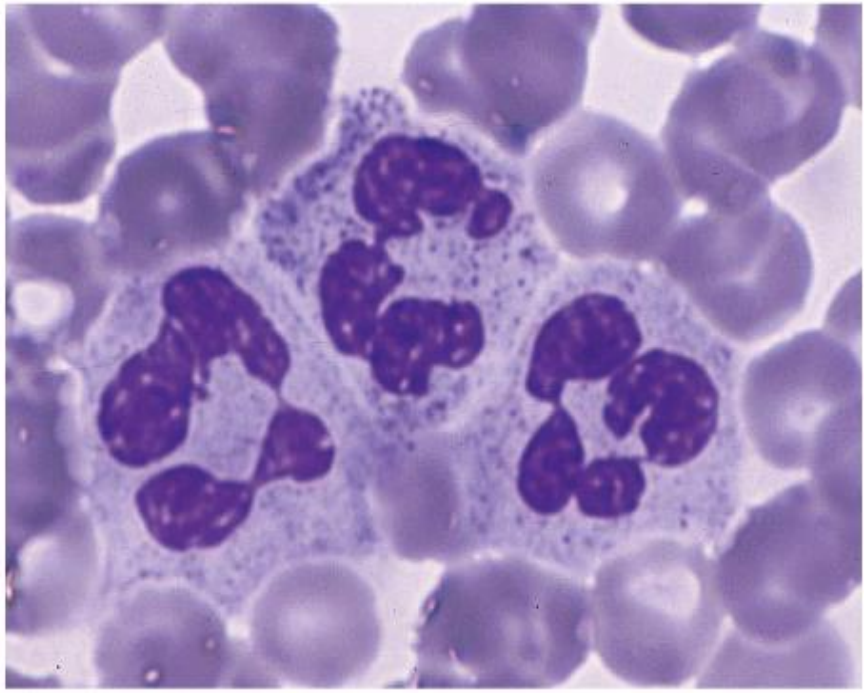
White Blood Cells

- White blood cells are named according to their appearance in stained preparations.
- There are five types of WCB:
  - Neutrophils
  - Monocytes
  - Basophils
  - Eosinophils
  - Lymphocytes

Neutrophils

- Have small cytoplasmic granules that stain with both acidic and basic dyes.
- Their nuclei are commonly lobed, with the number of lobes varying from two to five.
- Seek out and phagocytize bacteria, antigen–antibody complexes, and other foreign matter.
- Secrete lysozymes, which are capable of destroying certain bacteria.

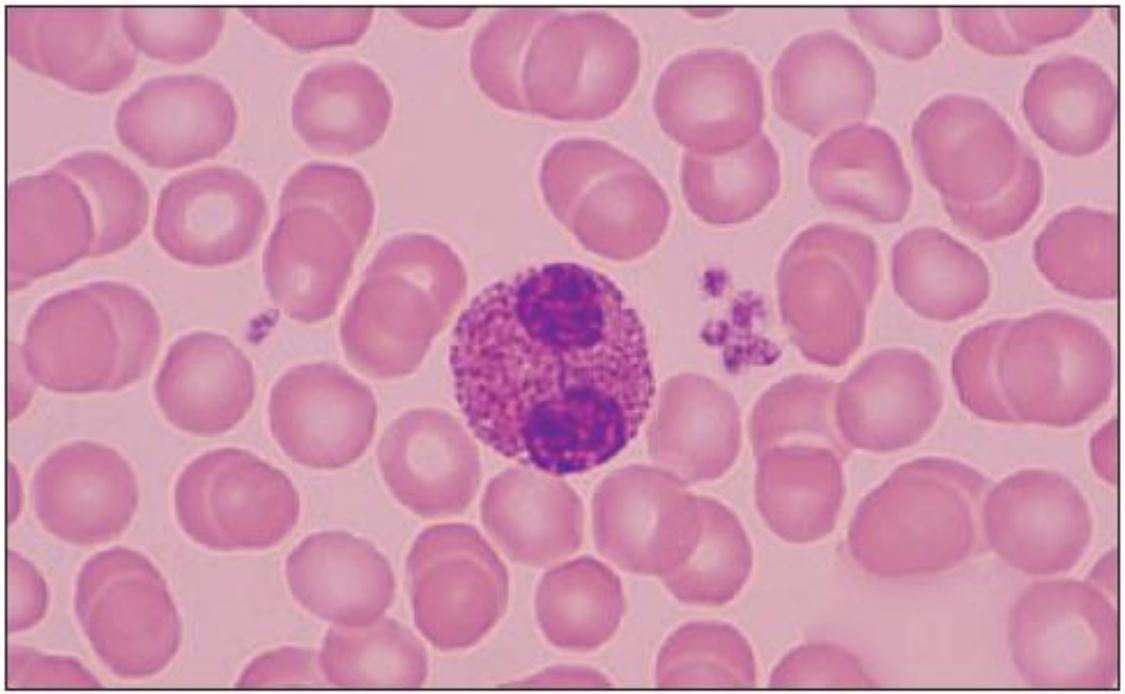
Neutrophils



Eosinophils

- Contain cytoplasmic granules that stain bright red with eosin, an acidic stain.
- Reduce the inflammatory response by producing enzymes that destroy inflammatory chemicals like histamine.
- Release toxic chemicals that attack certain worm parasites such as tapeworms, flukes, pinworms, and hookworms.

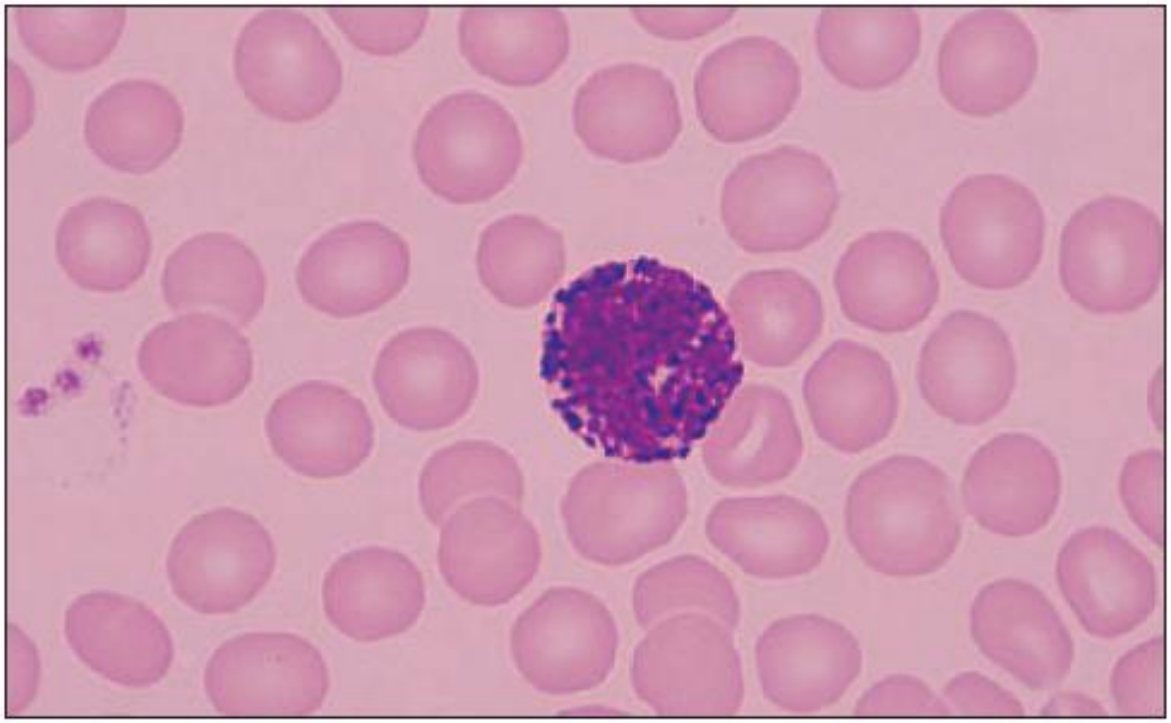
Eosinophils



Basophils

- Contain large cytoplasmic granules that stain blue or purple with basic dyes.
- Contain large amounts of **histamine**, which they release within tissues to increase inflammation.
- Release **heparin**, which inhibits blood clotting.

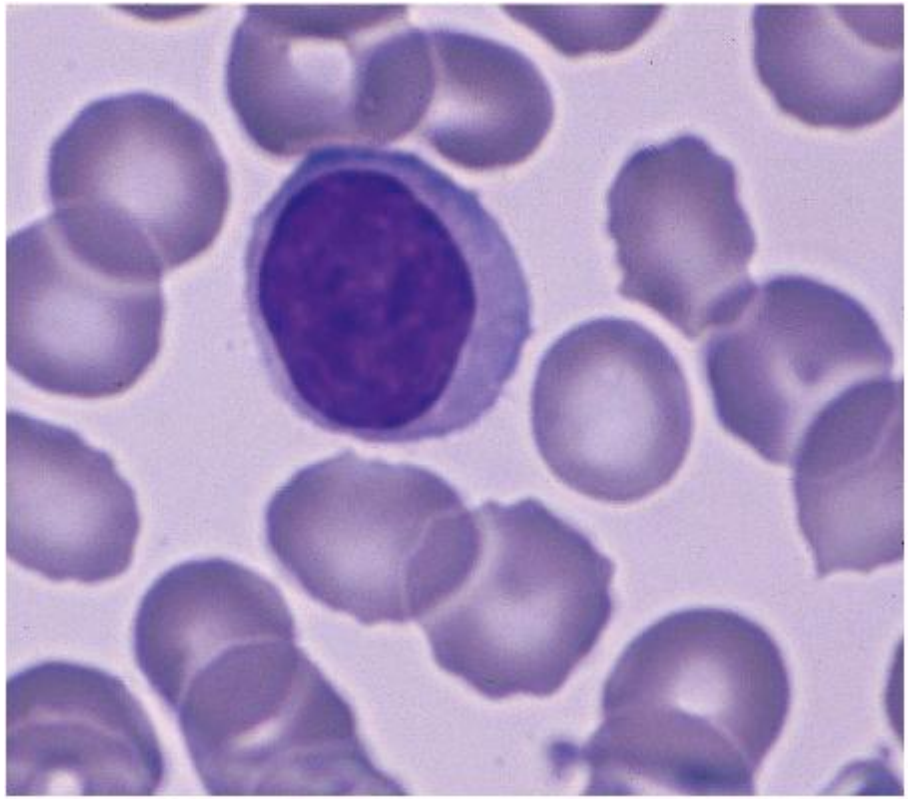
Basophils



Lymphocytes

- Are the smallest white blood cells.
- The lymphocytic cytoplasm consists of only a thin, sometimes imperceptible ring around the nucleus.
- They play important roles in immunity

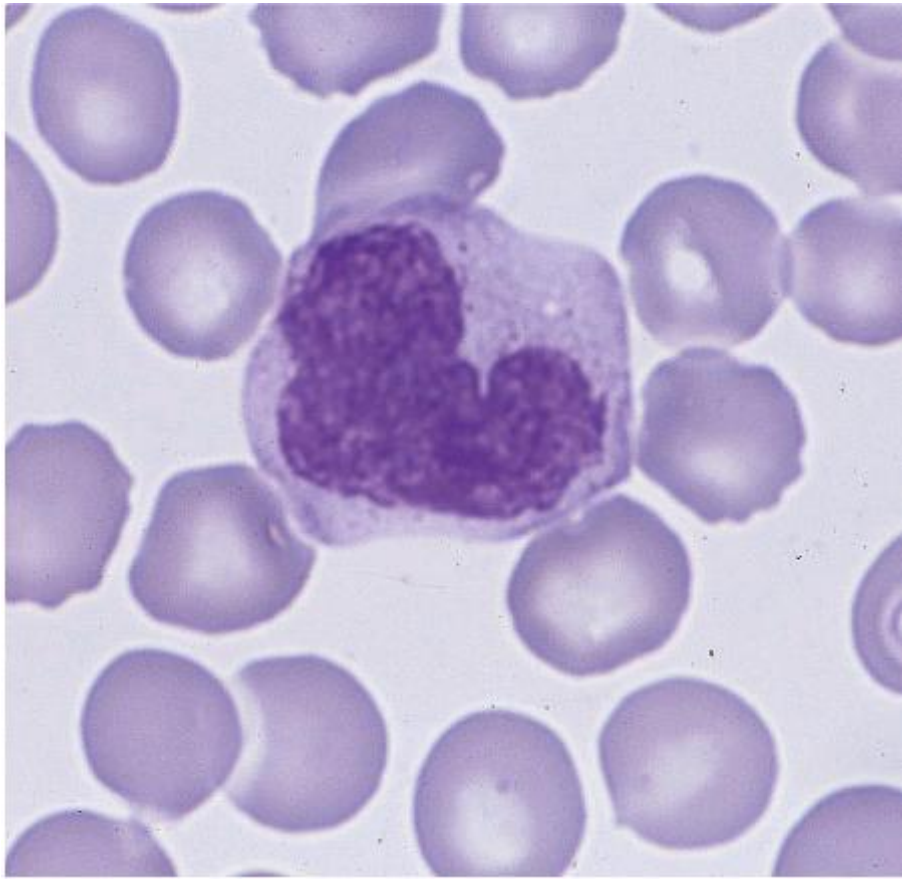
Lymphocyte



Monocytes

- Are the largest white blood cells.
- They phagocytize bacteria, dead cells, cell fragments, and other debris within the tissues.

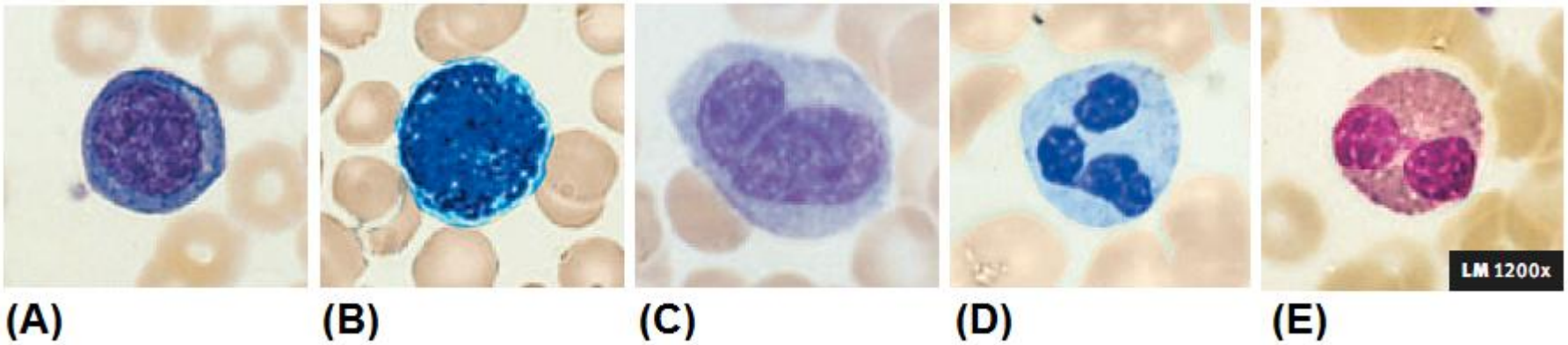
Monocyte



Platelets

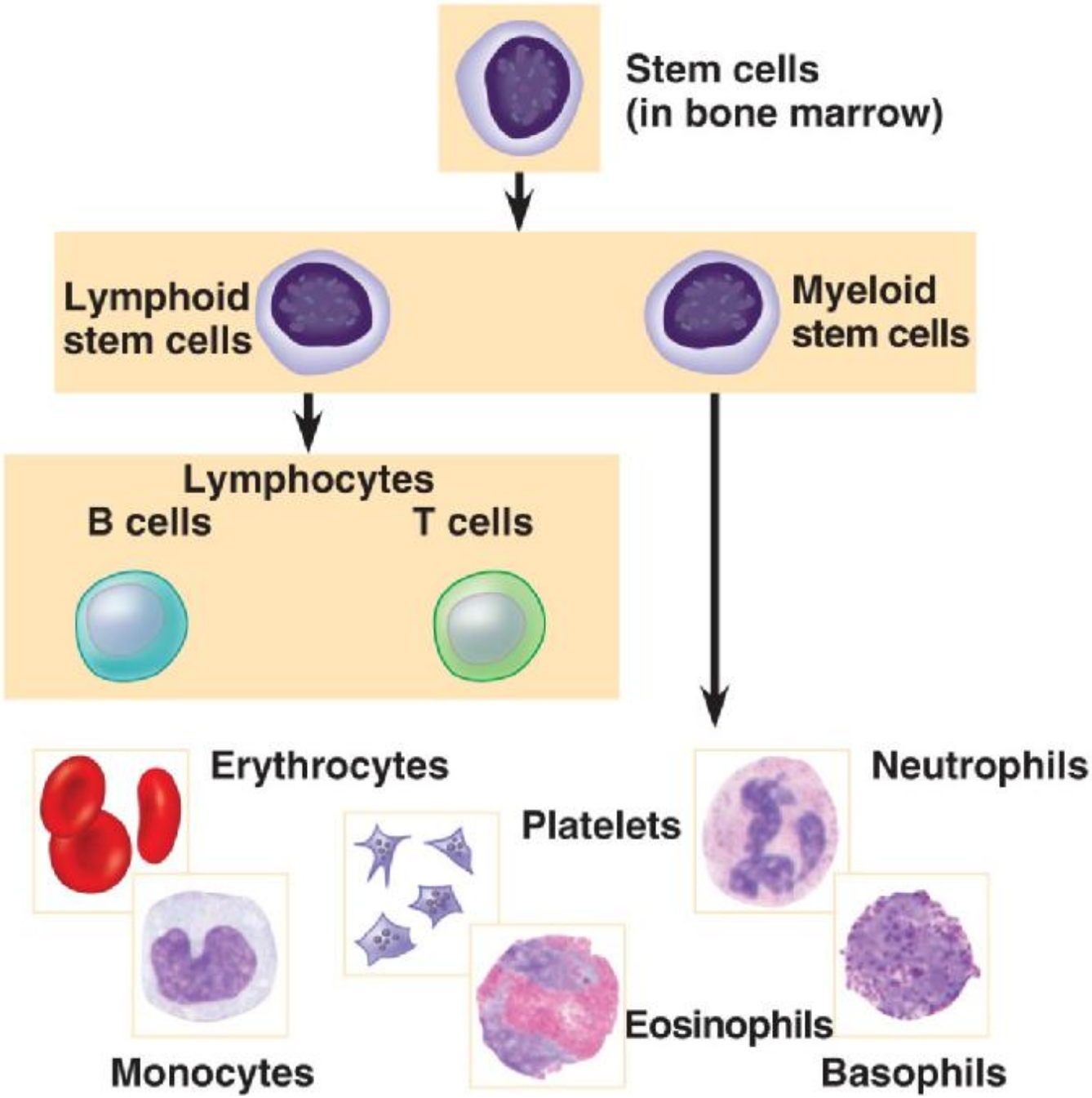
- Platelets (thrombocytes) function in blood clotting

- Base on their morphology, identify each of the white blood cells.



Hematopoiesis

- New blood cells are continually formed from unspecialized stem cells found in red bone marrow
  - Stem cells differentiate into red and white blood cells and the cells that produce platelets
  - Bone marrow stem cells can be isolated and used to treat leukemia

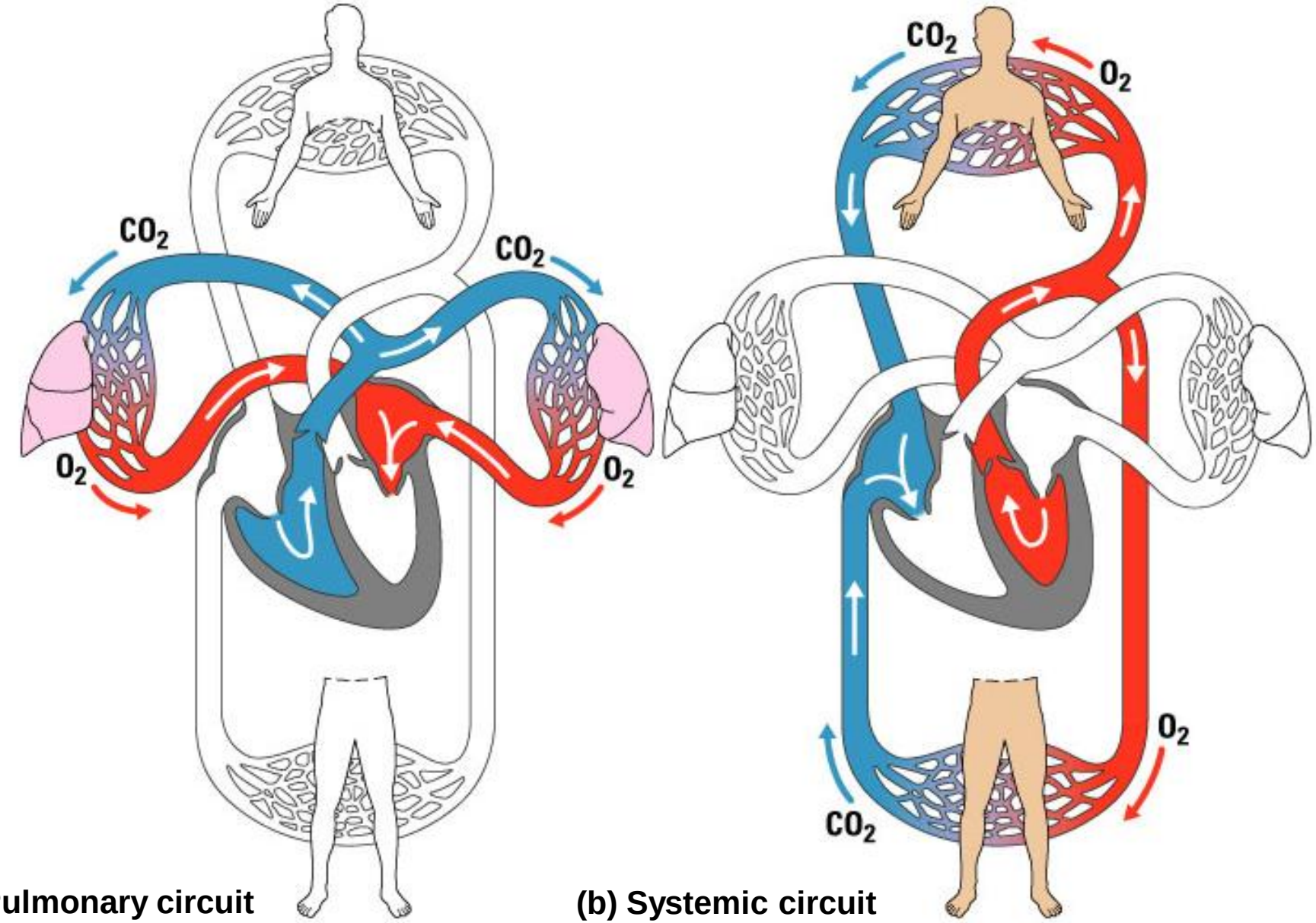

Stem cells
(in bone marrow)
Lymphoid
stem cells
Myeloid
stem cells
Lymphocytes
B cells
T cells
Erythrocytes
Platelets
Neutrophils
Eosinophils
Monocytes
Basophils

THE HUMAN CARDIOVASCULAR SYSTEM

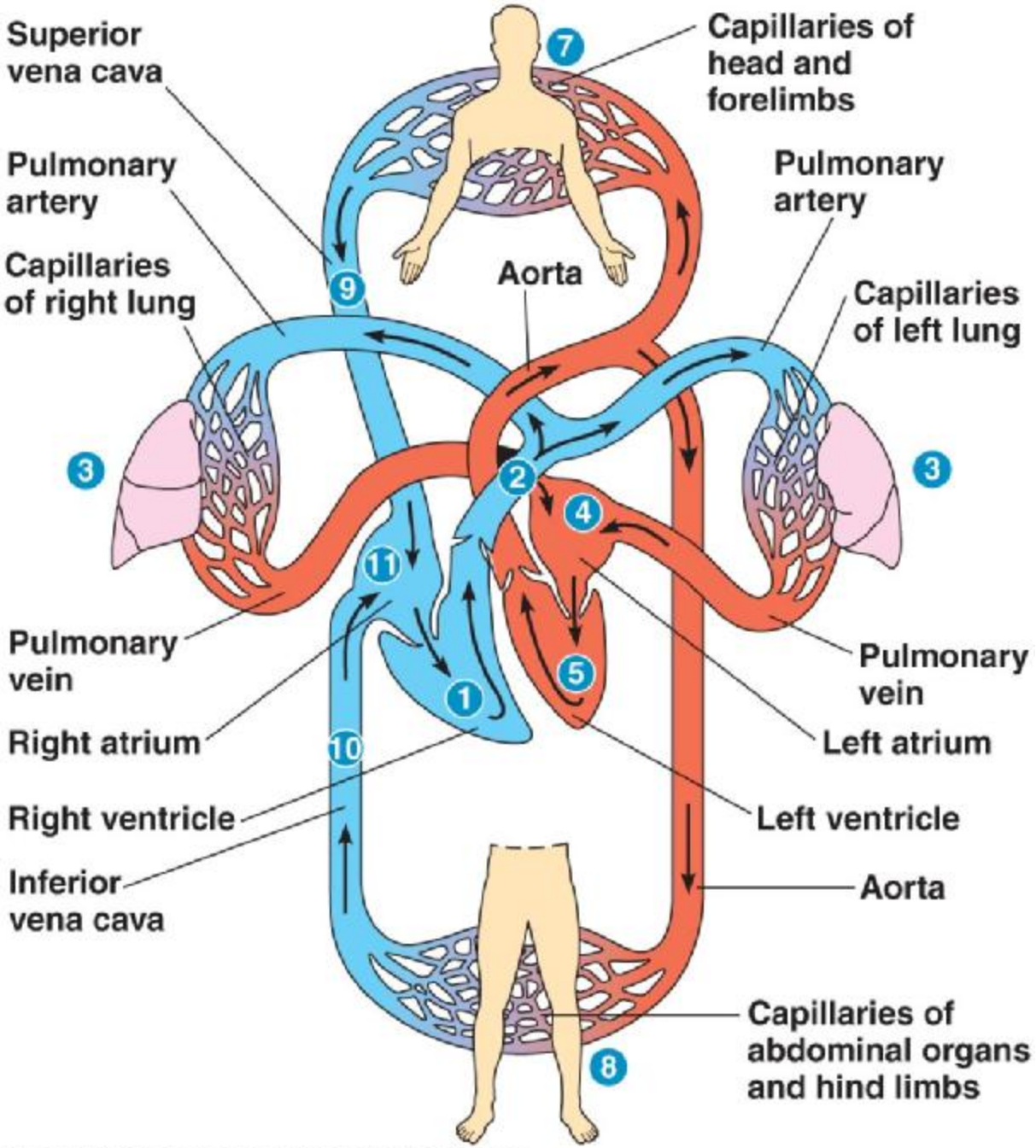
- In the human cardiovascular system
  - The central pump is your heart
  - The vascular system is your blood vessels
  - The circulating fluid is your blood

The Path of Blood

- The three components of the cardiovascular system are organized into a double circulation system:
  - The **pulmonary circuit** carries blood between the heart and the lungs
  - The **systemic circuit** carries blood between the heart and the rest of the body

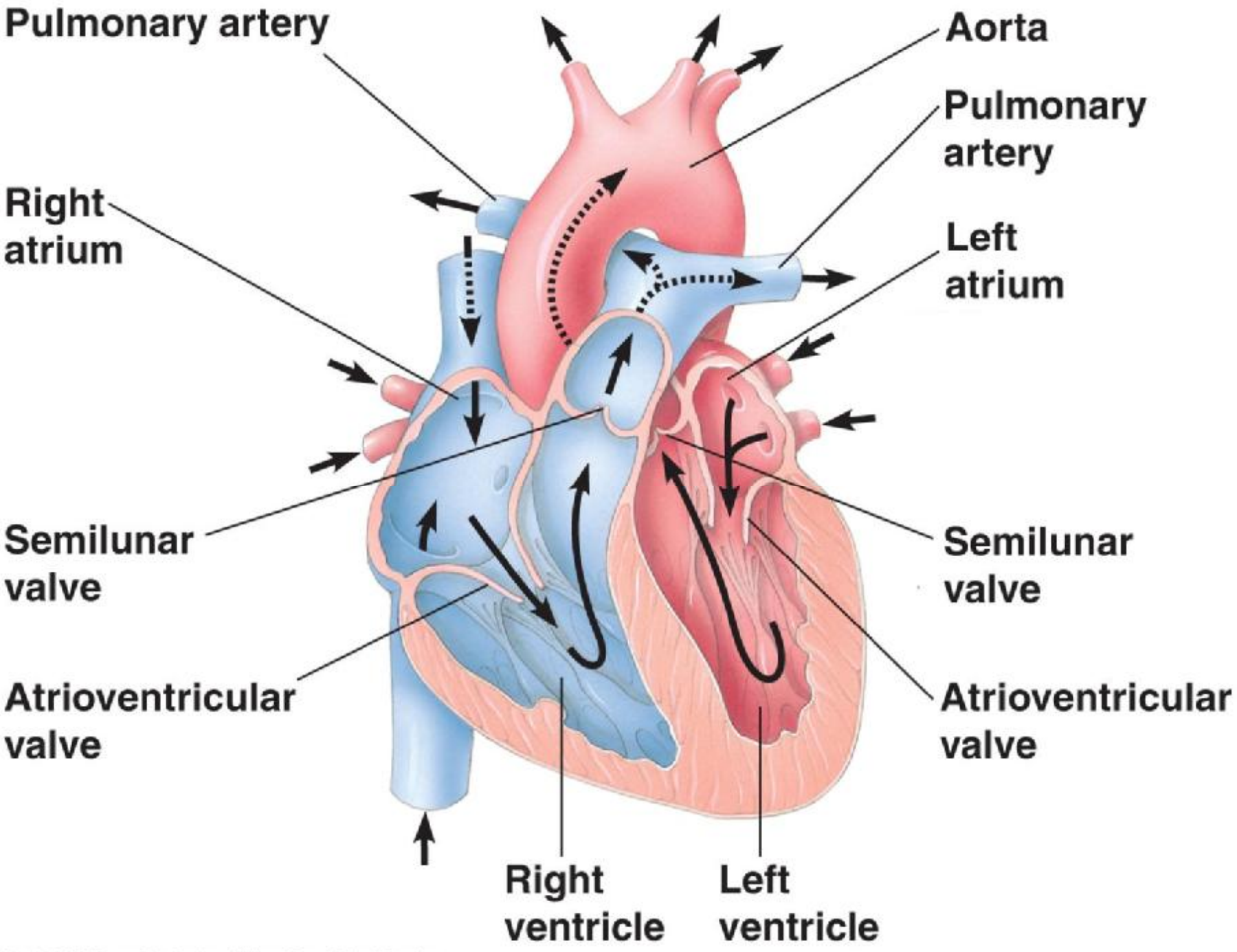


(a) Pulmonary circuit **(b) Systemic circuit**



The Heart

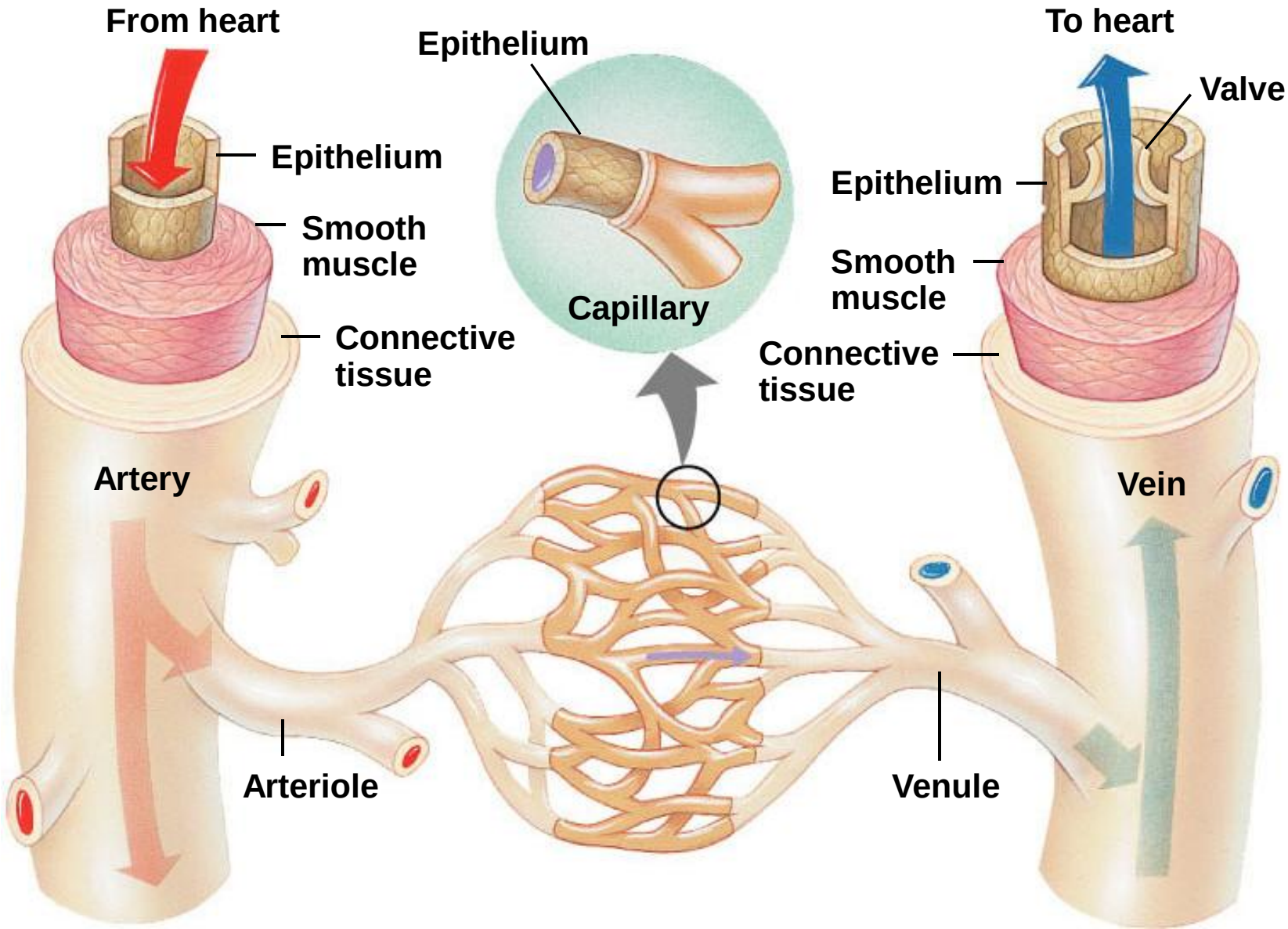
- The human heart is a muscular organ about the size of a fist
  - It is located under the breastbone
  - It has four chambers



Blood Vessels

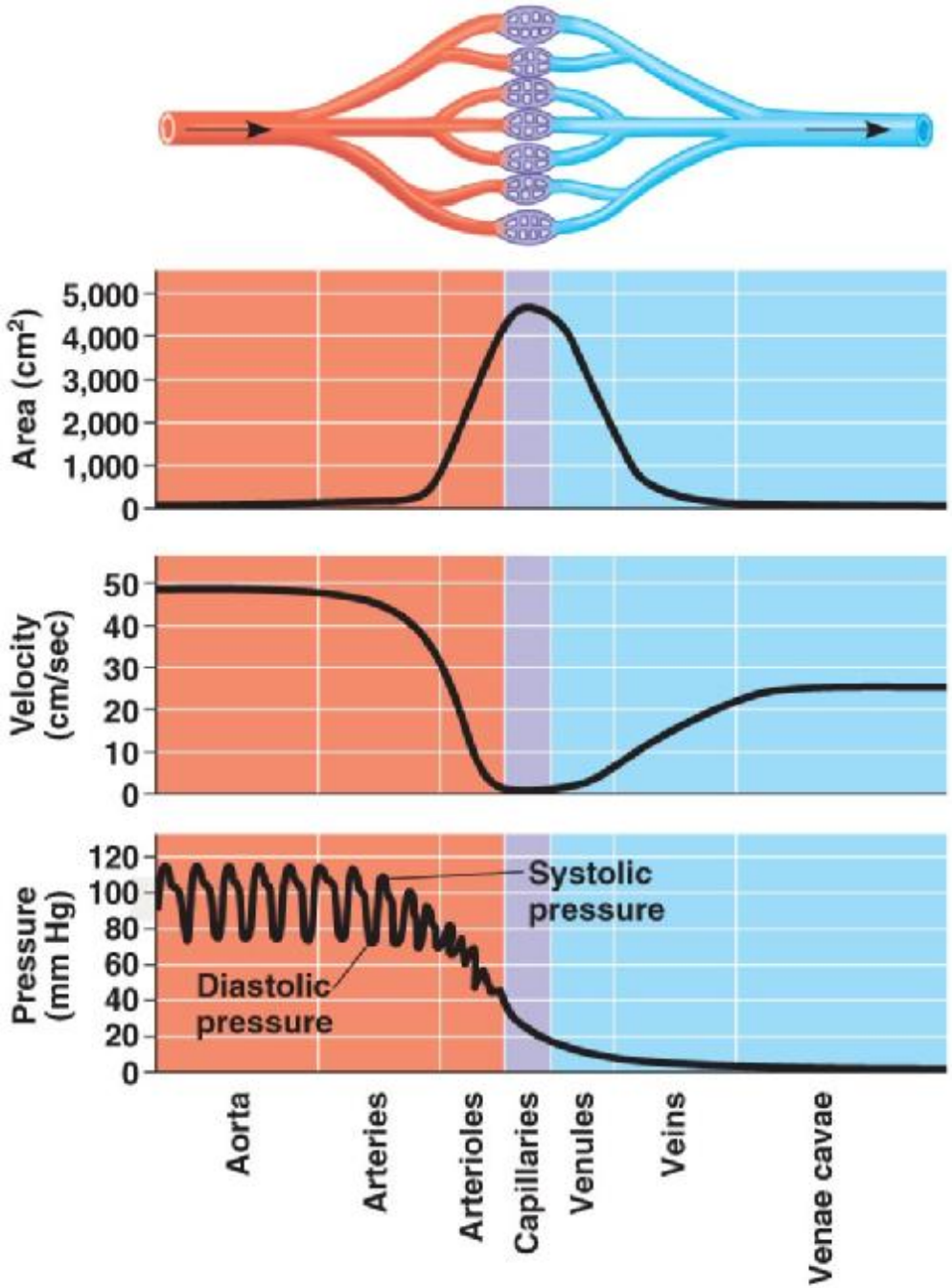
- If the heart is the body's "pump," then the "plumbing" is the system of arteries, veins, and capillaries
  - Arteries carry blood away from the heart
  - Veins carry blood toward the heart
  - Capillaries allow for exchange between the bloodstream and tissue cells

- All blood vessels
  - Are built of similar tissues
  - Have three similar layers
- Structural differences in arteries, veins, and capillaries
  - Correlate with their different functions


From heart
Epithelium
Smooth muscle
Connective tissue
Artery
Arteriole
Epithelium
Capillary
To heart
Valve
Epithelium
Smooth muscle
Connective tissue
Vein
Venule

Blood Flow Velocity

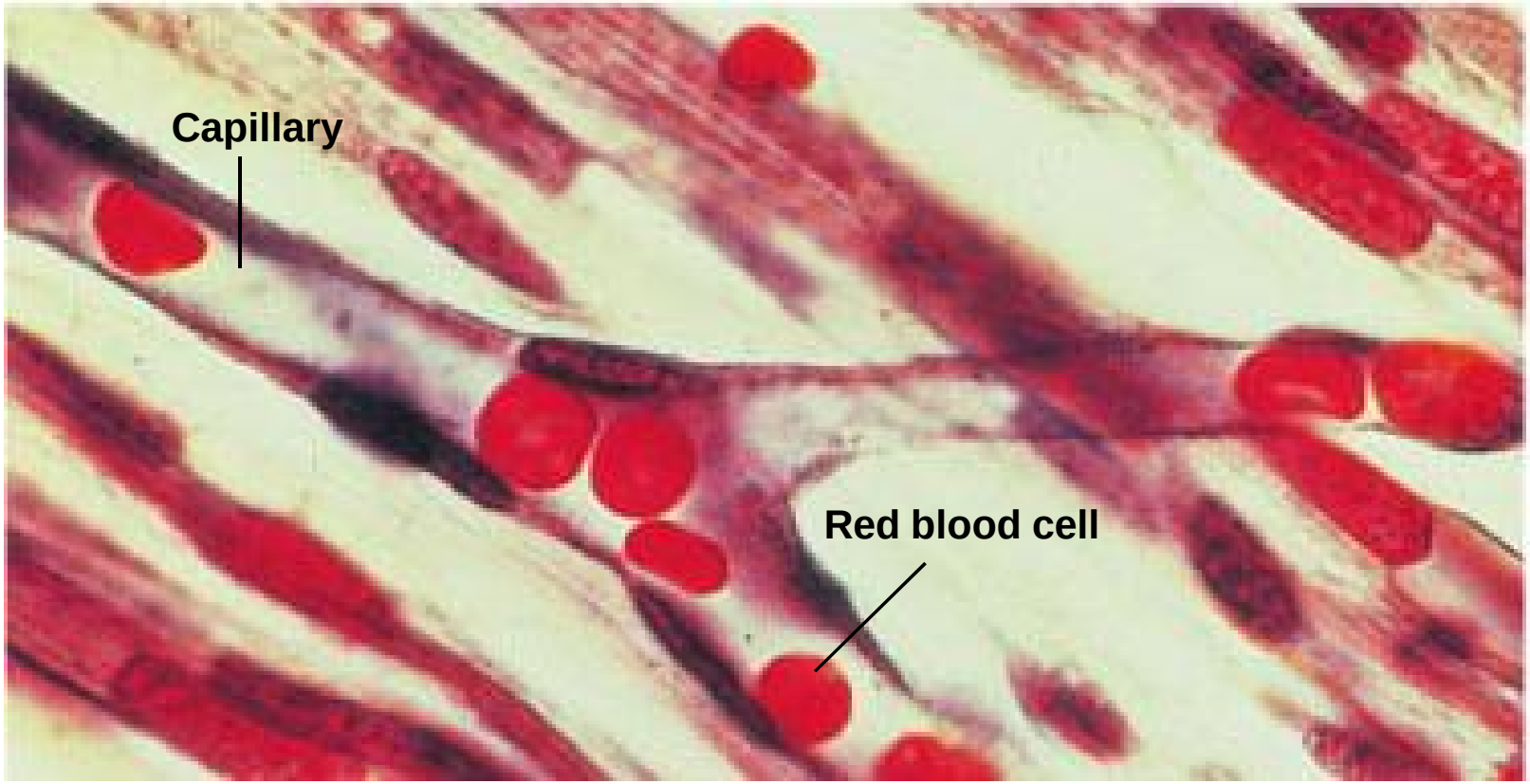
- Physical laws governing the movement of fluids through pipes
  - Influence blood flow and blood pressure
- The velocity of blood flow varies in the circulatory system
  - And is slowest in the capillary beds as a result of the high resistance and large total cross-sectional area



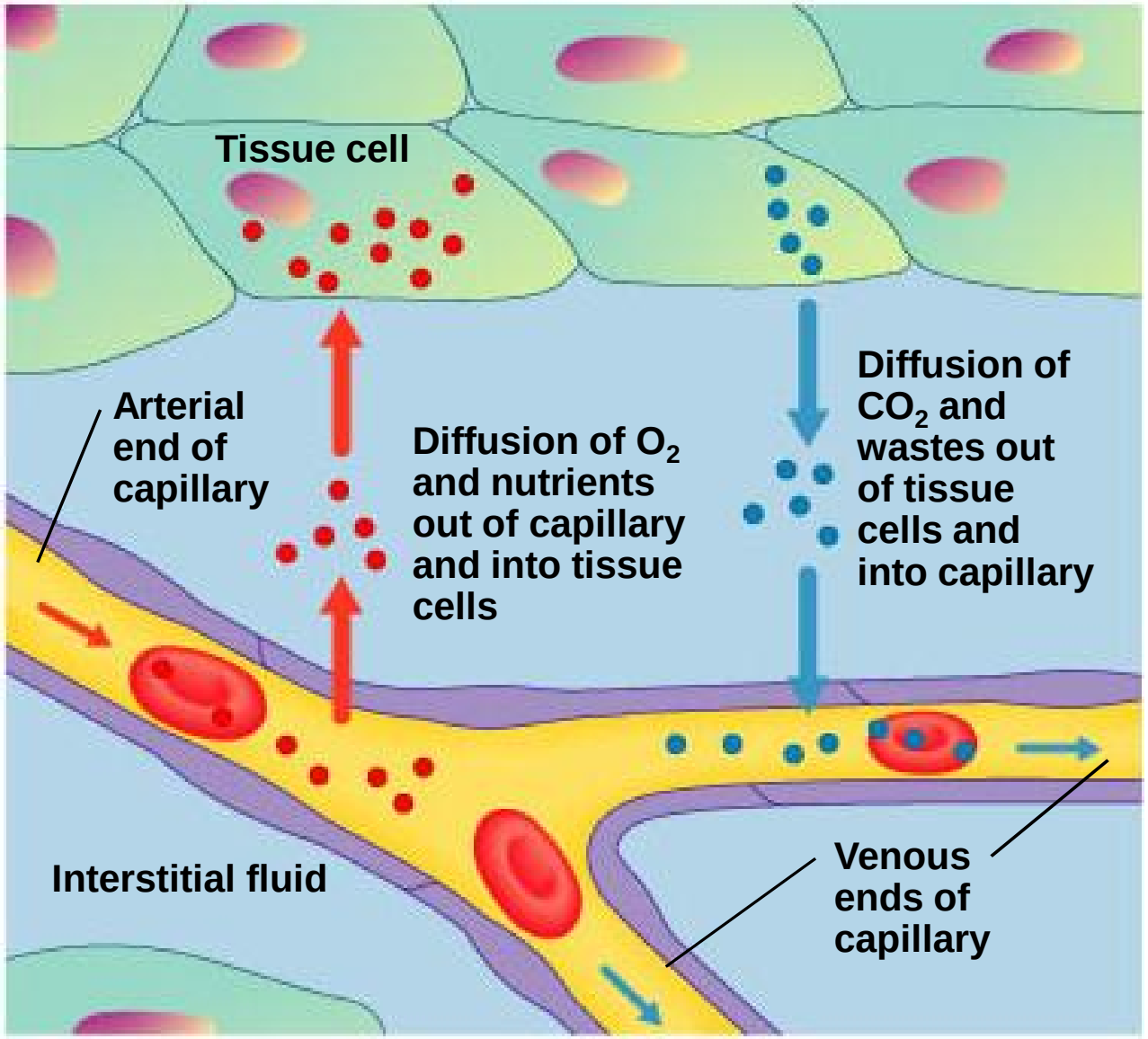
Capillary Function

- Capillaries in major organs are usually filled to capacity
  - But in many other sites, the blood supply varies
- At any given time, about 5–10% of your capillaries have a steady flow of blood running through them

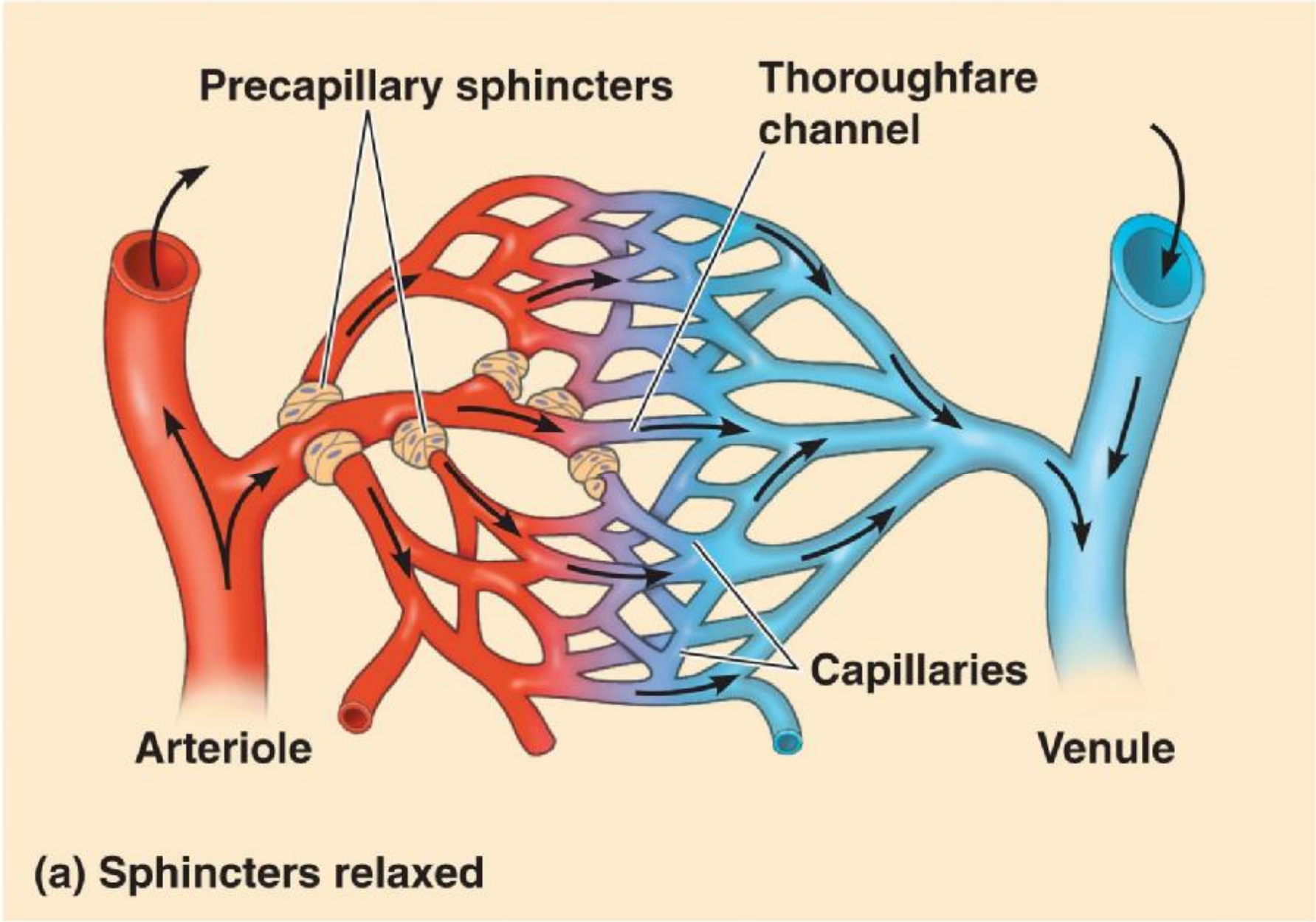
Capillary Function

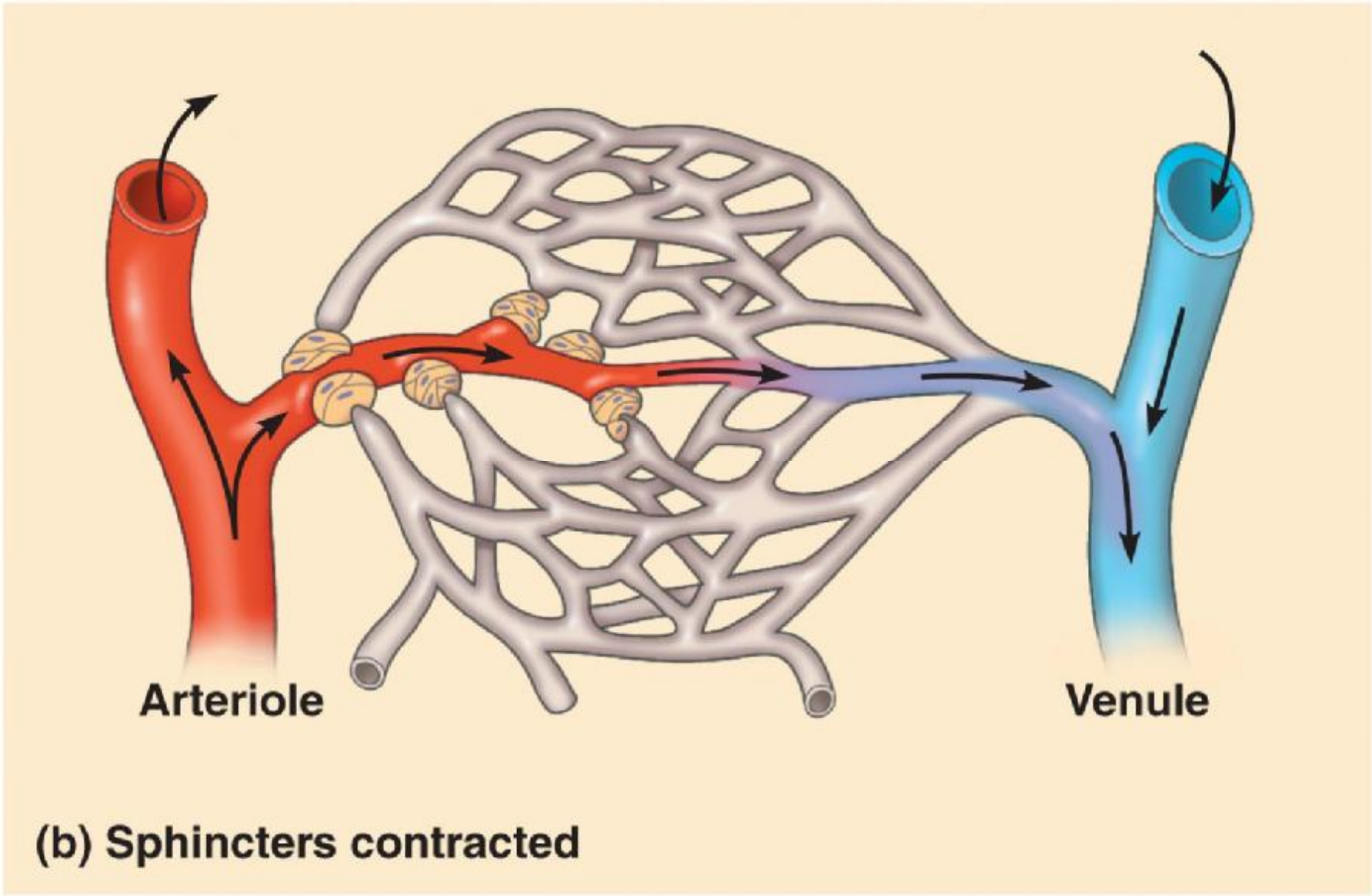


- The walls of capillaries are thin and leaky
  - As blood enters a capillary at the arterial end, blood pressure pushes fluid rich in oxygen, nutrients, and other substances into the interstitial fluid
  - At the venous end of the capillary, CO_2 and other wastes diffuse from tissue cells and into the capillary bloodstream


Tissue cell
Arterial end of capillary
Diffusion of O_2 and nutrients out of capillary and into tissue cells
Diffusion of CO_2 and wastes out of tissue cells and into capillary
Interstitial fluid
Venous ends of capillary

- Two mechanisms regulate the distribution of blood in capillary beds
- In one mechanism
  - Contraction of the smooth muscle layer in the wall of an arteriole constricts the vessel
- In a second mechanism
  - Precapillary sphincters control the flow of blood between arterioles and venules





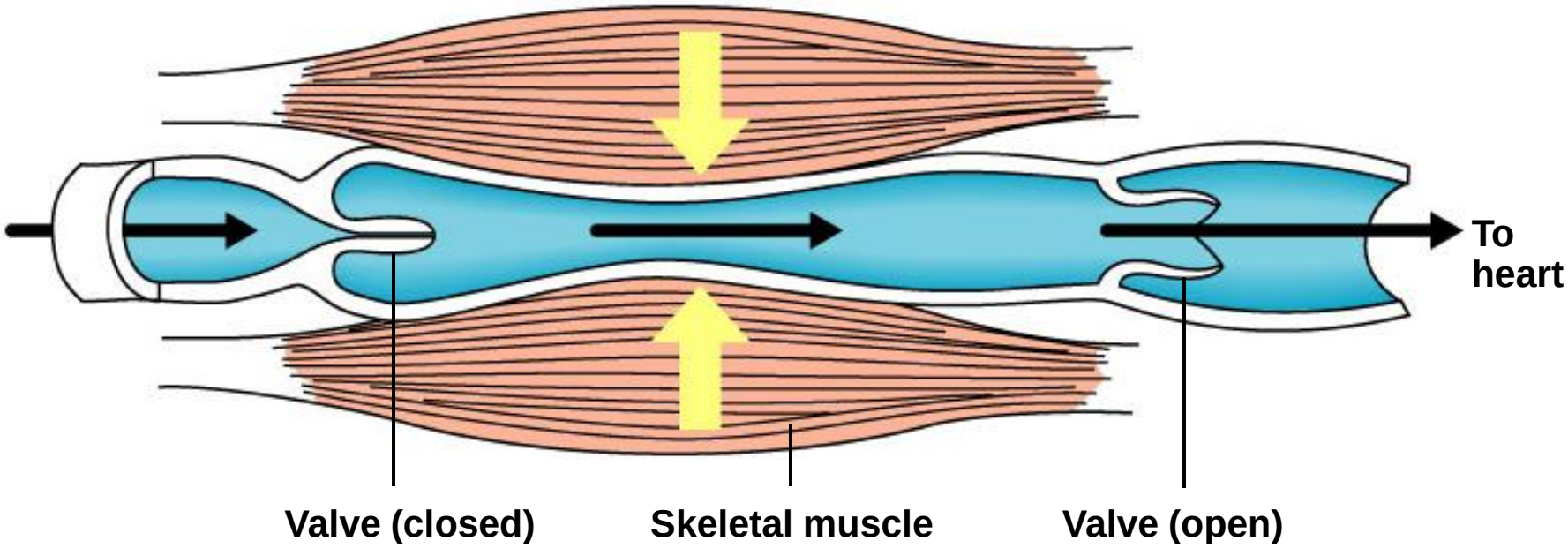
- The critical exchange of substances between the blood and interstitial fluid
  - Takes place across the thin endothelial walls of the capillaries

Blood Return Through Veins

- After chemicals are exchanged between the blood and body cells, blood returns to the heart via the veins
  - By the time blood exits the capillaries and enters the veins, the pressure originating from the heart has dropped to near zero

– Blood still moves through the veins against the force of gravity

– As skeletal muscles contract, they help squeeze the blood along



Circulation

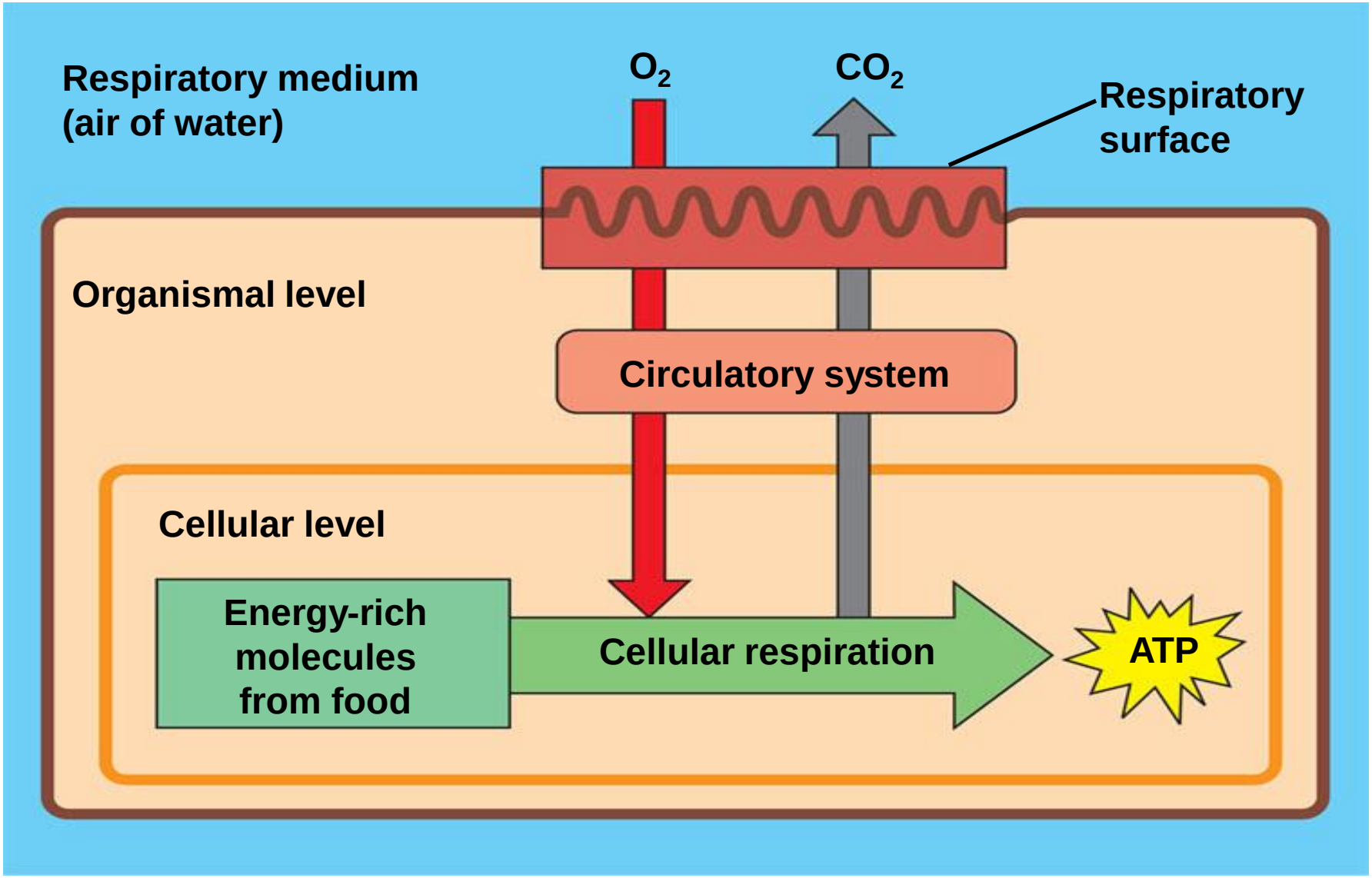
Gas Exchange

Obtaining Nutrients

Waste Disposal

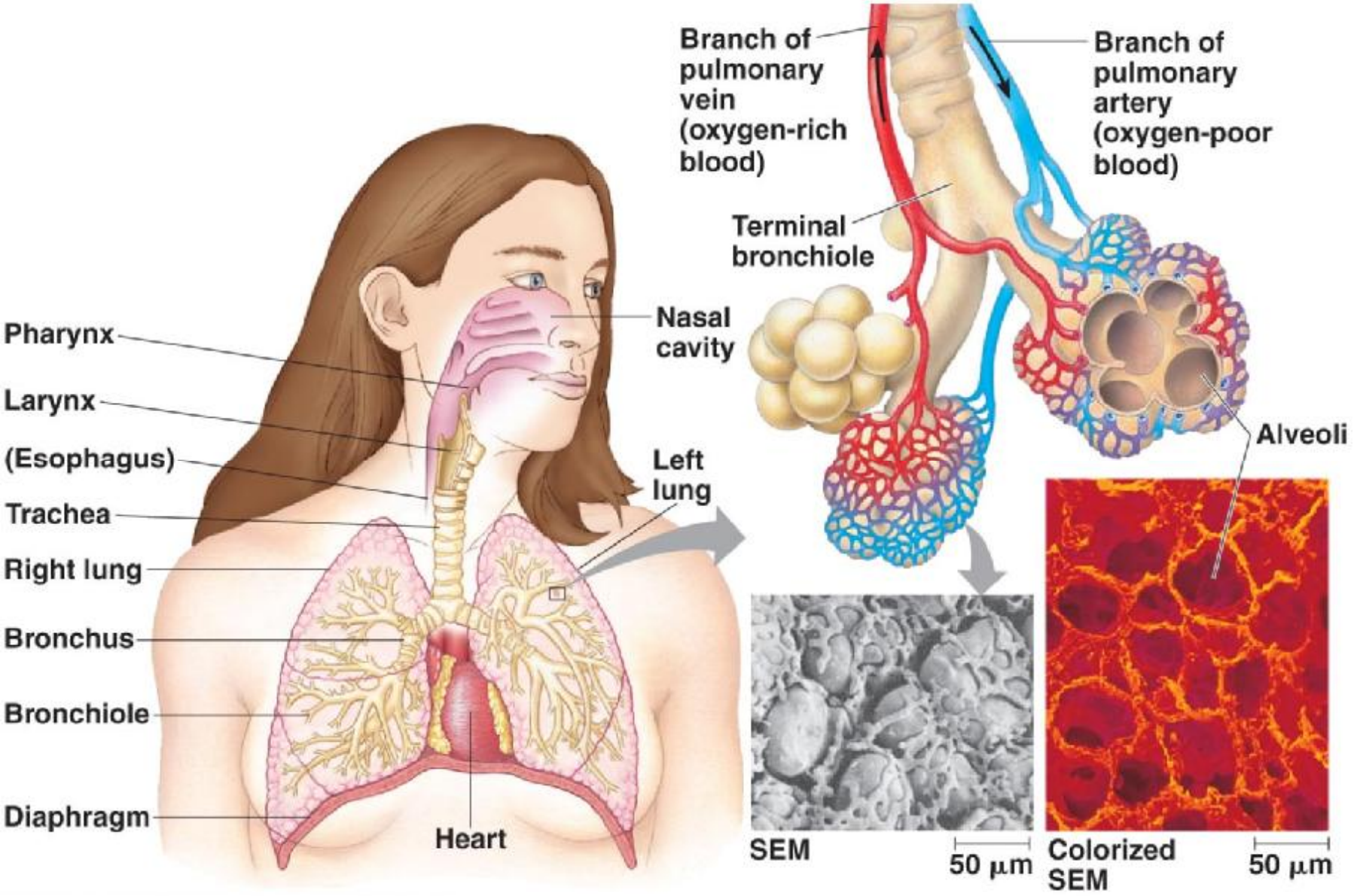
Gas exchange

- Gas exchange
  - Occurs across specialized respiratory surface
  - Supplies oxygen for cellular respiration and disposes of carbon dioxide



- Animals require large, moist respiratory surfaces for the adequate diffusion of respiratory gases
  - Between their cells and the respiratory medium, either air or water

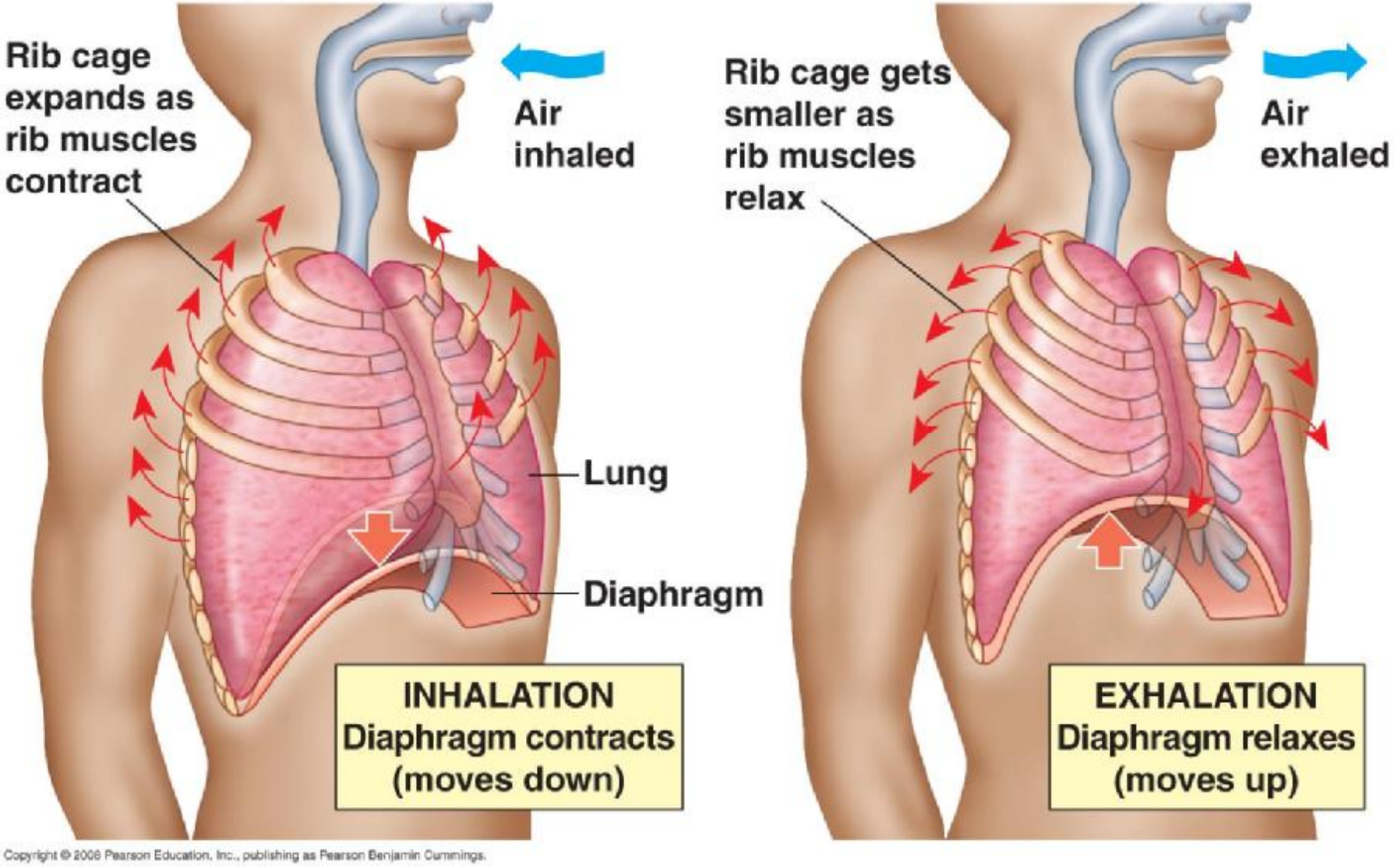
Mammalian Respiratory Systems



- In mammals, air inhaled through the nostrils
  - Passes through the pharynx into the trachea, bronchi, bronchioles, and dead-end alveoli, where gas exchange occurs

How a Mammal Breathes

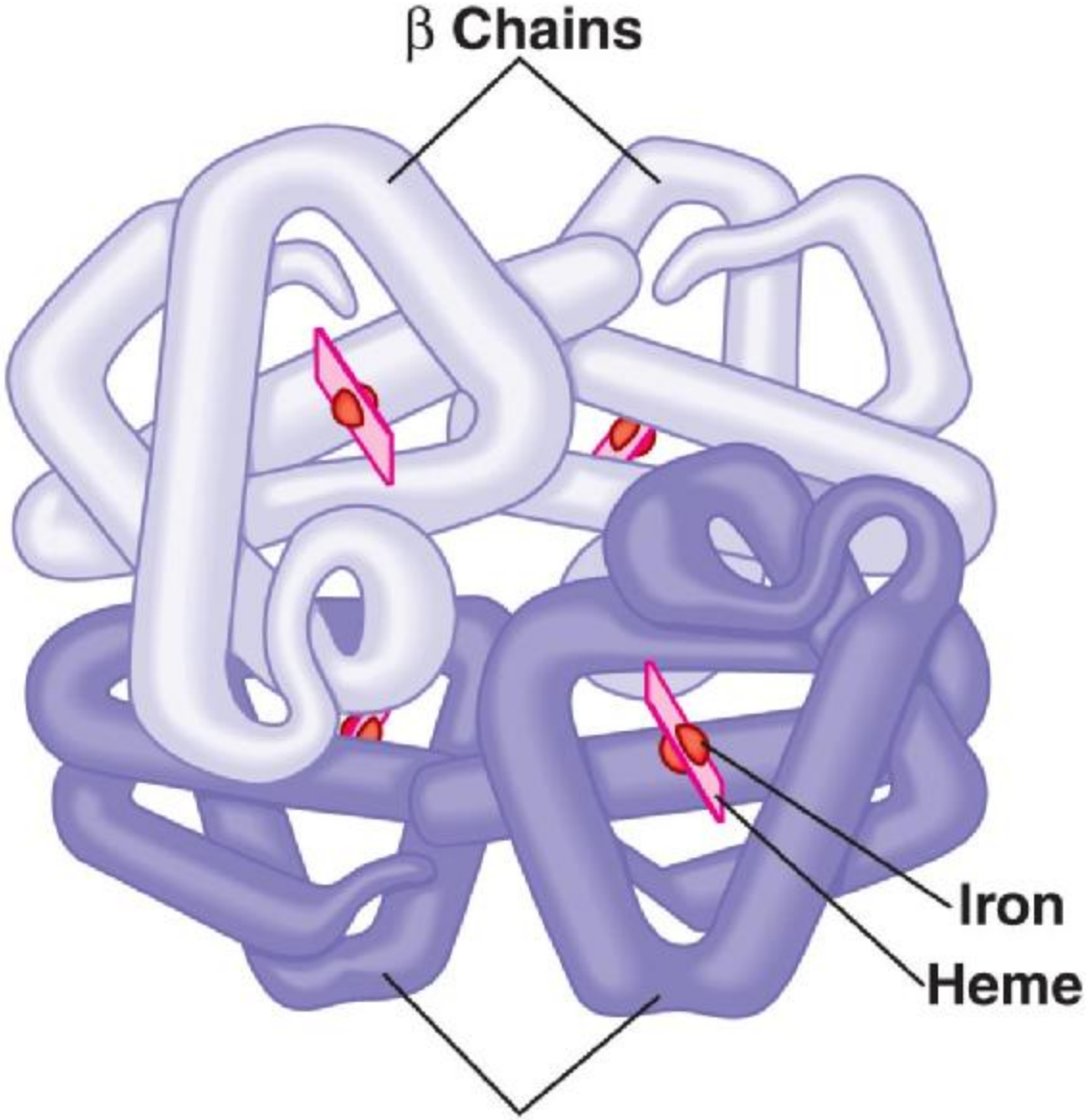
- Mammals ventilate their lungs
  - By negative pressure breathing, which pulls air into the lungs



Oxygen Transport

- The respiratory pigment of almost all vertebrates
  - Is the protein hemoglobin, contained in the erythrocytes

- Like all respiratory pigments
  - Hemoglobin must reversibly bind O_2, loading O_2 in the lungs and unloading it in other parts of the body

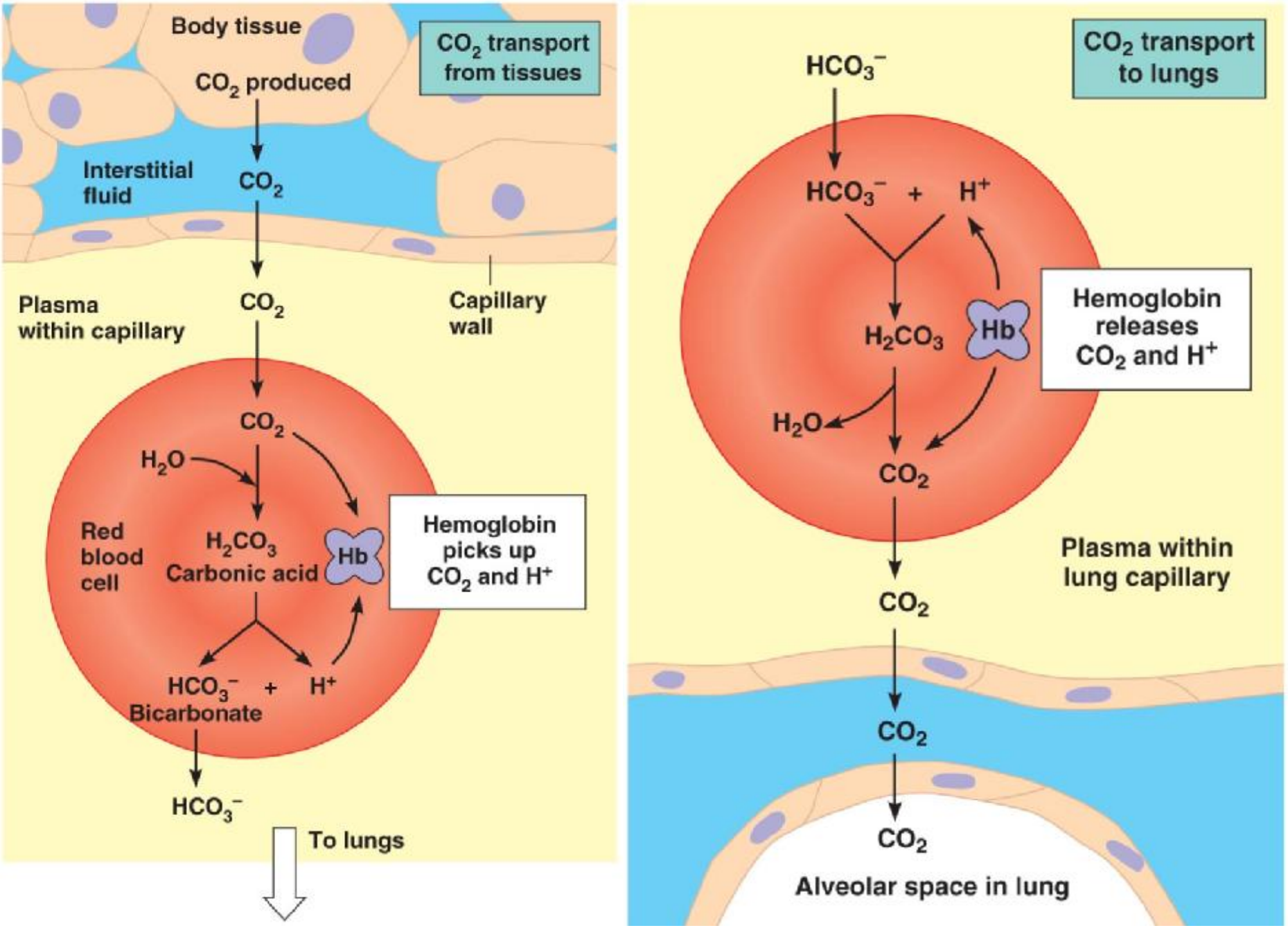


- Loading and unloading of O_2
  - Depend on cooperation between the subunits of the hemoglobin molecule
- The binding of O_2 to one subunit induces the other subunits to bind O_2 with more affinity

Carbon Dioxide Transport

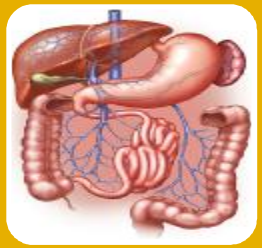
- Hemoglobin also helps transport CO_2
  - And assists in buffering

- Carbon from respiring cells
  - Diffuses into the blood plasma and then into erythrocytes and is ultimately released in the lungs


Body tissue
CO_2 transport from tissues
CO_2 produced
Interstitial fluid
CO_2
Plasma within capillary
CO_2
Capillary wall
CO_2
H_2O
Red blood cell
H_2CO_3 Carbonic acid
Hb
Hemoglobin picks up CO_2 and H^+
HCO_3^- + H^+
Bicarbonate
HCO_3^-
To lungs
CO_2 transport to lungs
HCO_3^-
HCO_3^- + H^+
H_2CO_3
Hb
Hemoglobin releases CO_2 and H^+
H_2O
CO_2
Plasma within lung capillary
CO_2
CO_2
CO_2
Alveolar space in lung

Circulation

Gas Exchange

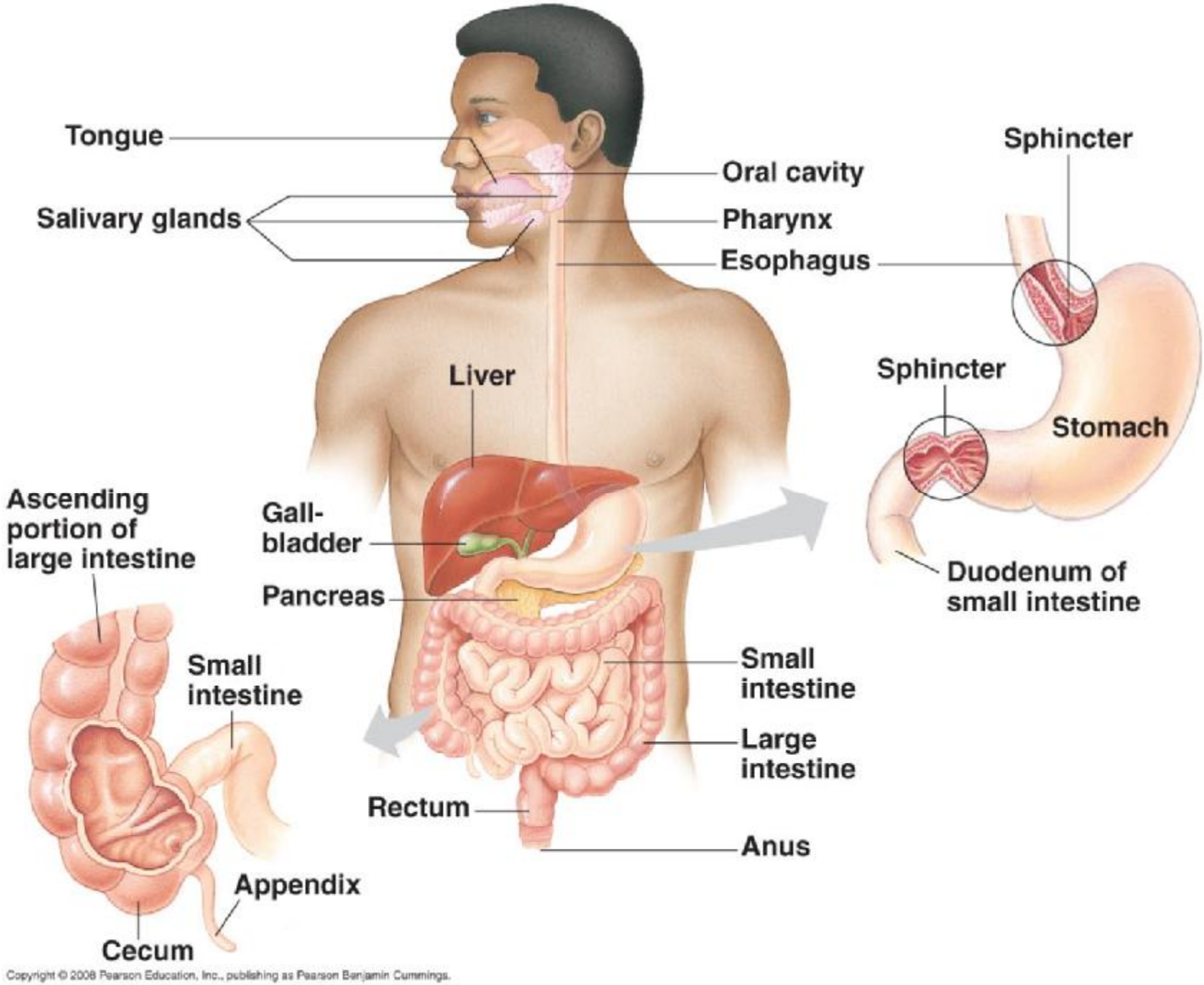


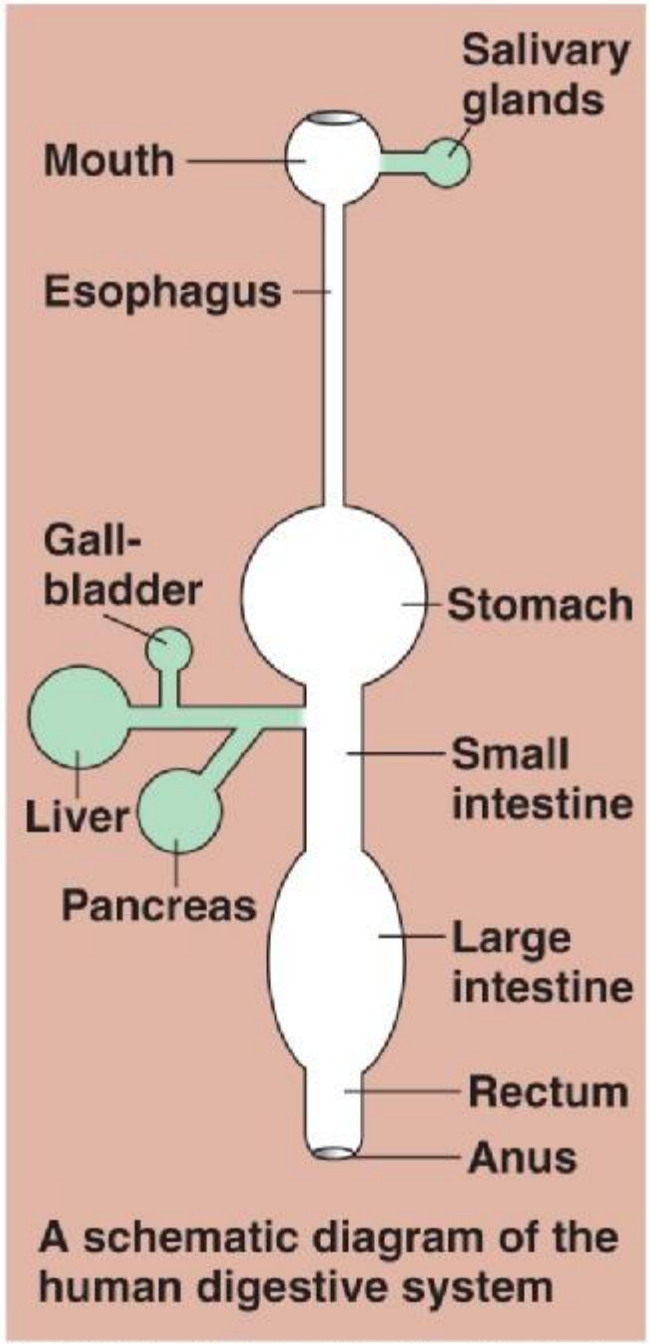
Obtaining Nutrients

Waste Disposal

The mammalian digestive system

- Each organ of the mammalian digestive system has specialized food-processing functions
- The mammalian digestive system consists of the alimentary canal
  - And various accessory glands that secrete digestive juices through ducts





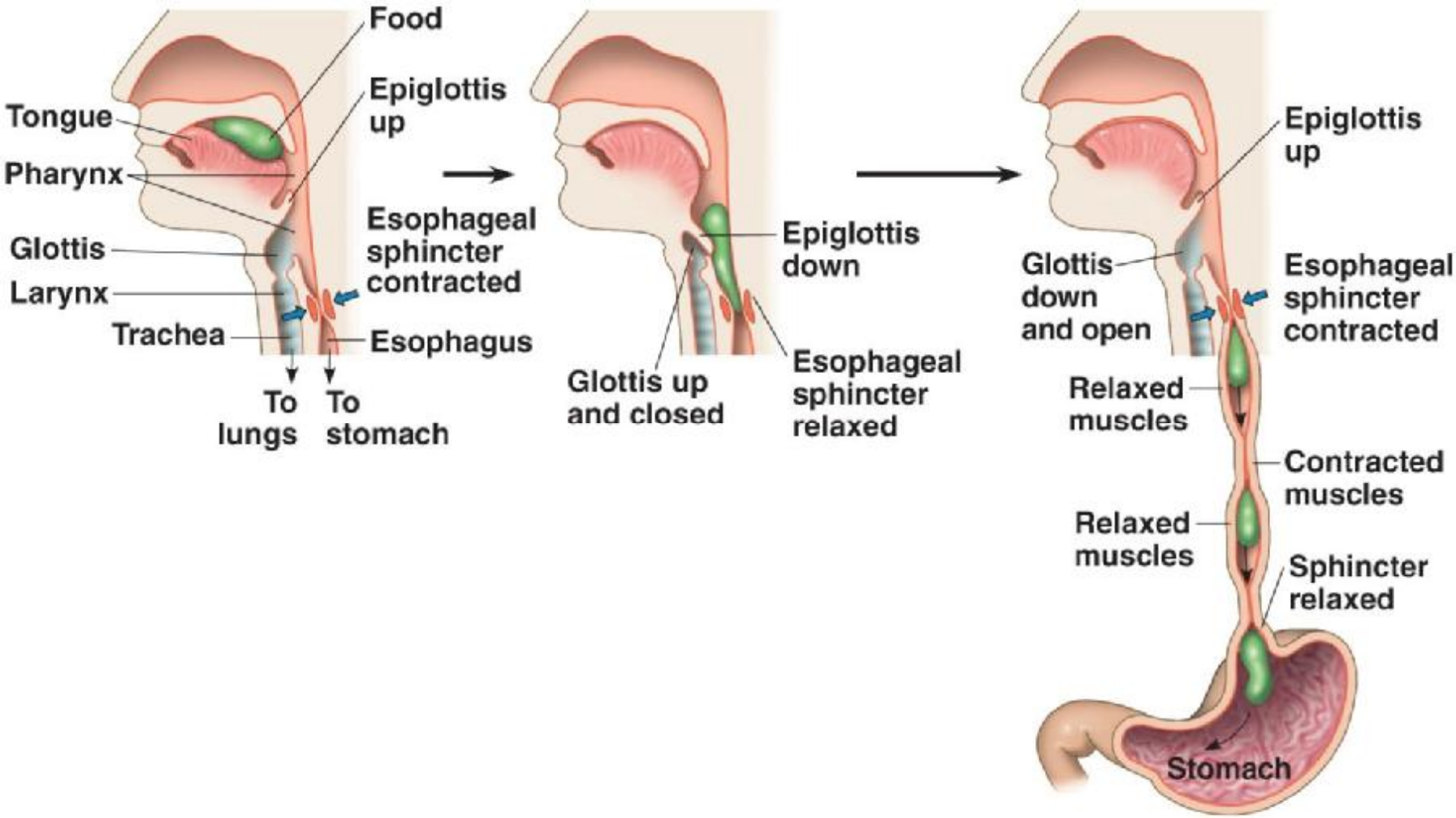
A schematic diagram of the human digestive system

- Food is pushed along the digestive tract by peristalsis
  - Rhythmic waves of contraction of smooth muscles in the wall of the canal

The Oral Cavity, Pharynx, and Esophagus

- In the oral cavity, food is lubricated and digestion begins
  - And teeth chew food into smaller particles that are exposed to salivary amylase, initiating the breakdown of glucose polymers

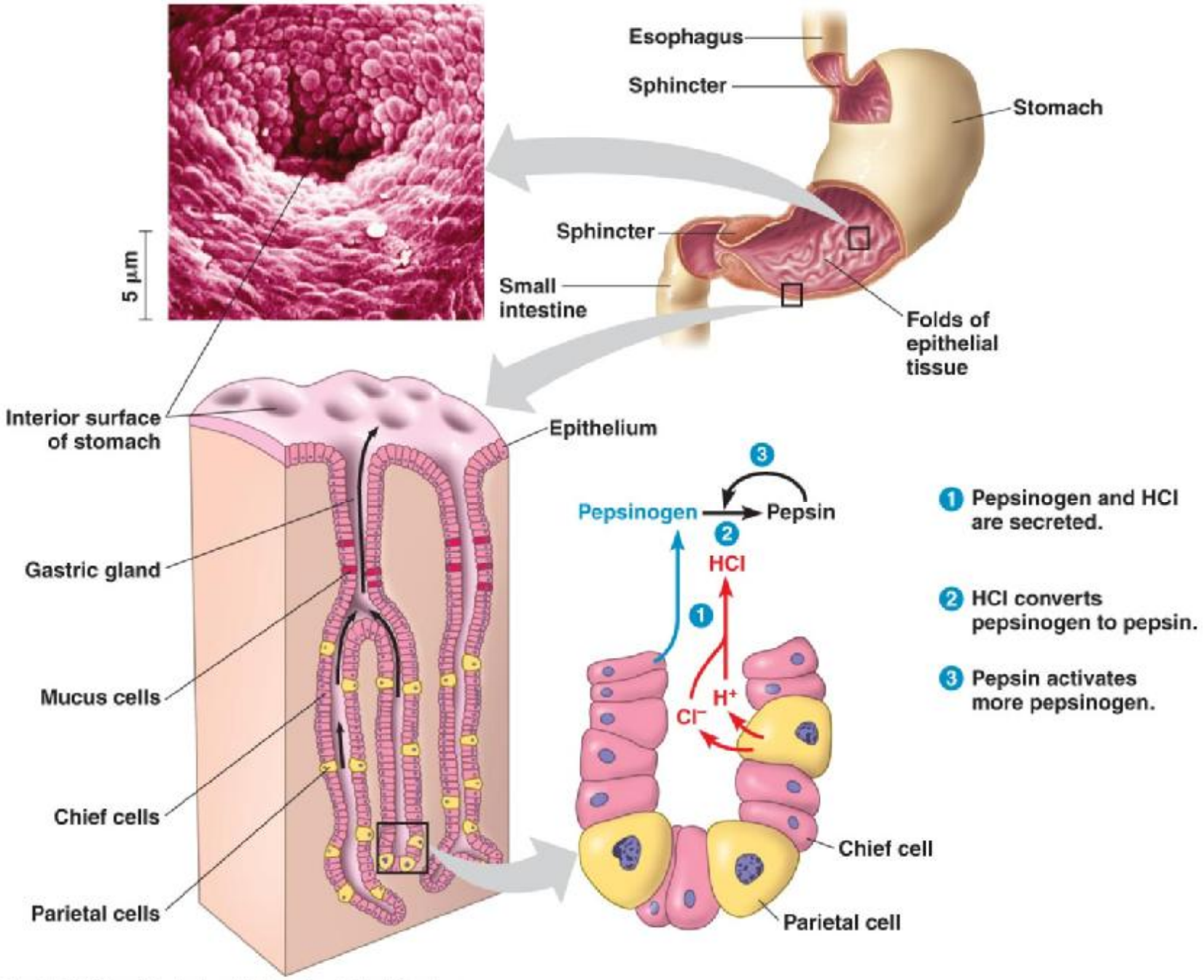
- The region we call our throat is the pharynx
  - A junction that opens to both the esophagus and the windpipe (trachea)
- The esophagus
  - Conducts food from the pharynx down to the stomach by peristalsis



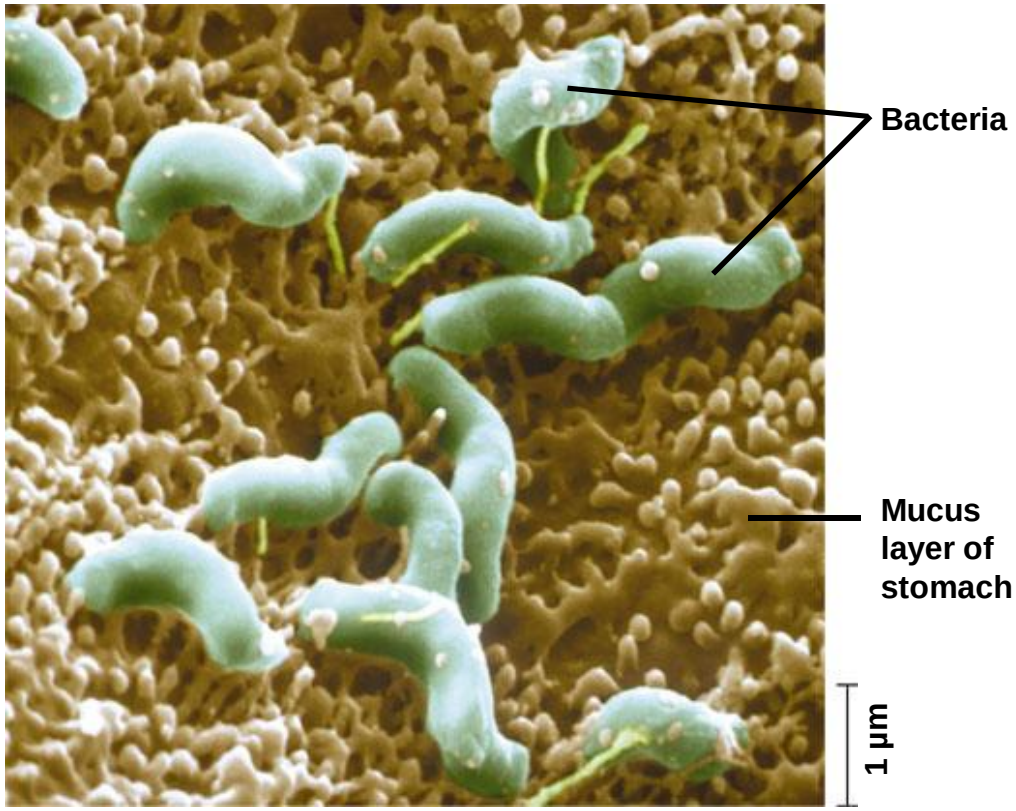
The Stomach

- The stomach stores food
  - And secretes gastric juice, which converts a meal to acid chyme
- Gastric juice
  - Is made up of hydrochloric acid and the enzyme pepsin

- The lining of the stomach
  - Is coated with mucus, which prevents the gastric juice from destroying the cells



- Gastric ulcers, lesions in the lining
  - Are caused mainly by the bacterium *Helicobacter pylori*



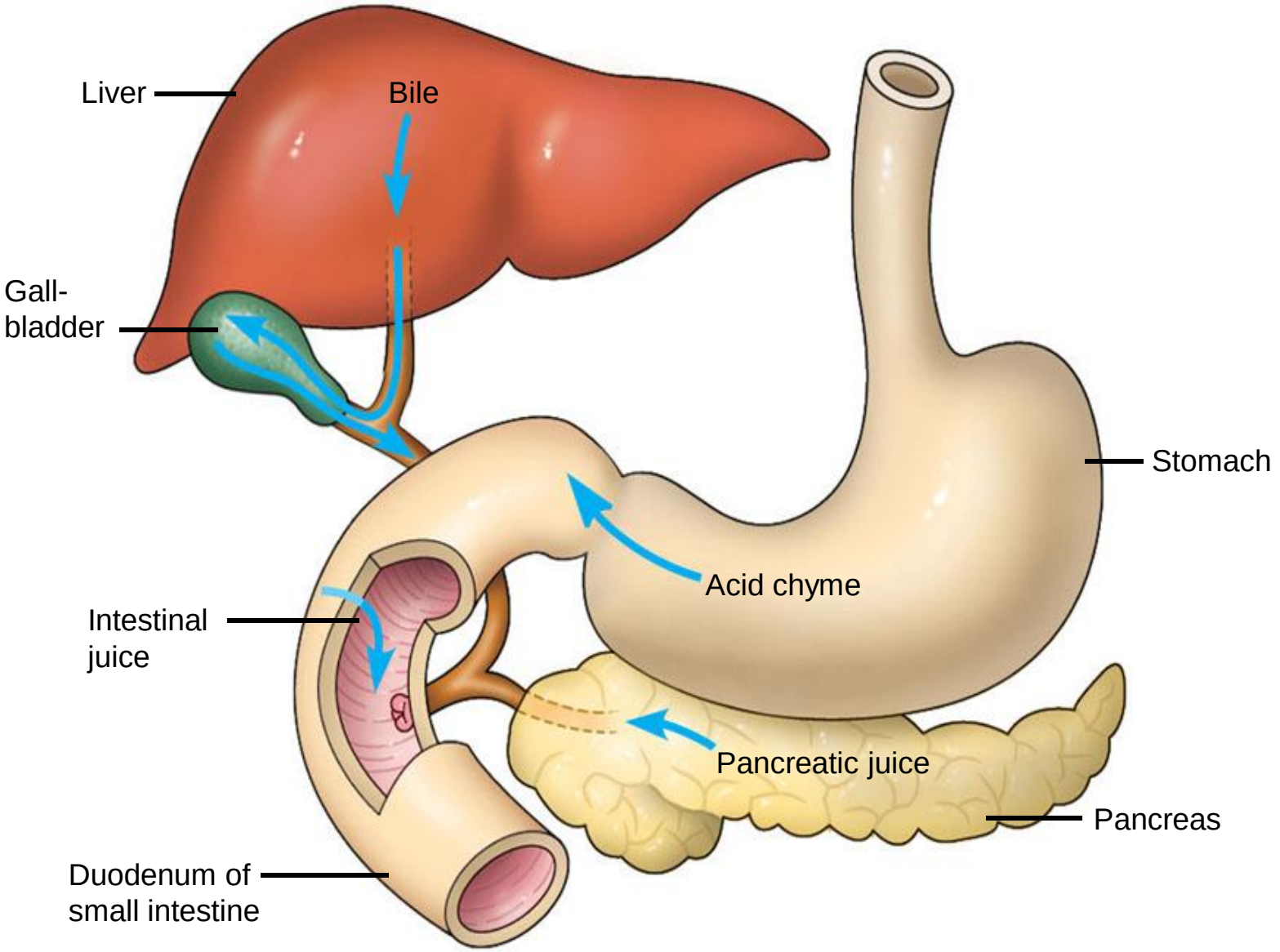
The Small Intestine

- The small intestine
  - Is the longest section of the alimentary canal
  - Is the major organ of digestion and absorption

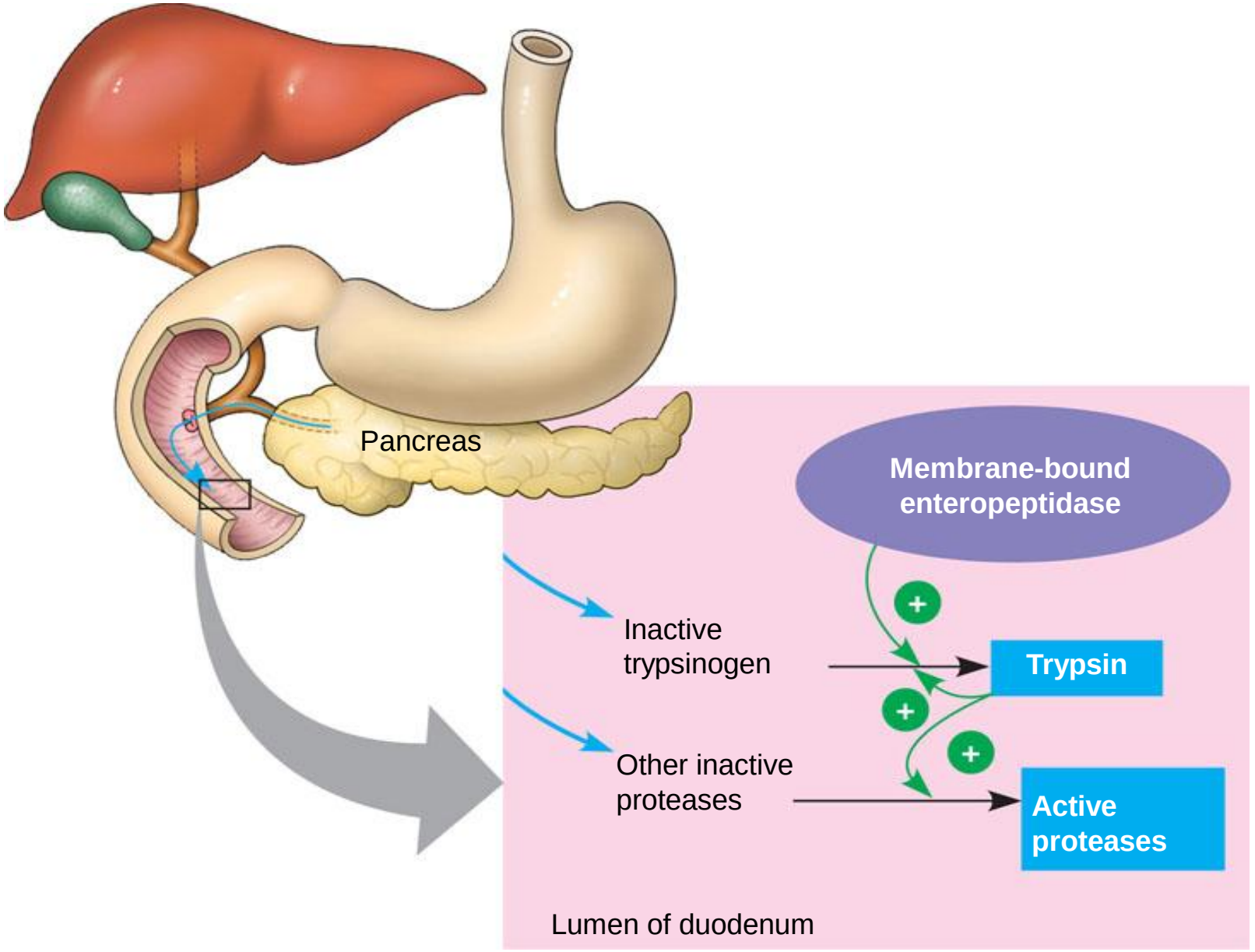
Enzymatic Action in the Small Intestine

- The first portion of the small intestine is the duodenum
  - Where acid chyme from the stomach mixes with digestive juices from the pancreas, liver, gallbladder, and intestine itself

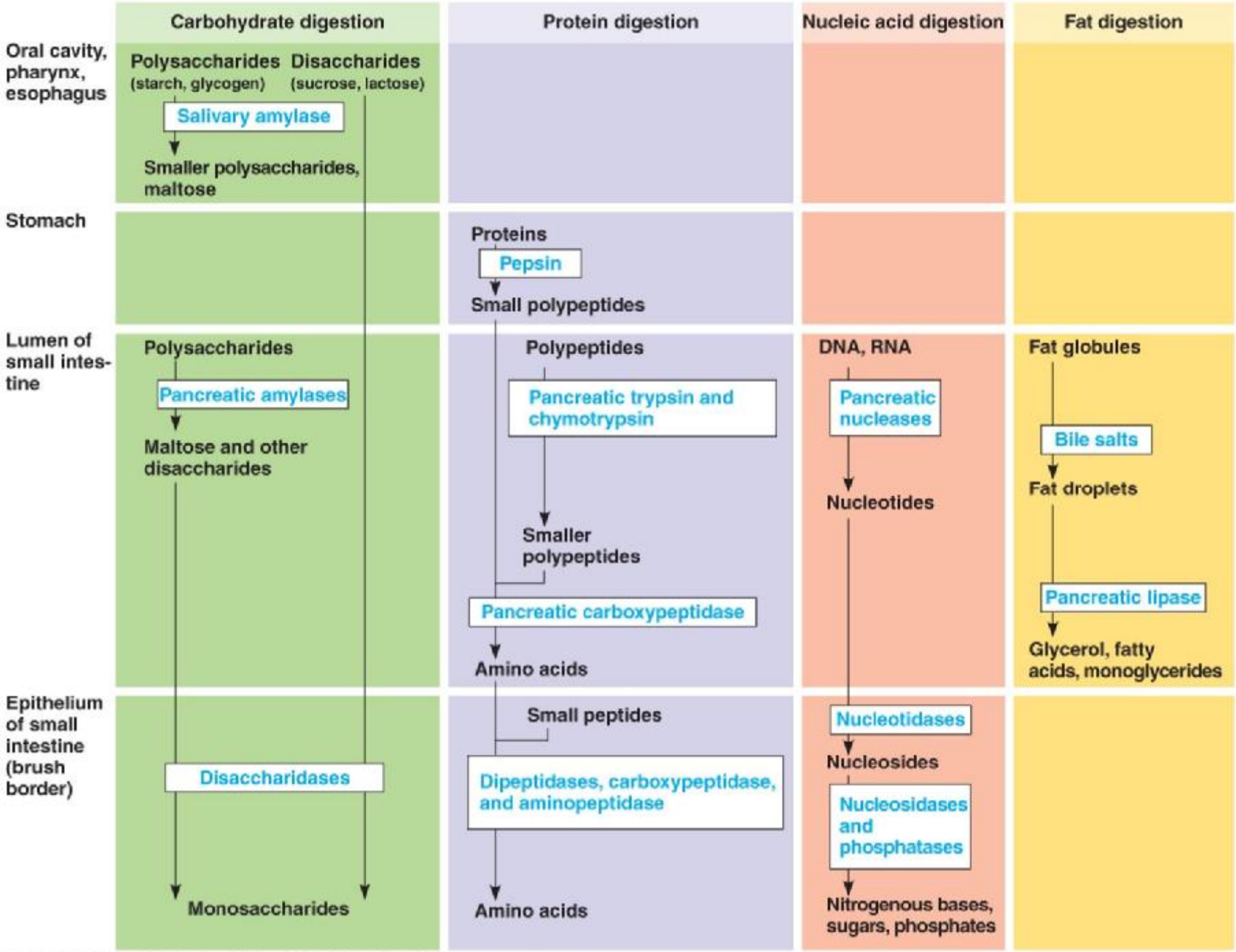
Enzymatic Action in the Small Intestine



- The pancreas produces proteases, protein-digesting enzymes
  - That are activated once they enter the duodenum


Pancreas
Membrane-bound enteropeptidase
Inactive trypsinogen
Trypsin
Other inactive proteases
Active proteases
Lumen of duodenum

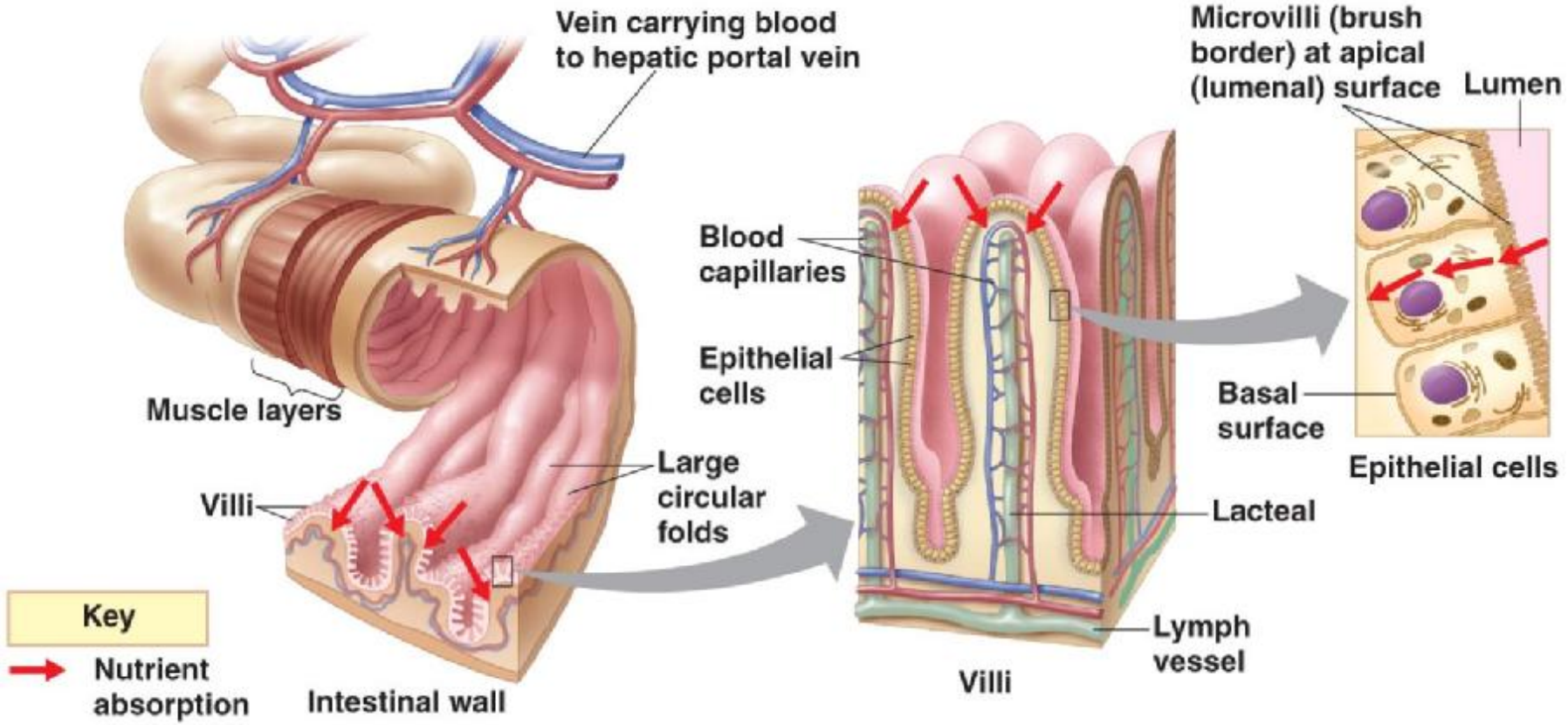
- Enzymatic digestion is completed
  - As peristalsis moves the mixture of chyme and digestive juices along the small intestine



Absorption of Nutrients

- The small intestine has a huge surface area
  - Due to the presence of villi and microvilli that are exposed to the intestinal lumen

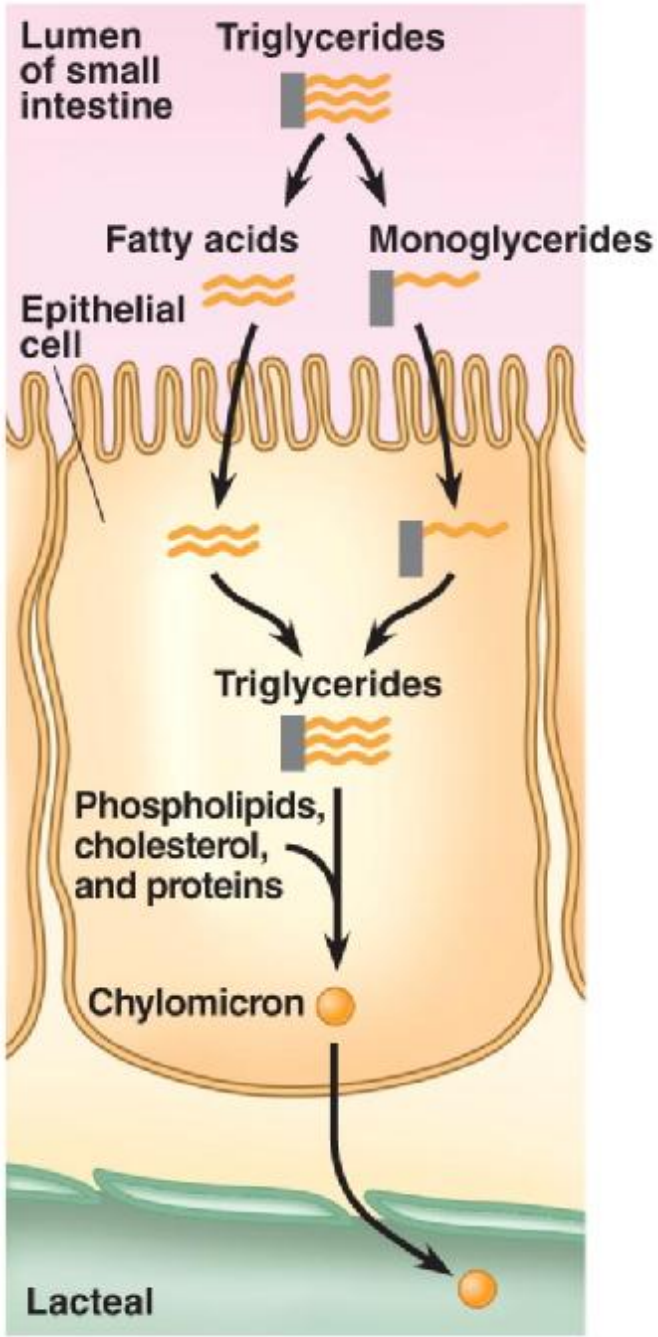
- The enormous microvillar surface
  - Is an adaptation that greatly increases the rate of nutrient absorption



- The core of each villus
  - Contains a network of blood vessels and a small vessel of the lymphatic system called a lacteal

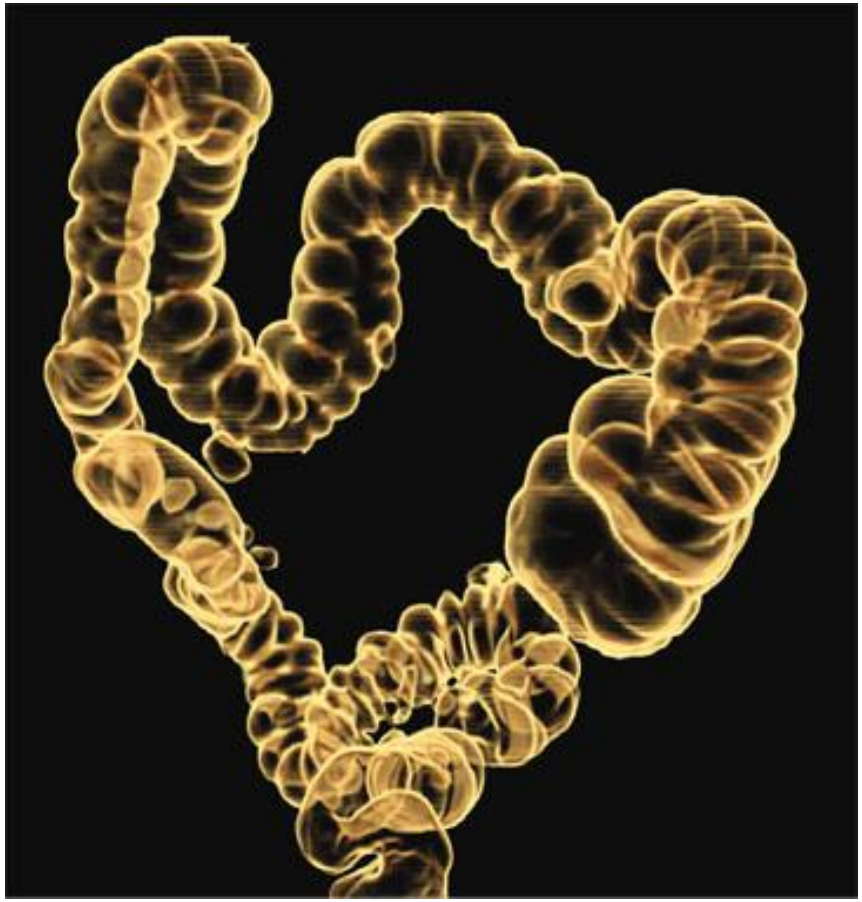
- Amino acids and sugars
  - Pass through the epithelium of the small intestine and enter the bloodstream
- After glycerol and fatty acids are absorbed by epithelial cells
  - They are recombined into fats within these cells

- These fats are then mixed with cholesterol and coated with proteins
  - Forming small molecules called chylomicrons, which are transported into lacteals



The Large Intestine

- The large intestine, or colon
  - Is connected to the small intestine



- A major function of the colon
  - Is to recover water that has entered the alimentary canal
- The wastes of the digestive tract, the feces
  - Become more solid as they move through the colon
  - Pass through the rectum and exit via the anus

- The colon houses various strains of the bacterium *Escherichia coli*
  - Some of which produce various vitamins

Circulation

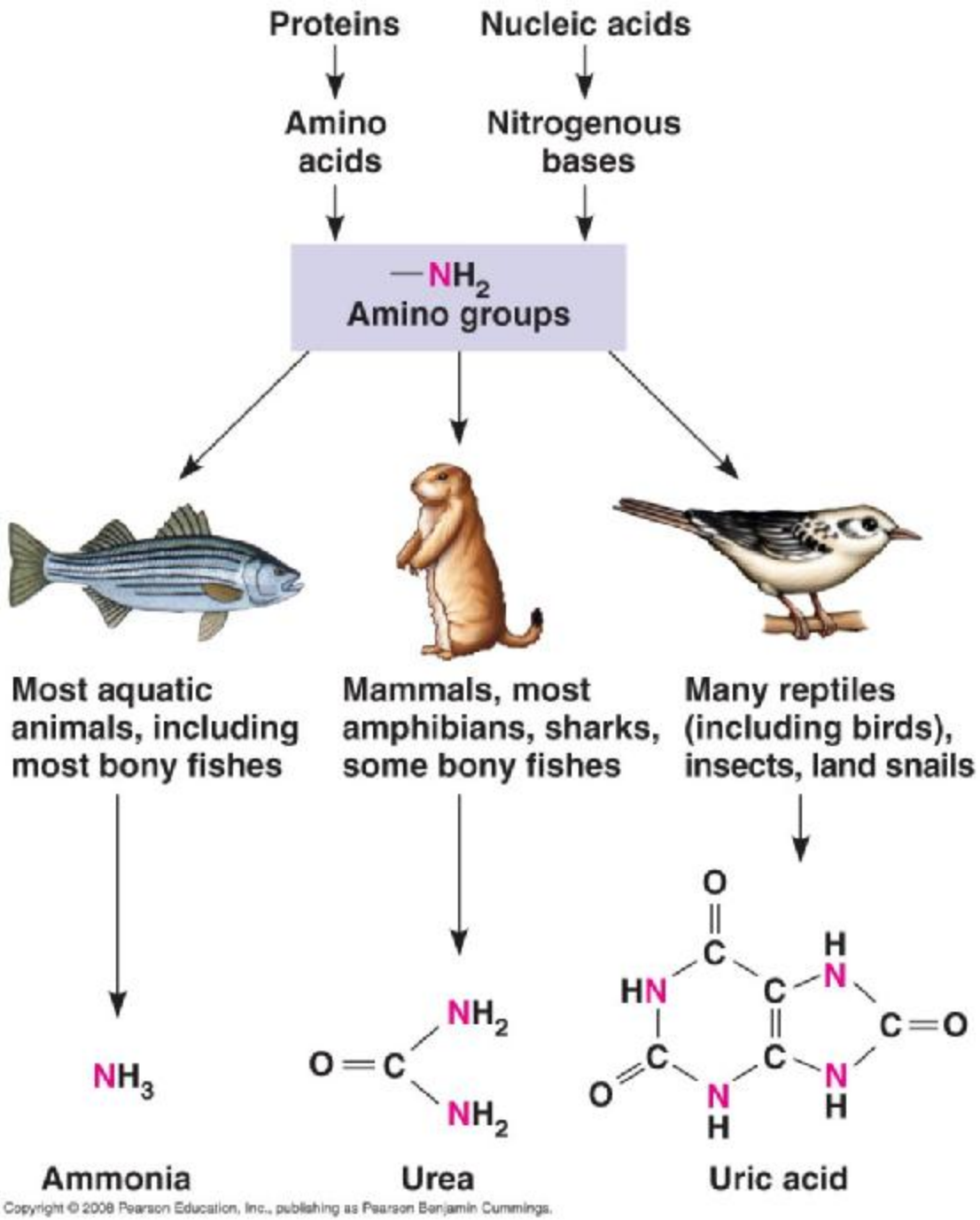
Gas Exchange

Obtaining Nutrients

Waste Disposal

Animal's nitrogenous wastes

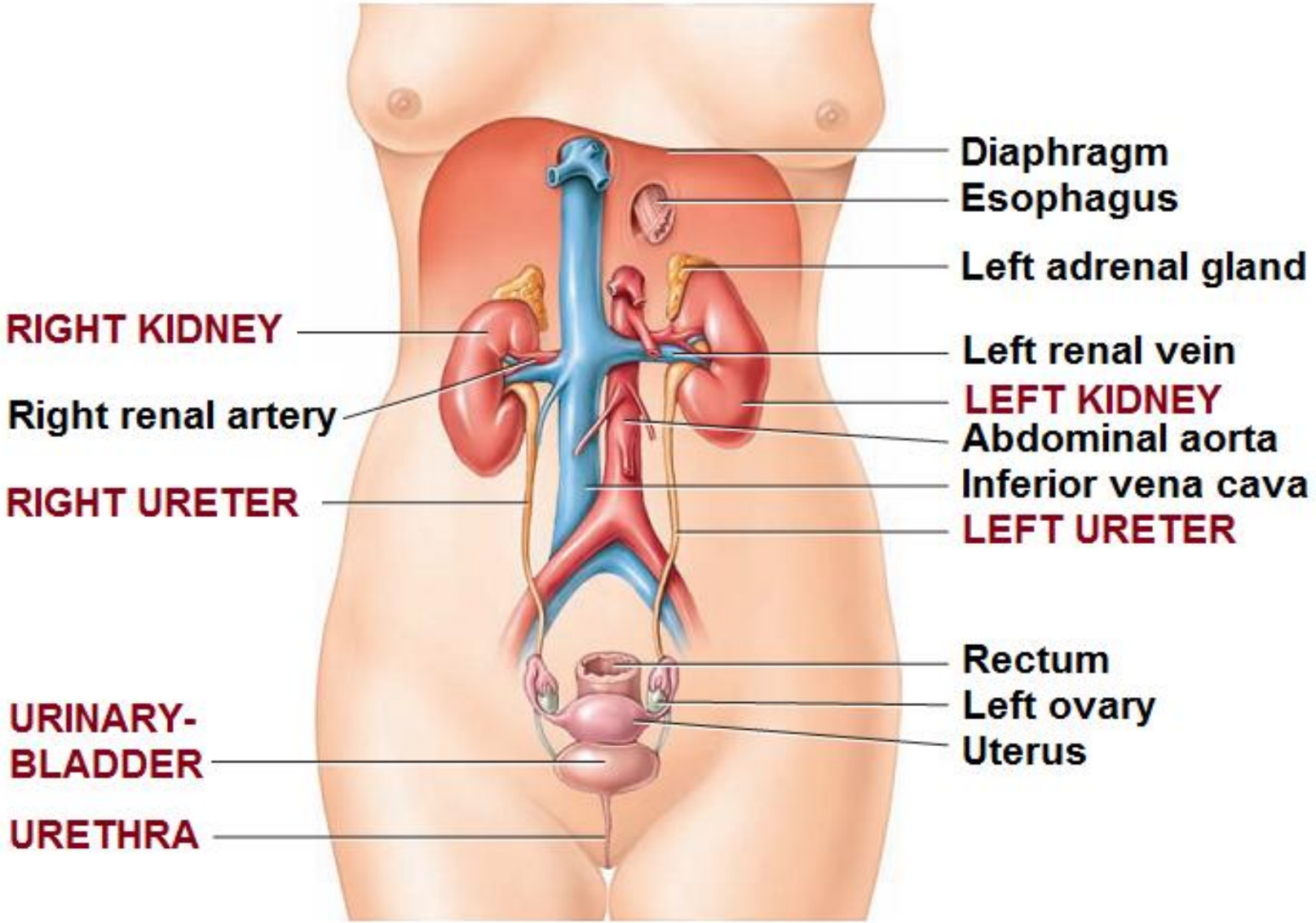
- The type and quantity of an animal's waste products
  - May have a large impact on its water balance
- Among the most important wastes
  - Are the nitrogenous breakdown products of proteins and nucleic acids



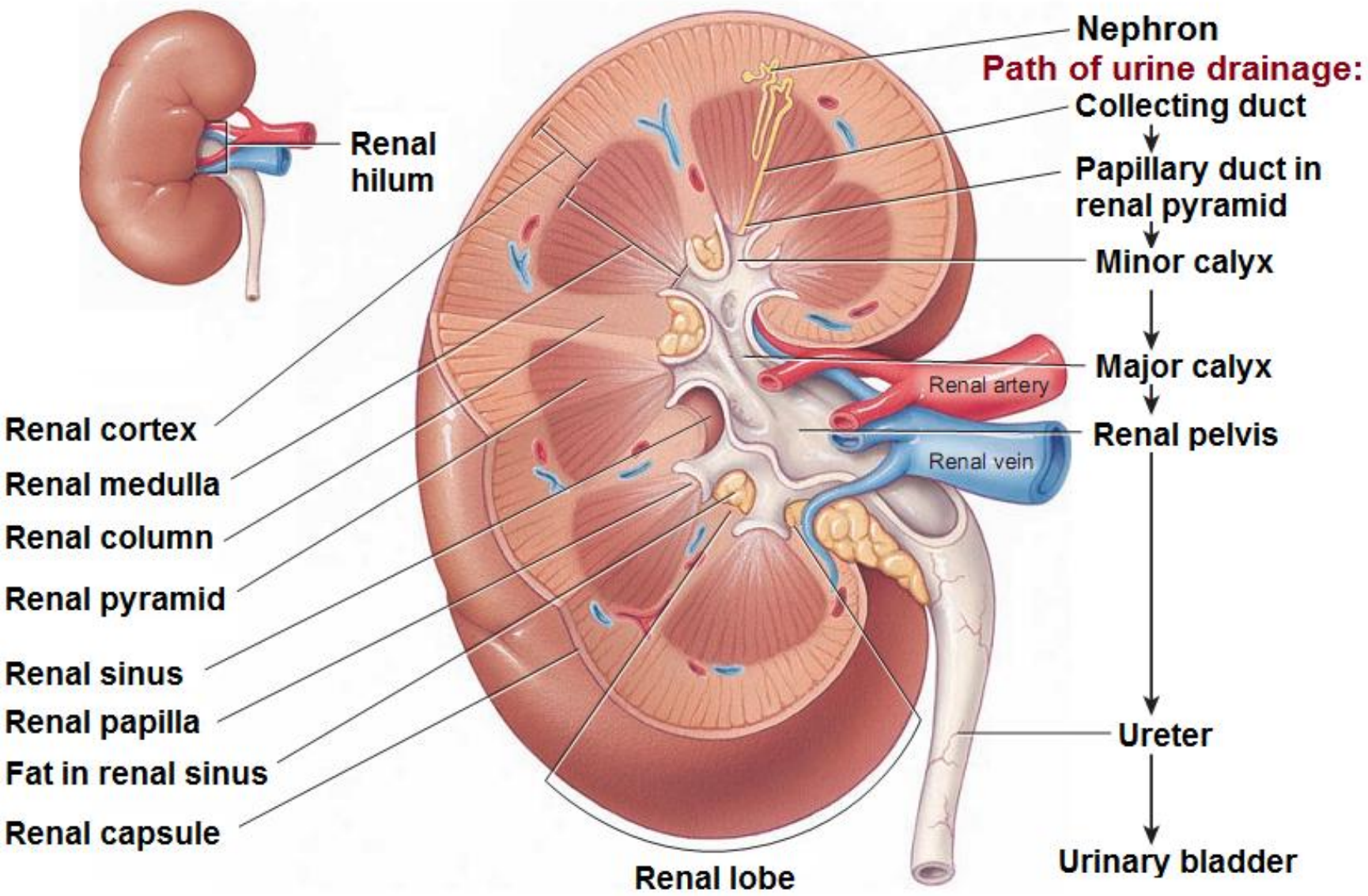
The mammalian excretory system

- Nephrons and associated blood vessels are the functional unit of the mammalian kidney
- The mammalian excretory system centers on paired kidneys
  - Which are also the principal site of water balance and salt regulation
- Each kidney
  - Is supplied with blood by a renal artery and drained by a renal vein

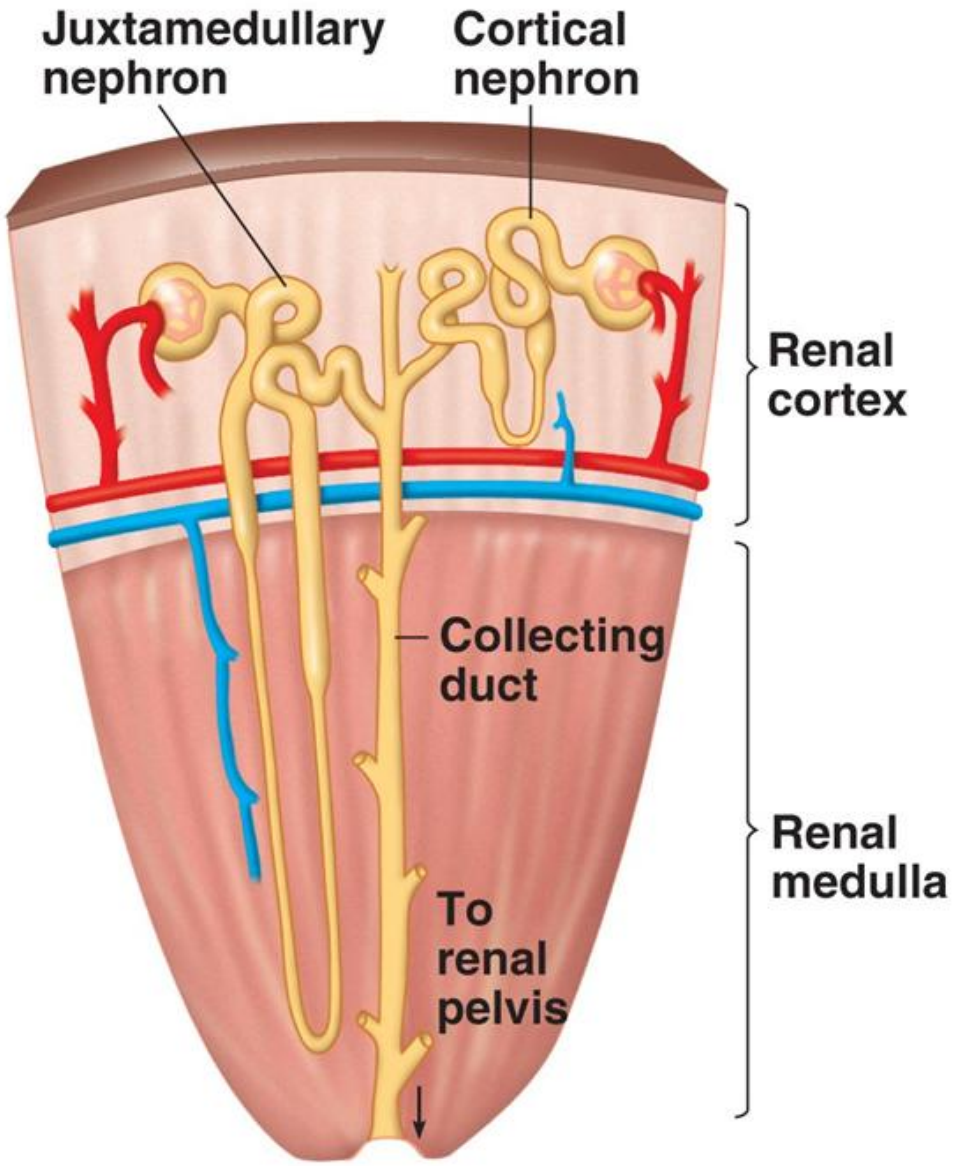
Organs of the Urinary System

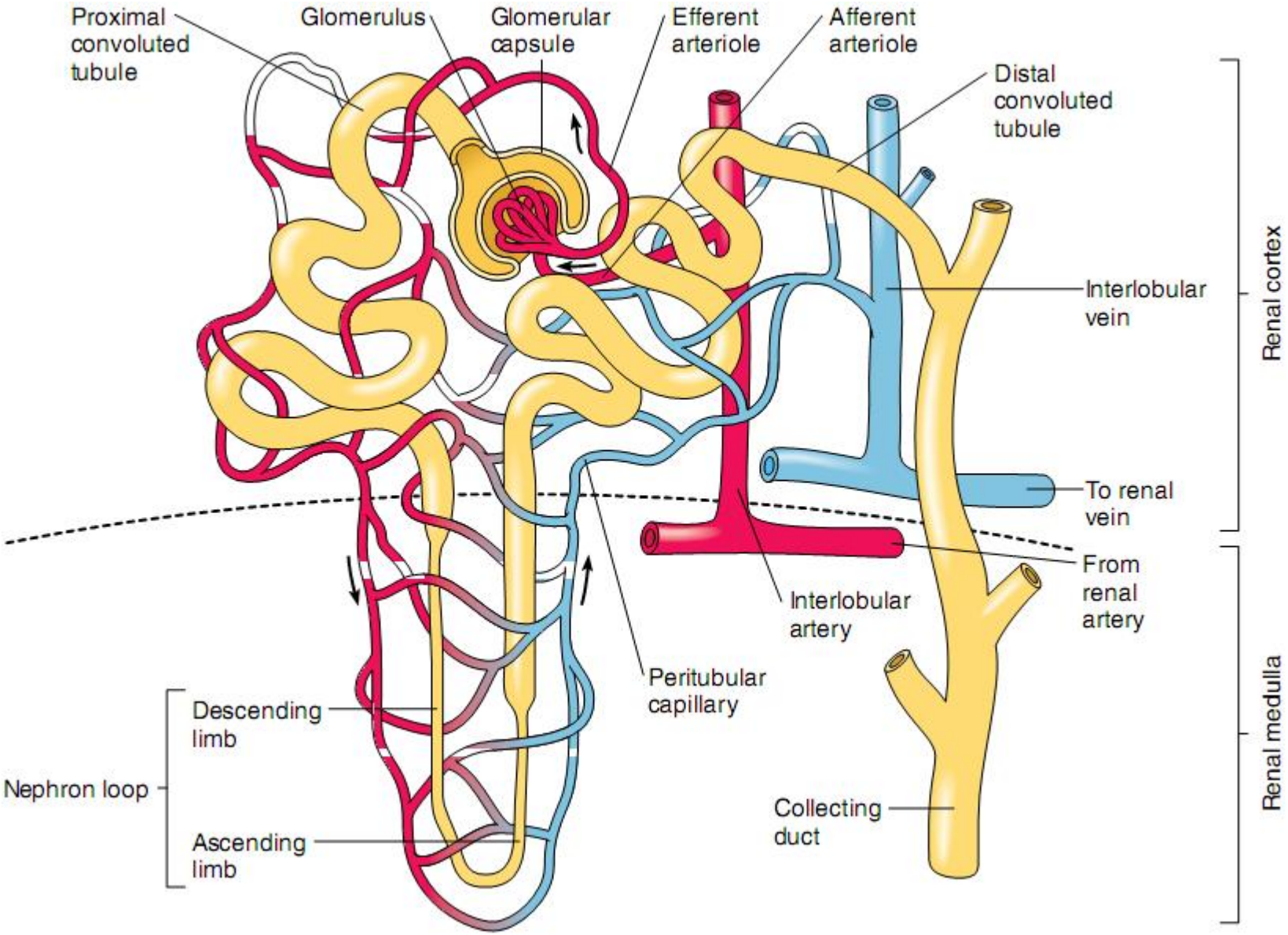


Anatomy of the Kidney

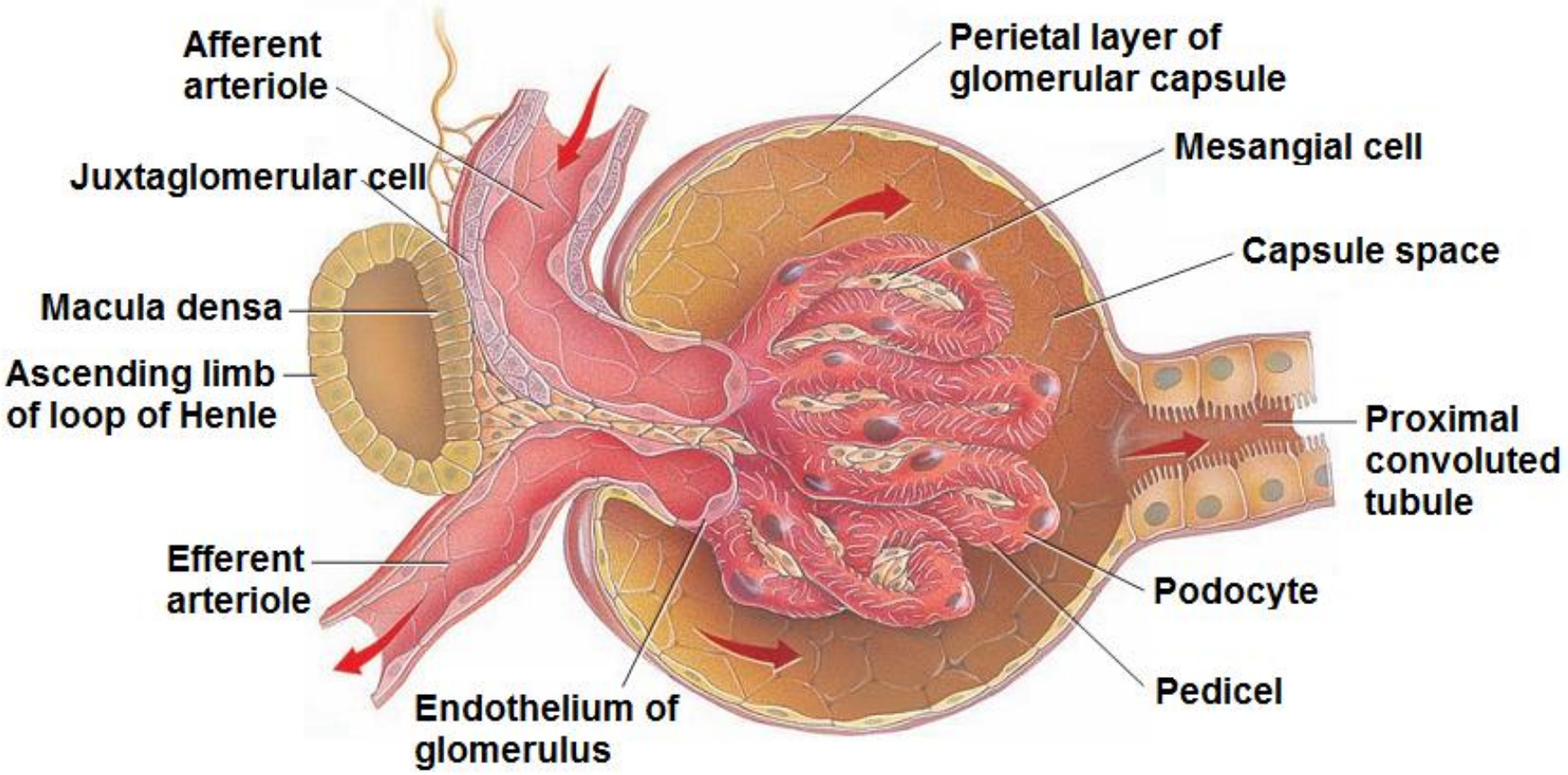


- The nephron, the functional unit of the vertebrate kidney
  - Consists of a single long tubule and a ball of capillaries called the glomerulus


Juxtamedullary nephron
Cortical nephron
Renal cortex
Collecting duct
Renal medulla
To renal pelvis


Proximal convoluted tubule
Glomerulus
Glomerular capsule
Efferent arteriole
Afferent arteriole
Distal convoluted tubule
Interlobular vein
To renal vein
From renal artery
Renal cortex
Renal medulla
Interlobular artery
Peritubular capillary
Descending limb
Nephron loop
Ascending limb
Collecting duct

A renal corpuscle

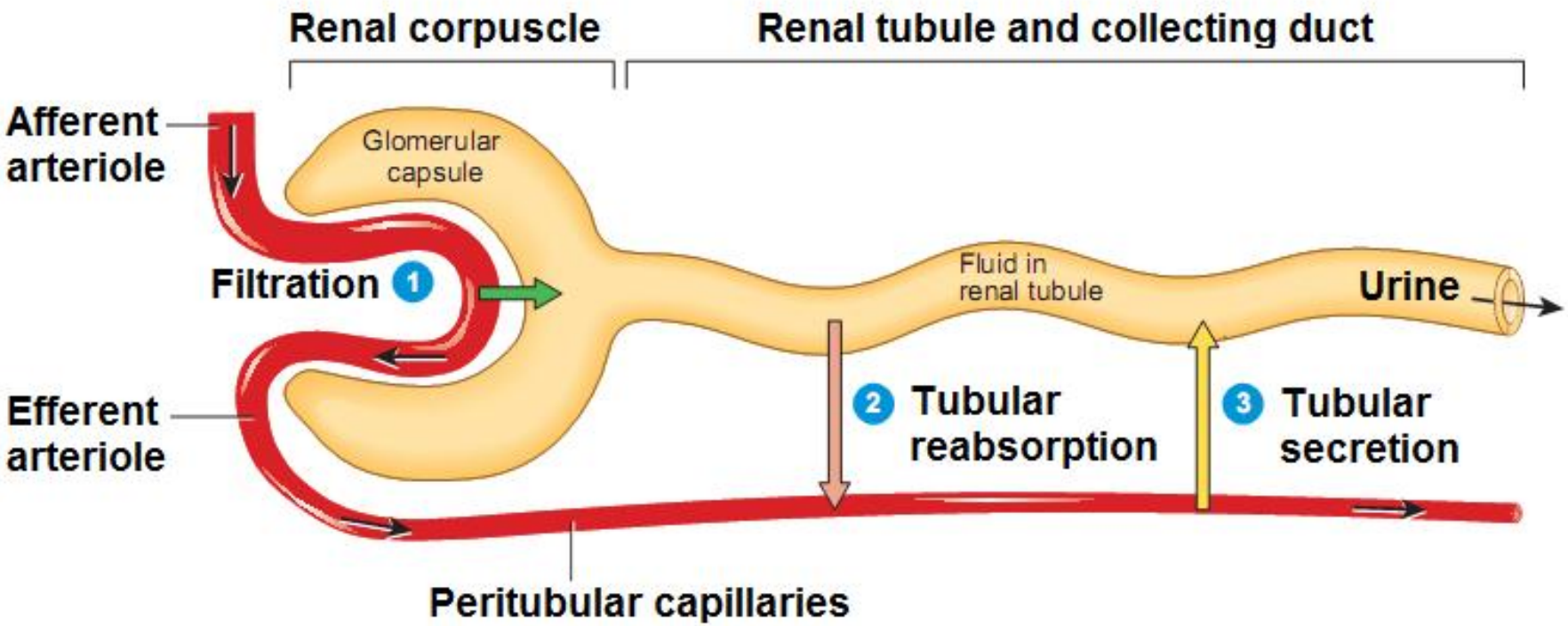


Excretory Processes

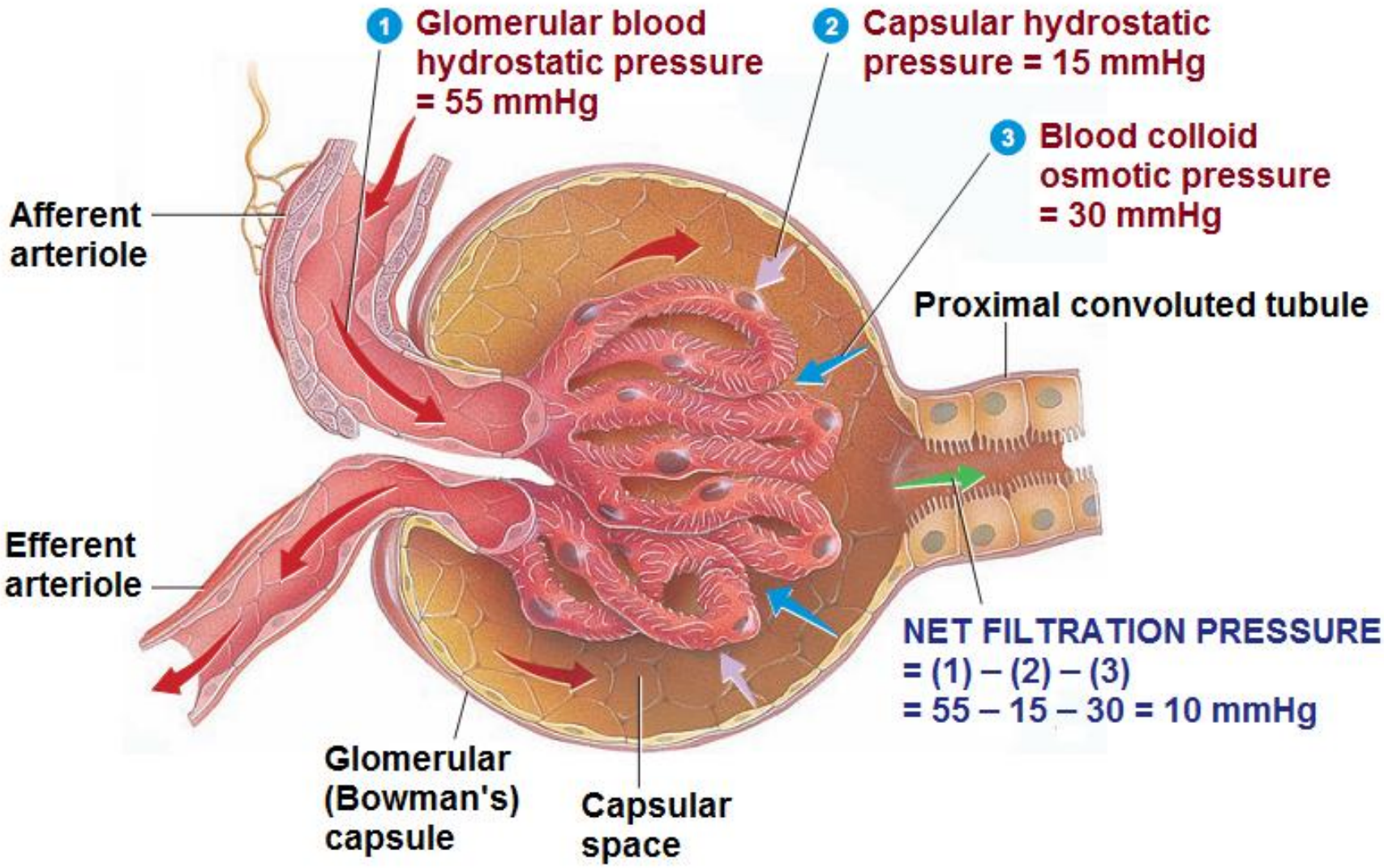
- Most excretory systems
  - Produce urine by refining a filtrate derived from body fluids

- Key functions of most excretory systems are
  - Filtration, pressure-filtering of body fluids producing a filtrate
  - Reabsorption, reclaiming valuable solutes from the filtrate
  - Secretion, addition of toxins and other solutes from the body fluids to the filtrate

Three basic function of nephron



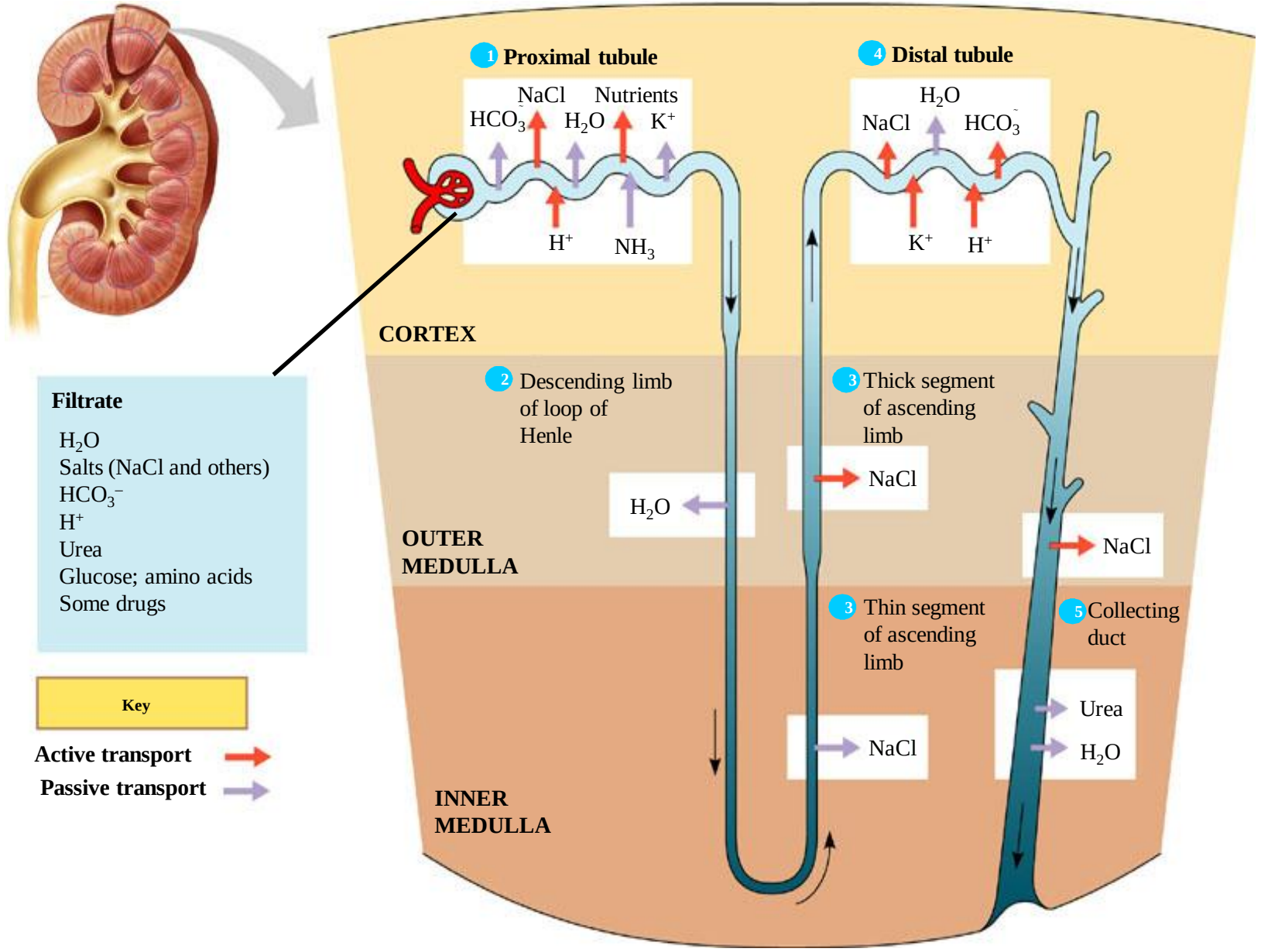
Glomerular Filtration

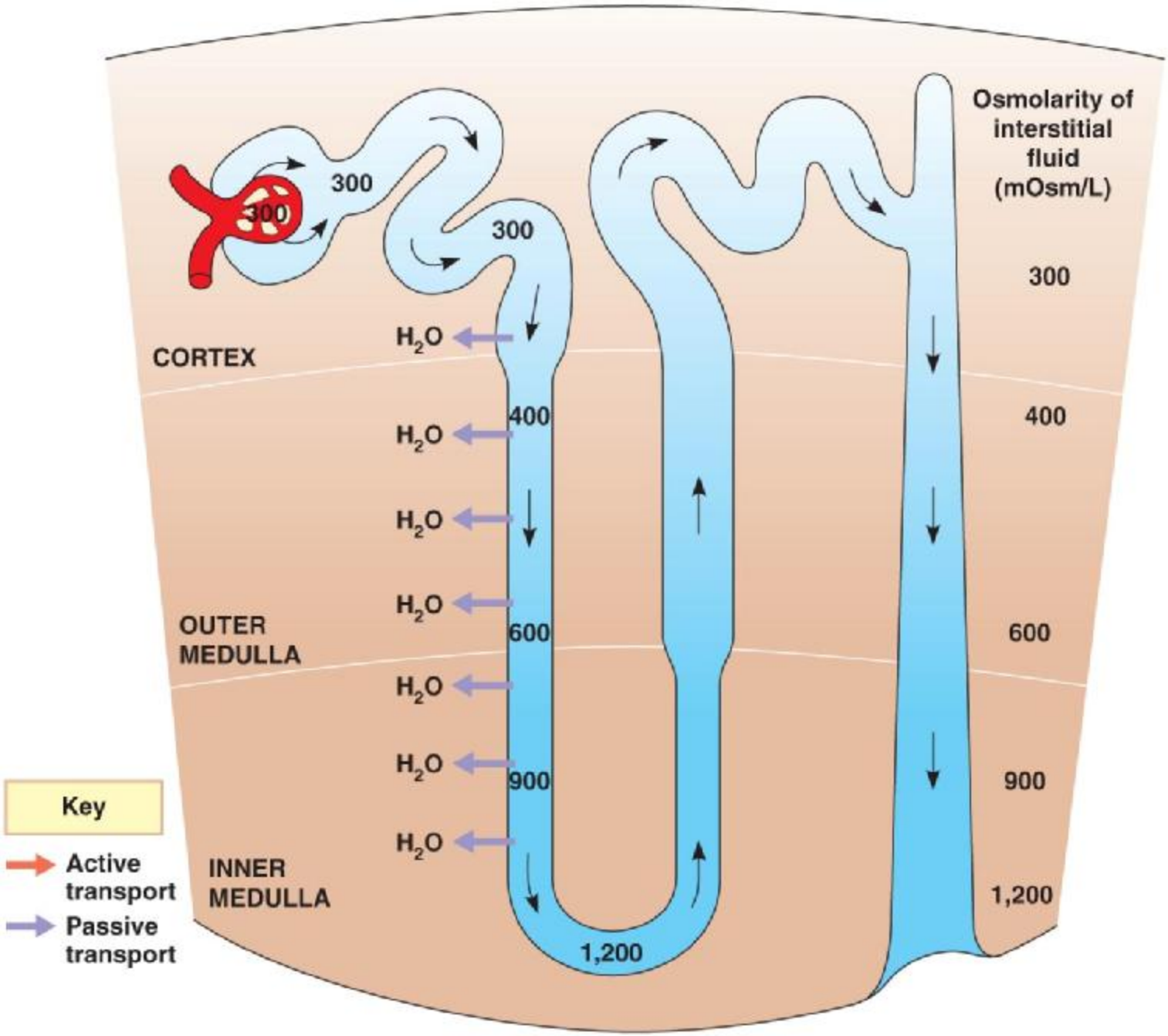


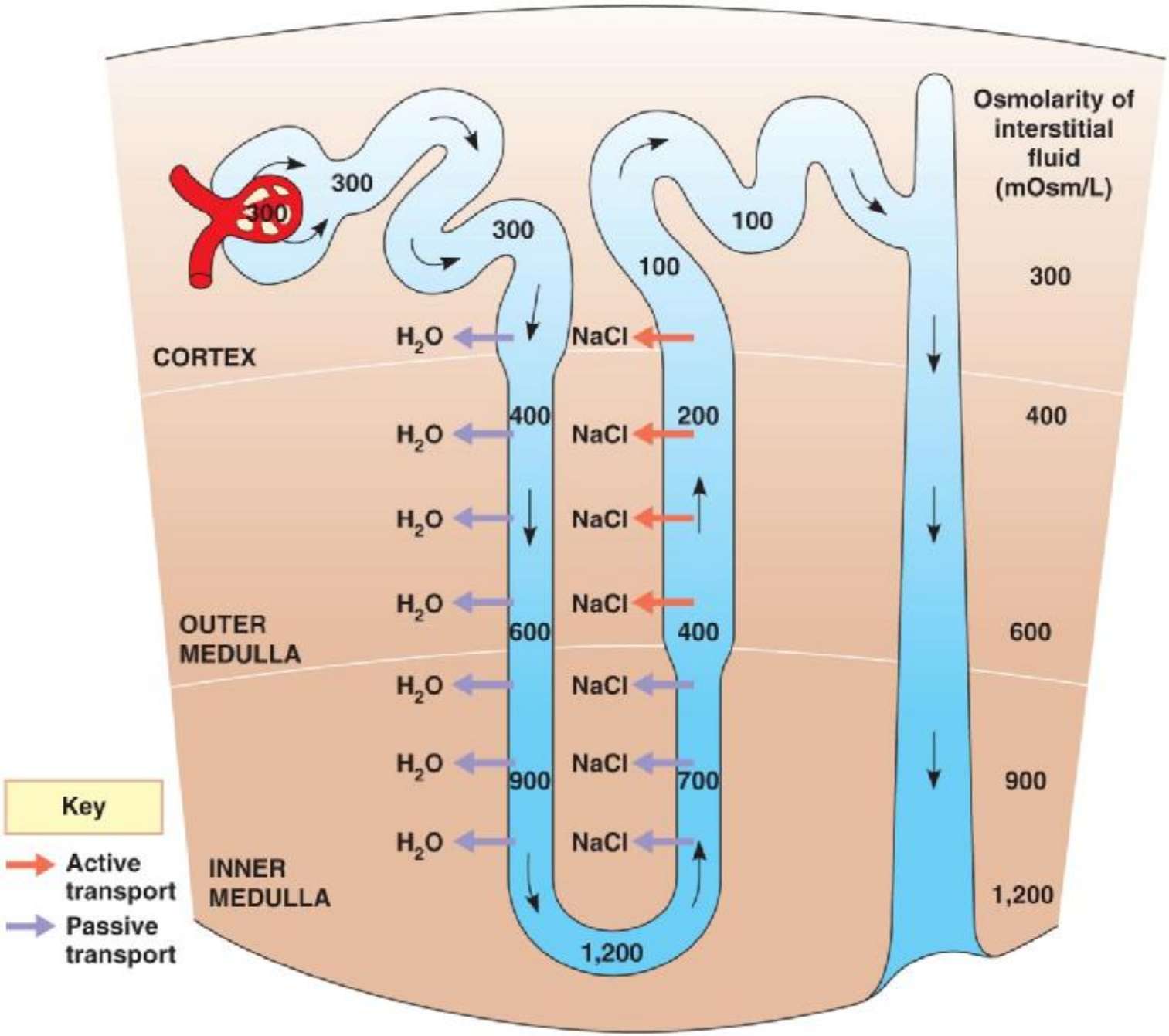
- Secretion and reabsorption in the proximal tubule
  - Substantially alter the volume and composition of filtrate
- Reabsorption of water continues
  - As the filtrate moves into the descending limb of the loop of Henle

- As filtrate travels through the ascending limb of the loop of Henle
  - Salt diffuses out of the permeable tubule into the interstitial fluid
- The distal tubule
  - Plays a key role in regulating the K^+ and NaCl concentration of body fluids
- The collecting duct
  - Carries the filtrate through the medulla to the renal pelvis and reabsorbs NaCl

From Blood Filtrate to Urine: A Closer Look




Osmolarity of interstitial fluid (mOsm/L)
300
300
300
CORTEX
H2O
400
400
H2O
H2O
H2O
600
600
OUTER MEDULLA
H2O
H2O
900
900
H2O
INNER MEDULLA
1,200
1,200
Key
Active transport
Passive transport


Osmolarity of interstitial fluid (mOsm/L)
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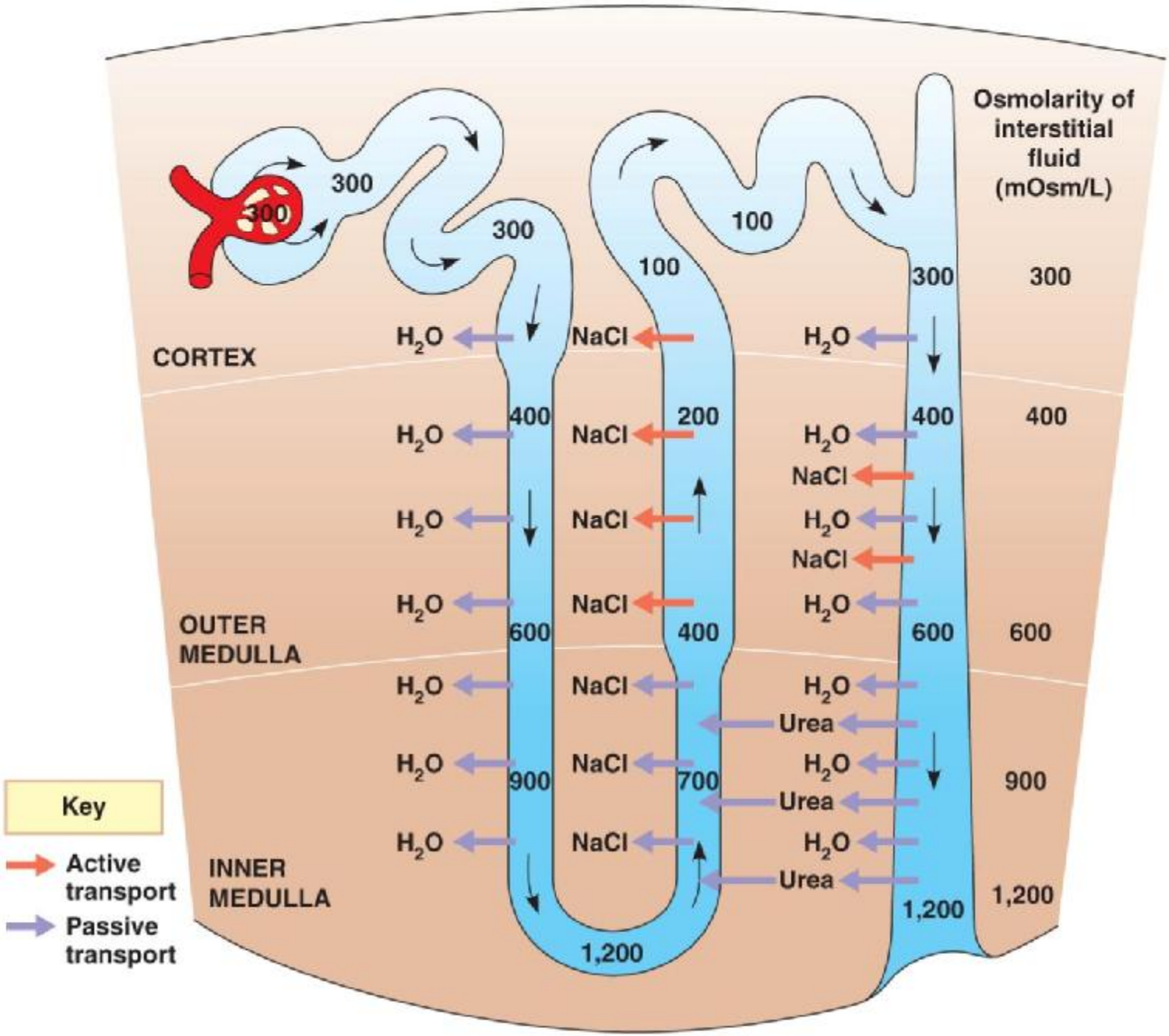
600
900
1,200
CORTEX
OUTER MEDULLA
INNER MEDULLA
300
300
300
100
100
H2O
NaCl
400
200
600
400
900
700
1,200
Key
Active transport
Passive transport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CORTEX
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H2O
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H2O
NaCl
H2O
NaCl
H2O
OUTER MEDULLA
600
400
600
600
H2O
NaCl
H2O
Urea
H2O
NaCl
H2O
900
700
900
Urea
H2O
NaCl
H2O
Urea
INNER MEDULLA
1,200
1,200
1,200
Key
Active transport
Passive transport