

## Animals and Ecology

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## Chapter 39: Form, Function, and Adaptation

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3. How Does Body Size Affect Animal Physiology?
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5. Thermoregulation: A Closer Look
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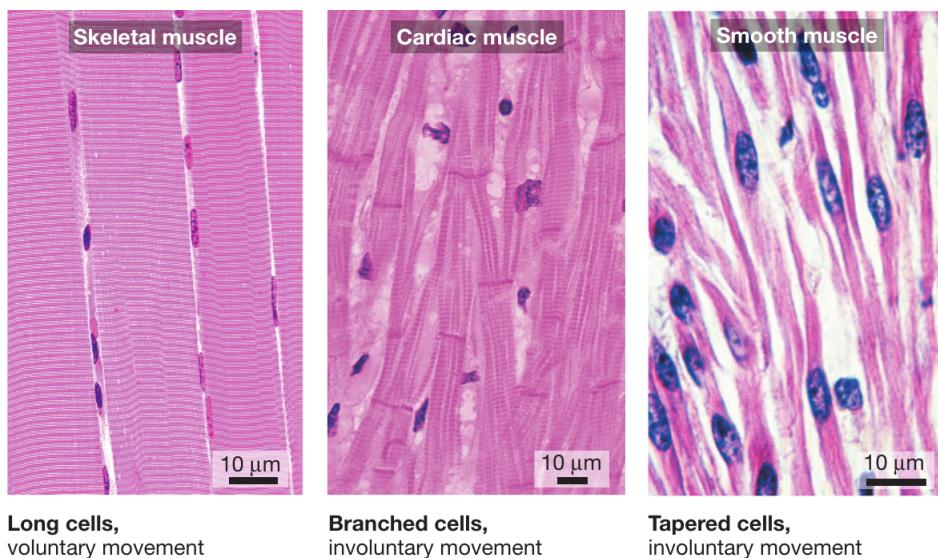
### Form, Function, and Adaptation

- **Anatomy:** reference to an organism's physical structure, or form.
- **Physiology:** how the physical structures in an organism function.
- **Adaptations:** heritable traits that make individuals more likely to survive and reproduce in a certain environment than individuals that lack those traits.
- **Trade-off:** inescapable compromises between traits
- **Spermatophore:** a packet of sperm surrounded by a large, gelatinous mass. (example for trade offs in crickets)
- **Acclimatization:** Short-term, phenotypic change in an individual in response to environmental fluctuations

### Tissues, Organs, and Systems

- **Tissue:** a group of cells that function as a unit.
- **Connective tissue:** cells that are loosely arranged in a liquid, jellylike, or solid matrix.
  - **Loose connective tissue:** an array of fibrous proteins in a soft matrix; it serves as a packing material holding organs and tissues together and as padding under the skin.
  - **Fibroblasts:** cells that make the fibers and extracellular matrix in loose connective tissue.
  - **Dense connective tissue:** found in the tendons and ligaments that connect muscles, bones, and organs. Tendons and ligaments are dominated by tough collagen fibers, also secreted by fibroblasts.
  - **Supporting connective tissue:** a firm extracellular matrix, such as bone and cartilage.
  - **Fluid connective tissue:** cells surrounded by a liquid extracellular matrix such as plasma that surrounds blood.
- **Nervous tissue:** nerve cells, which are also called neurons, and several types of supporting cells.

- **Dendrites:** highly branched, relatively short processes that transmit signals from adjacent cells to the neuronal cell body.
- **Axon:** a relatively long structure that carries electrical signals from the cell body to other cells.
- **Muscle tissue:** a key innovation in the evolution of animals—like nervous tissue, it appears in no other lineage on the tree of life.
- **Skeletal muscle:** attaches to bones and exerts a force on them when it contracts and has long cells with a striated, or striped, appearance produced by an overlapping arrangement of proteins.
- **Cardiac muscle:** makes up the walls of the heart and is responsible for pumping blood throughout the body. The branching pattern of cardiac muscle allows electrical signals to spread throughout all cells of the heart, resulting in their coordinated contraction and relaxation.
- **Smooth muscle:** cells, which are tapered at each end, form a muscle tissue that lines the walls of the digestive tract and the blood vessels.

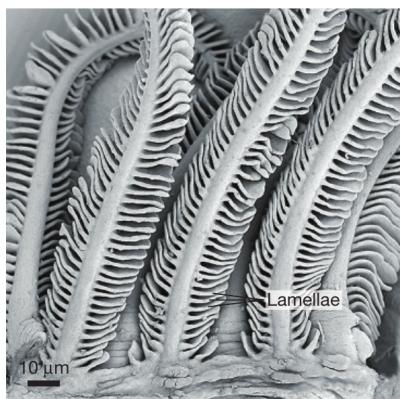


- **Epithelial tissues:** tissue that covers the outside of the body, line the inner surface of many organs, and form glands.
  - **Organ:** a structure that serves a specialized function and consists of two or more tissues
  - **Gland:** an organ that secretes specific molecules or solutions such as hormones or digestive enzymes.
  - **Apical:** faces away from other tissues and toward the environment
  - **Basolateral:** faces the interior of the animal and connects to connective tissues.
  - **Basal lamina:** the connection made by a layer of fibers on the basolateral side.
- **Organ system :** consists of groups of tissues and organs that work together to perform one or more functions.

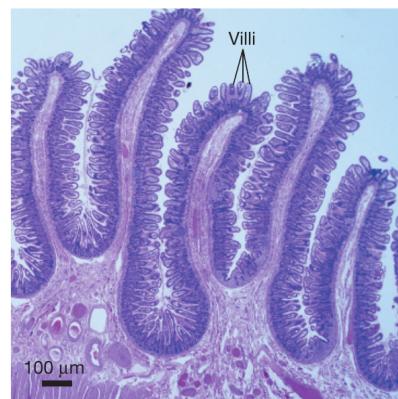
## How Does Body Size Affect Animal Physiology?

- **Metabolic rate:** the overall rate of energy consumption by an individual.
- **Basal metabolic rate (BMR):** the rate at which an animal consumes oxygen while at rest, with an empty stomach, under normal temperature and moisture conditions.
- **Gills:** organs that allow the exchange of gases and dissolved substances between the animals' blood and the surrounding water.
- **Adaptations for increased surface area:**
  - **Flattening:** Fish have gill lamellae—thin sheets of epithelial cells that provide the gill with an extremely high surface area relative to its volume.
  - **Folding:** portions of the digestive tract where nutrients are transported into the body, the surface of the structure is folded. Extending from these folds are narrow projections called villi.
  - **Branching:** a highly branched network of small, thin-walled blood vessels called capillaries, which are the sites where gases, nutrients, and waste products diffuse into and out of blood, and branching greatly increases their surface area.

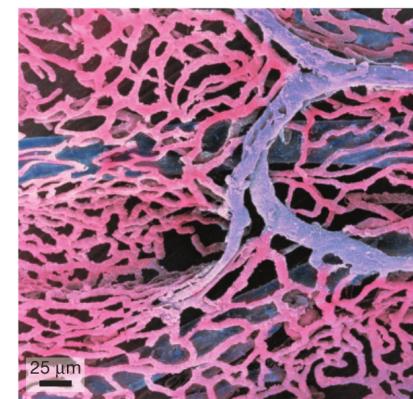
(a) Flattening: fish gill lamellae



(b) Folding: intestinal folds and villi



(c) Branching: capillaries



## Homeostasis

- **Homeostasis:** stability in the chemical and physical conditions within an organism's cells, tissues, and organs.
- **Regulate:** to actively maintain relatively constant internal conditions even when the environment fluctuates.
- Epithelia are responsible for forming an internal environment that can be dramatically different from the external environment and for allowing physical and chemical conditions inside an animal to be maintained at relatively constant levels.
- **Homeostatic system:** A homeostatic system consists of three general components: a sensor, an integrator, and an effector.
- **Hypothalamus:** a receptor region in the brain that responds to changes in blood temperature.

## Thermoregulation: A Closer Look

- **Thermoregulatory strategies:** conduction, convection, radiation, and evaporation.
- **Endotherm:** produces heat.
- **Ectotherm:** relies on heat.
- **Homeotherms:** keep their body temperature constant
- **Poikilotherms:** allow their body temperature to rise or fall depending on environmental conditions.
- **Torpor:** reduction of metabolic rate and that allows body temperature to drop, a form of poikilothermy.
- **Hibernation:** Extended periods of Torpor.
- **Countercurrent exchanger:** fluids that flow through adjacent pipes in opposite directions to reduce heat loss.

### Chpater 39: Review

#### Form, Function, and Adaptation

- Animal structures and their functions represent adaptations, which are heritable traits that improve survival and reproduction in a certain environment.
- Adaptations involve trade-offs, or inescapable compromises between traits.
- Acclimatization is a reversible response to the environment that improves physiological function in that environment.

#### Tissues, Organs, and Systems

- Animal cells with a common function are grouped together into four general types of tissue: connective tissue, nervous tissue, muscle tissue, and epithelial tissue.
- Organs are structures that are composed of two or more tissues that together perform specific tasks.
- Organ systems comprise organs that work together in an integrated fashion to perform one or more functions.

#### How Does Body Size Affect Animal Physiology?

- Large animals have smaller surface area/volume ratios than small animals. As animals grow, their volume increases more rapidly than their surface area.
- Large animals have low mass-specific metabolic rates, in keeping with their relatively small surface area for exchanging the oxygen and nutrients required to support metabolism and the wastes and heat produced by metabolism.
- The relatively high surface area of small animals means that they lose heat extremely rapidly.

## Homeostasis

- Homeostasis refers to relatively constant physical and chemical conditions inside the body.
- Homeostasis in a fluctuating environment is usually achieved by regulation.
- Animals have set points, or target values, for various body parameters. When a parameter is not at its set point, negative feedback occurs. Responses to negative feedback return the parameter to the set point and result in homeostasis.
- Most animals have a set point for body temperature. If an individual overheats, it may pant, sweat, or seek a cool environment; if an individual is cold, it may shiver, bask in sunlight, or fluff its fur or feathers.

## Thermoregulation: A Closer Look

- Animals vary from endothermic to ectothermic and from homeothermic to poikilothermic.
- Endotherms can be active in cold environments but must obtain a lot of energy to fuel their metabolism. Ectotherms do not require as much energy, but their activity depends on environmental temperature.
- Countercurrent heat exchangers have vessels in close contact that carry warm and cool fluids in opposite directions.

## Chapter 40: Water and Electrolyte

1. Osmoregulation and Exertion
2. Water and Electrolyte in Marine Fishes
3. Water and Electrolyte in Freshwater Fishes
5. Water and Electrolyte in Vertebrates
  - Review

### Osmoregulation and Exertion

- **Electrolyte:** compound that dissociates into ions when dissolved in water. Electrolytes got their name because they conduct electrical current.
- **Osmosis:** movement of water down its gradient across a semi permeable membrane
- **Osmoregulation:** is the process by which organisms control the concentration of water and solutes in their bodies.
- **Osmoconformers:** animals with concentrations of electrolytes and other solutes that match those of the sea.
- **Isosmotic:** solute concentrations inside and outside these animals are equal.
- **Osmoregulators:** most marine invertebrates, marine and fresh water bony fishes and terrestrial animals. These organisms actively regulate osmolarity inside their bodies to achieve homeostasis.
- **Hyperosmotic:** the solution outside the body has a higher solute concentration than the solution inside.
- **Hyposmotic:** higher solute concentration than the freshwater outside
- **Aquaporins:** specialized membrane channels where water follows by osmosis due to cells that transport ions and that set up an osmotic gradient.
- **Ammonia:** the result of excess amino acids and nucleic acids when broken down in catabolic reactions and of which animals must secret since it raises the pH of cells.
- **Urea:** a much less toxic compound created by enzyme-catalyzed reactions of ammonia.

**SUMMARY** **Table 40.1** Attributes of Three Forms of Nitrogenous Waste

Attribute	Ammonia	Urea	Uric Acid
Solubility in water	high	medium	very low
Amount of water required for excretion	high	medium	very low
Toxicity	high	medium	low
Groups where it is the primary waste	most bony fishes, aquatic invertebrates	mammals, most adult amphibians, sharks, rays, skates	birds and other reptiles, most terrestrial arthropods (insects, spiders)
Method of synthesis	product of breakdown of amino acids and nucleic acids	synthesized in liver, starting with ammonia or amino groups from amino acids	synthesis starts with nucleic acids
Energy cost of synthesis	low	high	high
Method of excretion	in urine, and diffuses across gills	in urine (mammals); diffuses across gills (sharks)	with feces

## Water and Electrolyte in Marine Fish

- **Rectal gland:** an gland in sharks that secretes a concentrated salt solution.
- **Ouabain:** toxic to animals because it binds to  $\text{Na}^+/\text{K}^+$ -ATPase and prevents it from functioning and strong evidence that  $\text{Na}^+/\text{K}^+$ -ATPase is essential for salt excretion.
- **Interstitial fluid:** the extra-cellular fluid surrounding the rectal gland.

## Water and Electrolyte in Freshwater Fish

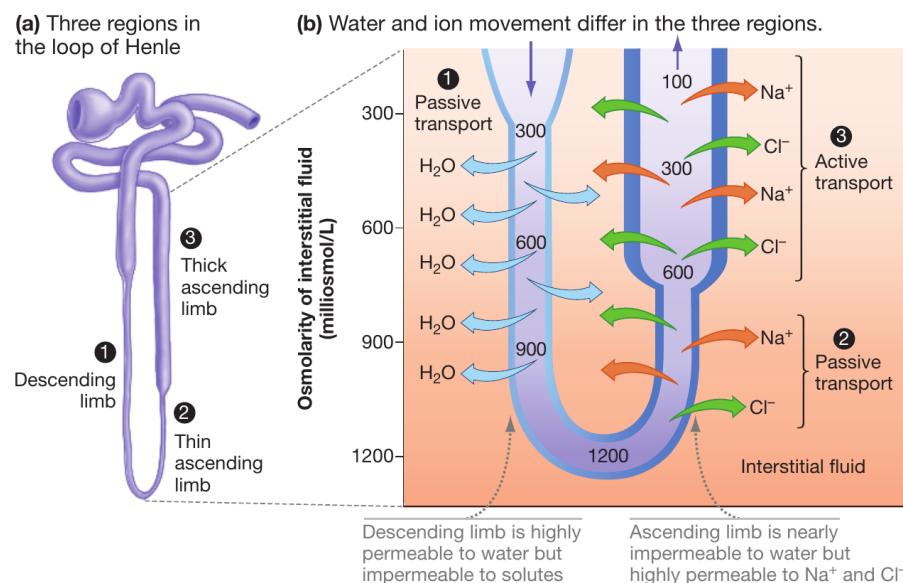
- **Osmoregulatory cells may be in different locations:** when osmotic stress changes, the structure of the gill epithelium changes. Specifically, active pumping of ions takes place in different populations of cells in seawater and freshwater.
- **Different forms of  $\text{Na}^+/\text{K}^+$ -ATPase may be activated:** the form activated when salmon are in seawater differs from the one activated when they are in freshwater.
- **The orientation of key transport proteins “flips.”:** When the fish are in seawater, the protein is located in the basolateral membrane of chloride cells. But when they are in freshwater, the protein is located in the apical membrane.

## Water and Electrolyte in Vertebrates

- **Kidney:** the key organ of the urinary system osmoregulation primally occurs.
- **Ureter:** a long tube where the urine that forms in the kidney is transported.
- **Bladder:** the storage organ urine in the ureter is transported to.
- **Urethra:** where urine is transported from bladder to the body surface.
- **Nephron:** small structures that are the basic functional unit of the kidney and makes up most of

the kidney's mass. Nephrons work involved in maintaining water and electrolyte balance. f

- **Cortex:** outer region of the an organ.
- **Medulla:** the kidney's inner region.
- **The Mammalian Kidney:** To move water, cells in the kidney set up a strong osmotic gradient in the interstitial fluid surrounding the nephrons. By regulating these gradients and specific channel proteins, kidney cells exert precise control over loss or retention of water and electrolytes.
- **Renal Corpuscle:** a filtration device where urine formation begins. The renal corpuscle forms a capsule that encloses a cluster of capillaries called a **glomerulus**
- **Bowman's capsule:** region of the nephron that surrounds the glomerulus
- **Proximal tubule:** where filtrate reabsorption begins after leaving the Bowman's capsule.
- **Microvilli:** small hairs that greatly increase the surface area of this epithelial cells of the proximal tubule.
- **Loop of Henle:** the location to which fluid that emerges from the proximal tubule flows to. In about 20 percent of the nephrons present in a human kidney, the loop is long and plunges from the cortex of the kidney deep into the medulla.
- The loop of Henle has three distinct regions: the descending limb, the thin ascending limb, and the thick ascending limb.
- **A Comprehensive View of the Loop of Henle:** Movement of NaCl from the ascending limb into surrounding tissue increases the osmolarity of the fluid outside the descending limb, which results in an outward flow of water across the waterpermeable epithelium of the descending limb, via osmosis. This loss of water in the descending limb increases the osmolarity of the fluid entering the ascending limb. The high concentration of salt in the fluid at the base of the ascending limb triggers a passive flow of ions out—reinforcing the osmotic gradient.



**Figure 40.12 The Loop of Henle Maintains an Osmotic Gradient Because Water Leaves the Descending Limb and Salt Leaves the Ascending Limb.** The values inside the loop in part (b) represent the osmolarity of the filtrate.

- **Vasa recta:** a network of blood vessels that runs along the loop of henle where water and electrolytes that are reabsorbed are returned to the bloodstream instead of being excreted in urine.
- the system created by the nephron, vasa recta, and collecting duct results in the creation and maintenance of a strong osmotic gradient with the minimum possible expenditure of energy.
- **Hormones Involved**
  - If  $\text{Na}^+$  levels in the blood are low, the adrenal glands release the hormone **aldosterone**, which leads to activation of sodium.
  - If an individual is dehydrated, the brain releases **antidiuretic hormone (ADH)**.
- **Cloaca:** a cavity into which the urinary, gastrointestinal, and reproductive tracts all empty. Reptiles are able to absorb water from urine across the wall of the cloaca into the bloodstream. Eventually, a semisolid uric acid paste is excreted along with the feces.

### Chapter 40: Review

#### Osmoregulation and Excretion

- Solutes move across membranes via passive transport, facilitated diffusion, or active transport. Water moves across membranes by osmosis.
- In most animals, epithelial cells that selectively transport water and electrolytes are responsible for homeostasis.
- The mechanisms involved in regulating water and electrolyte balance vary widely among animal groups because different habitats present different types of osmotic stress.
- The type of nitrogenous waste excreted by an animal is affected by its phylogeny and its habitat type. Most fishes excrete ammonia; mammals and most adult amphibians excrete urea; and insects and reptiles excrete uric acid.

#### Water and Electrolyte in Marine Fishes

- Seawater is strongly hyperosmotic to the tissues of marine bony fishes, so they tend to lose water by osmosis and gain electrolytes by diffusion.
- Marine bony fishes are osmoregulators, whereas cartilaginous fishes including sharks are osmoconformers.
- Epithelial cells in the shark rectal gland and in the gills of marine bony fishes excrete excess salt using  $\text{Na}^+/\text{K}^+$ ATPase and  $\text{Na}^+/\text{Cl}^+/\text{K}^+$  cotransporters located in the basolateral membrane.
- Similar saltexcreting cells also exist in the salt glands of marine birds and other reptiles and in the kidneys of mammals.

#### Water and Electrolyte in Freshwater Fishes

- Freshwater is strongly hypotonic to the blood of freshwater fishes, so they tend to gain water by osmosis and lose electrolytes by diffusion.
- Epithelial cells in the gills of freshwater fishes import ions using  $\text{Na}^+/\text{K}^+$ ATPase located in the basolateral membrane and  $\text{Na}^+/\text{Cl}^-/\text{K}^+$  cotransporters located in the apical membrane.

### Water and Electrolyte in Vertebrates

- Nephrons in the vertebrate kidney form a filtrate in the renal corpuscle and then reabsorb valuable nutrients, electrolytes, and water in the proximal tubule.
- A solution containing urea and electrolytes flows through the loop of Henle of mammalian kidneys, where changes in the permeability of epithelial cells to water and salt—along with active transport of salt—create a steep osmotic gradient.
- Antidiuretic hormone increases the water permeability of the collecting duct, causing water to be reabsorbed along the osmotic gradient and hyperosmotic urine to be produced.
- The nephrons of fishes, amphibians, and nonavian reptiles do not have loops of Henle and therefore cannot produce urine that is hyperosmotic to the body fluids. However, some of these vertebrates can produce hyperosmotic urine by reabsorbing water from the cloaca or bladder.

## Chapter 41: Nutrition

1. Nutritional Requirements
3. How are Nutrients Digested and Absorbed?
4. Nutritional Homeostasis
- i. Review

### Nutritional Requirements

- **Ingestion:** bringing in food.
- **Digestive tract:** also known as the alimentary canal or gastrointestinal (GI) tract.
- **Digestion:** breaking down food.
- **Absorption:** the uptake of specific ions and molecules across the epithelium that lines the digestive tract.
- **Essential nutrient:** are those that cannot be synthesized and must be obtained from the diet.

**Table 41.1** Some Important Vitamins Required by Humans

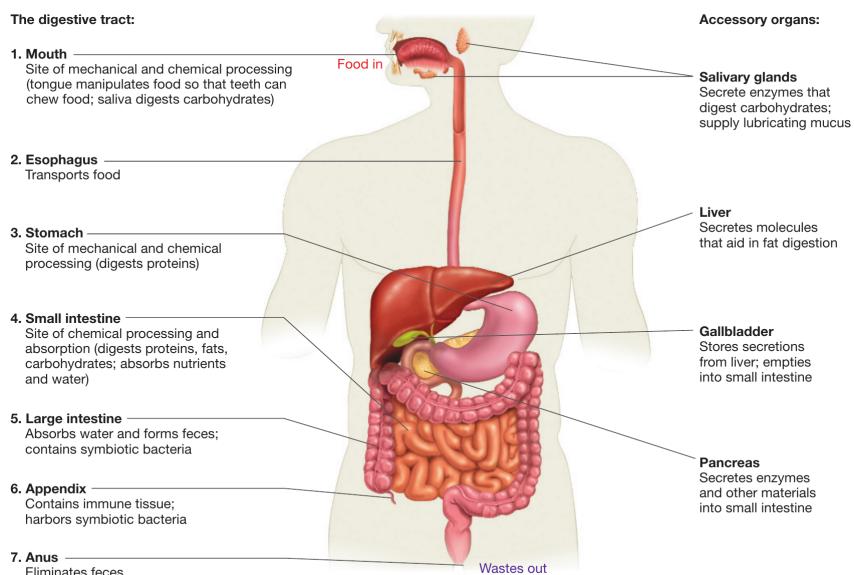
	Source	Function	Effects if Deficient
<b>Vitamin B<sub>1</sub> (thiamine)</b>	legumes, whole grains, potatoes, peanuts	formation of coenzyme in citric acid cycle	beriberi (fatigue, nerve disorders, anemia)
<b>Vitamin B<sub>12</sub></b>	red meat, eggs, dairy products; also synthesized by bacteria in intestine	coenzyme in synthesis of proteins and nucleic acids and in formation of red blood cells	anemia (fatigue and weakness due to low hemoglobin content in blood)
<b>Niacin</b>	meat, whole grains	component of coenzymes NAD <sup>+</sup> and NADP <sup>+</sup>	pellagra (digestive problems, skin lesions, nerve disorders)
<b>Folate</b>	green vegetables, oranges, nuts, legumes, whole grains; also synthesized by bacteria in intestine	coenzyme in nucleic acid and amino acid metabolism	anemia
<b>Vitamin C (ascorbic acid)</b>	citrus fruits, tomatoes, broccoli, cabbage, green peppers	used in collagen synthesis, prevents oxidation of cell components, improves absorption of iron	scurvy (degeneration of teeth and gums)
<b>Vitamin D</b>	fortified milk, egg yolk; also synthesized in skin exposed to sunlight	aids absorption of calcium and phosphorus in small intestine	rickets (bone deformities) in children; bone softening in adults

**Table 41.2** Major Minerals Required by Humans

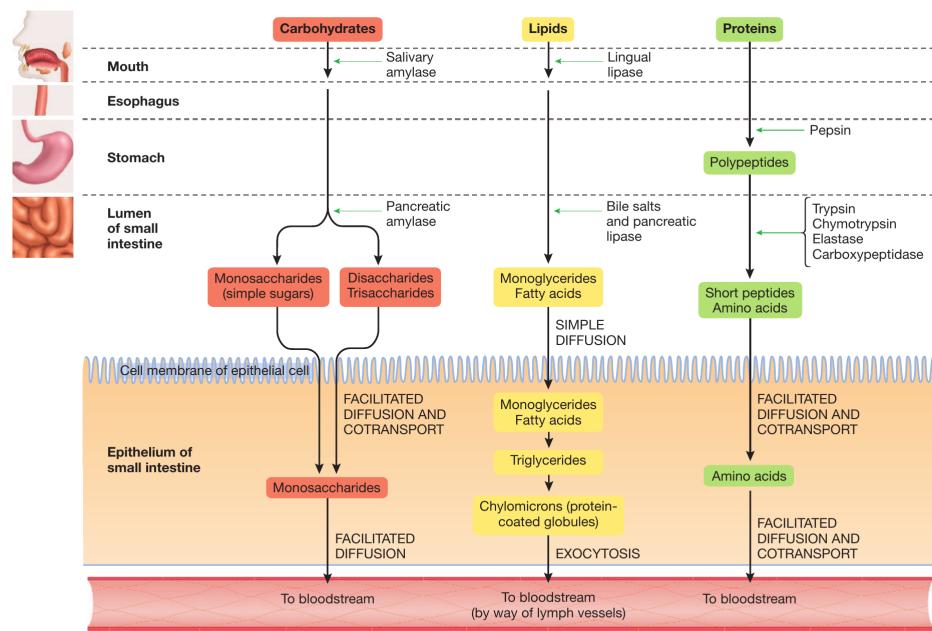
	Source in Diet	Function	Effects if Deficient
<b>Calcium (Ca)</b>	dairy products, green vegetables, legumes	bone and tooth formation, nerve signaling, muscle response	loss of bone mass, slow growth
<b>Chlorine (Cl)</b>	table salt or sea salt, vegetables, seafood	fluid balance in cells, protein digestion in stomach (HCl), acid-base balance	weakness, loss of muscle function
<b>Fluorine (F)</b>	fluoridated water, seafood	maintenance of tooth structure	higher frequency of tooth decay
<b>Iodine (I)</b>	iodized salt, algae, seafood	component of the thyroid hormones thyroxine and T <sub>3</sub>	goiter (enlarged thyroid gland)
<b>Iron (Fe)</b>	meat, eggs, whole grains, green leafy vegetables, legumes	enzyme cofactor; synthesis of hemoglobin and electron carriers	anemia, weakness
<b>Magnesium (Mg)</b>	whole grains, green leafy vegetables	enzyme cofactor	nerve disorders
<b>Phosphorus (P)</b>	dairy products, meat, grains	bone and tooth formation; synthesis of nucleotides and ATP	weakness, loss of bone mass
<b>Potassium (K)</b>	dairy products; meat; nuts; fruits; potatoes, legumes, and other vegetables	nerve signaling, muscle response, acid-base balance	weakness, muscle cramps, loss of muscle function
<b>Sodium (Na)</b>	table salt or sea salt, seafood	nerve signaling, muscle response, blood pressure regulation	weakness, muscle cramps, loss of muscle function, nausea, confusion
<b>Sulfur (S)</b>	any source of protein	amino acid synthesis	swollen tissues, degeneration of liver, mental retardation

## How are Nutrients Digested and Absorbed?

- Incomplete digestive tracts:** a single opening, the mouth, through which the animal both ingests food and eliminates wastes.
- Complete digestive tracts:** two openings—they start at the mouth and end at the anus.



**Figure 41.6** Humans Have a Complete Digestive Tract. In humans, as in all vertebrates and most other animals, the digestive tract is a tube that runs from the mouth to the anus. The salivary glands, liver, gallbladder, and pancreas are not part of the tract itself. Instead, they secrete material into the tract at specific points.



**Figure 41.7 Carbohydrates, Lipids, and Proteins Are Processed in a Series of Steps.** Three key types of macromolecules enter the digestive system (top of diagram). As they proceed through the digestive tract, they are broken apart by various enzymes. Simple sugars, monoglycerides, fatty acids, and amino acids then enter epithelial cells in the small intestine and are transported to the bloodstream.

- **Feces:** the material remaining in the large intestine and excreted.
- **Salivary amylase:** the enzyme responsible for starch digestion in the mouth
- **Lingual lipase:** which begins the digestion of lipids by breaking triglycerides into diglycerides and fatty acids.
- **Salivary glands:** glands in the mouth that not only secrete amylase but also produce the slimy substance called mucus.
- **Esophagus:** a muscular tube called that connects the mouth and stomach.
- **Peristalsis:** wave of muscular contractions called peristalsis propels food down the esophagus.
- **Crop:** where food can be stored and, in some cases, processed.
- **Stomach:** a tough, muscular pouch in the digestive tract, bracketed on both the superior and inferior ends by ringlike muscles called **sphincters**, which control the passage of material.
- **Pepsin:** enzyme that is responsible for digesting proteins in the stomach
- **Parietal cells:** the source of the HCl in gastric juice, which may have a pH as low as 1.5.
- **Mucous cell:** secretes additional mucus that is found in gastric juice. Mucus lines the gastric epithelium and protects the stomach from damage by HCl.
- **Carbonic anhydrase:** catalyzes the formation of carbonic acid ( $H_2CO_3$ ) from carbon dioxide and water.
- **Ulcer:** an eroded area in an epithelium; it exposes the underlying tissues to damage

- **Ruminants:** the stomach is specialized for digesting cellulose instead of proteins.
- **Cellulase:** an enzyme capable of breaking the chemical bonds in cellulose, yielding glucose.
- **Small intestine:** a long tube that is folded into a compact space within the abdomen where most nutrients—along with large quantities of water—have been absorbed.
- **Villi:** fingerlike projections that cover the small intestine's tissue. Villi themselves have microvilli that protrude on the apical side.
- **Lacteal:** lymphatic vessel that allows nutrients to quickly pass from epithelia to the body's transport system.
- **Proteases:** protein-digesting enzymes specific to certain types or configurations of amino acids in a polypeptide chain.
- **Pancreas:** an organ connected to the small intestine by the pancreatic duct that is responsible for production of proteases.
- **Trypsin:** triggers the activation of other proteases, such as chymotrypsin, elastase, and carboxypeptidase.
- **Hormone:** a chemical messenger that influences physiological processes at very low concentrations.
- **Secretin:** a hormone produced by the small intestine in response to the arrival of food from the stomach.
- **Cholecystokinin:** stimulates the secretion of digestive enzymes from the pancreas and the secretion of molecules from the gallbladder that aid in processing lipids.
- **Gastrin:** stimulates parietal cells to begin secreting HCl.
- **Pancreatic amylase:** continues the digestion of carbohydrates that began in the mouth.
- **Pancreatic lipase:** breaks certain bonds present in fats and results in the release of fatty acids and other small lipids.
- **Emulsification:** the process in which large fat globules that emerge from the stomach are broken up.
- **Liver:** organ that performs an array of functions related to digestion, and secreted in a complex solution called **bile**, which is stored in the **gallbladder** and contains bile salts used to break up lipids in plasma membranes.

**SUMMARY** **Table 41.3** Digestive Enzymes in Mammals

Digestion is accomplished by the enzymes listed here, by HCl produced in the stomach in response to the hormone gastrin, and by bile salts from the liver. Bile salts are stored in the gallbladder. They are released in response to the hormone cholecystokinin and emulsify fats in the small intestine.

	Where Synthesized	Regulation	Function
<b>Carboxypeptidase</b>	Pancreas	Released in inactive form in response to cholecystokinin from small intestine; activated by trypsin	In small intestine, breaks peptide bonds in polypeptides—releasing amino acids
<b>Chymotrypsin</b>	Pancreas	Released in inactive form in response to cholecystokinin from small intestine; activated by trypsin	In small intestine, breaks peptide bonds in polypeptides—releasing amino acids
<b>Elastase</b>	Pancreas	Released in inactive form in response to cholecystokinin from small intestine; activated by trypsin	In small intestine, breaks peptide bonds in polypeptides—releasing amino acids
<b>Lingual lipase</b>	Salivary glands	Released in response to taste and smell stimuli	In mouth and stomach, breaks bonds in fats—releasing fatty acids and monoglycerides
<b>Nucleases</b>	Pancreas	Released in response to cholecystokinin from small intestine	In small intestine, break apart nucleic acids—releasing nucleotides
<b>Pancreatic amylase</b>	Pancreas	Released in response to cholecystokinin from small intestine	In small intestine, breaks apart carbohydrates—releasing sugars
<b>Pancreatic lipase</b>	Pancreas	Released in response to cholecystokinin from small intestine	In small intestine, breaks bonds in fats—releasing fatty acids and monoglycerides
<b>Pepsin</b>	Stomach	Released in inactive form (pepsinogen); activated by low pH in stomach lumen	In stomach, breaks peptide bonds between certain amino acids in proteins—releasing polypeptides
<b>Salivary amylase</b>	Salivary glands	Released in response to taste and smell stimuli	In mouth, breaks apart carbohydrates—releasing sugars
<b>Trypsin</b>	Pancreas	Released in inactive form (trypsinogen) in response to cholecystokinin from small intestine; activated by enteropeptidase from small intestine	In small intestine, breaks specific peptide bonds in polypeptides—releasing amino acids

- **Large intestine:** form feces by absorbing additional water and compacting the wastes that remain.
- **Colon:** the main section of the large intestine.
- **Rectum:** the final part of the large intestine, until they can be eliminated.
- **Cecum:** a blind sac at the anterior end of the large intestine in some herbivores.
- **Appendix:** the function of the appendix has long been debated, either vestigial or a storage sac for symbiotic organisms.
- **Coprophagy:** reabsorption of feces, allowing the animal to absorb more nutrients from food.
- **Cloaca:** an enlarged portion of the large intestine into which the reproductive tract also empties in the rectum of amphibians, reptiles, and birds.

## Nutritional Homeostasis

- **Diabetes mellitus:** abnormally high levels of glucose in their blood because cells cannot import the glucose.
- **Insulin:** a hormone that is secreted by cells in the pancreas when blood glucose levels are too high.
- **Glucagon:** a hormone that causes liver cells catabolize stored glycogen and produce glucose via **gluconeogenesis**, the synthesis of glucose from non-carbohydrate compounds.
- **Diabetes mellitus**

- type 1 does not synthesize sufficient insulin
- type 2 are resistant to insulin, meaning that insulin does not effectively activate its receptor in target cells.
- In both types, effector cells do not receive the signal that would result in a drop in blood glucose levels.
- **Body mass index (BMI):** a measure of obesity. BMI is calculated as body mass (in kilograms) divided by height (in meters) squared. A person with a BMI of 30 or higher is considered obese and has a far greater risk of developing type 2 diabetes mellitus than people with lower BMIs.

## Chapter 41: Review

### Nutritional Requirements

- The diets of animals include fats, carbohydrates, and proteins that provide energy; vitamins that serve as coenzymes and perform other functions; minerals that are used as components of enzyme cofactors or structural materials; and ions of electrolytes required for osmotic balance and normal membrane function.
- Fats contain more energy (about 9 kcal/g) than carbohydrates or proteins (about 4 kcal/g), making fats an efficient way to store energy in the body.

### How Are Nutrients Digested and Absorbed?

- Most animals have a digestive tract that begins at the mouth and ends at the anus.
- In many animals, chemical digestion of food begins in the mouth. In mammals, salivary amylase hydrolyzes bonds in starch and glycogen, and lingual lipase hydrolyzes bonds in fats.
- Once food is swallowed, it is propelled down the esophagus by peristalsis.
- Digestion continues in the stomach. In the human stomach, a highly acidic environment denatures proteins, and the enzyme pepsin begins the cleavage of peptide bonds that link amino acids.
- Food passes from the stomach into the small intestine, where it is mixed with secretions from the pancreas and liver.
- In the small intestine, carbohydrate digestion is continued by pancreatic amylase; fats are emulsified by bile salts and digested by pancreatic lipase; and protein digestion is completed by a suite of pancreatic proteases.
- Cells that line the small intestine absorb the nutrients released by digestion. In many cases, uptake is driven by an electrochemical gradient established by  $\text{Na}^+/\text{K}^+$ -ATPase that favors the diffusion of  $\text{Na}^+$  into the cells.
- As solutes leave the lumen of the small intestine and enter cells, water follows by osmosis.
- Water reabsorption is completed in the large intestine, where feces form.
- The structure of organs in the digestive tract varies widely among species, in ways that support processing of the food each species ingests.

### Nutritional Homeostasis

- Diabetes mellitus is a condition in which the level of glucose in the blood is abnormally high.
- Type 1 diabetes mellitus is caused by a defect in the production of insulin—a hormone secreted by the pancreas that promotes the uptake of glucose from the blood.
- Type 2 diabetes mellitus is characterized by a failure of cells to respond to insulin.
- The development of type 2 diabetes is correlated with obesity. The incidence of this disease has reached epidemic proportions in many populations.

## Chapter 42: Gas Exchange

1. The Respiratory and Circulatory System
2. Air and Water as Respiratory Media
3. Organs of Gas Exchange
4. How are Oxygen and Carbon Dioxide Transported in Blood?
5. Circulation
  - Review

### The Respiratory and Circulatory System

1. **Ventilation:** the movement of air or water through a specialized gas exchange organ, such as a lung or gill.
2. **Diffusion at the respiratory surface:** where O<sub>2</sub> moves from the air or water into the blood and CO<sub>2</sub> moves from the blood into the air or water
3. **Circulation:** the transport of dissolved O<sub>2</sub> and CO<sub>2</sub> throughout the body—along with nutrients, wastes, and other types of molecules—via the circulatory system.
4. **Diffusion at the tissues:** where O<sub>2</sub> moves from the blood into the tissues and CO<sub>2</sub> moves from the tissues into the blood.
5. **Cellular respiration:** the cell's use of O<sub>2</sub> and production of CO<sub>2</sub>. In tissues, where cellular respiration has led to low O<sub>2</sub> levels and high CO<sub>2</sub> levels, gas exchange occurs between blood and cells.
  - **Respiratory system:** the collection of cells, tissues, and organs responsible for gas exchange between the animal and its environment, or steps 1 and 2.
  - **Circulatory system:** the system which moves O<sub>2</sub>, CO<sub>2</sub>, and other materials around the body. In many cases, a muscular heart propels a specialized, liquid transport tissue throughout the body via a system of vessels.

### Air and Water as Respiratory Media

- **Partial pressure:** the pressure of a particular gas in a mixture of gases.
- **Affects on Gas in Solution**
  - Solubility of the gas in water
  - Temperature of the water
  - Presence of other solutes
  - Partial pressure of the gas in contact with the water

- Affects on Oxygen in Solution

- Habitats with large numbers of photosynthetic organisms tend to be relatively oxygen rich.
- Water near the surface has much higher oxygen content than water near the bottom of the same habitat under nonmoving conditions.
- Shallow ponds and streams tend to be much better oxygenated than deep bodies of water because shallower bodies have a higher ratio of surface area to volume.
- Rapids, waterfalls, and breaking waves are the most highly oxygenated of all aquatic environments because a large surface area is exposed to the atmosphere as water splashes and because air bubbles are incorporated into the water.

## Organs of Gas Exchange

- **Fick's law of diffusion** the rate of diffusion of a gas depends on five parameters: the solubility of the gas in the aqueous film lining the gas exchange surface; the temperature; the surface area available for diffusion; the difference in partial pressures of the gas across the gas exchange surface; and the thickness of the barrier to diffusion
- **Operculum:** the stiff flap of tissue that covers the gills.
- **Gill filament:** long, thin structures that extend from each gill arch. Each gill filament is composed of hundreds or thousands of **gill lamellae**.
- **Tracheae (insect):** an extensive system of air-filled tubes that connect to the exterior spiracles.
- **Spiracles:** openings in the exoskeleton that can be closed to minimize the loss of water by evaporation.
- **Trachea (human):** a tube that carries the inhaled air to narrower tubes called **bronchi**, which branch into yet narrower tubes called **bronchioles**. All together these structures make up the lungs.
- **Lungs:** the internal organs that are used for gas exchange. Terrestrial vertebrates—amphibians, reptiles (including birds), and mammals—have lungs, as do certain fishes and invertebrates.
- **Alveoli:** tiny sacs that make up the lungs of mammals. Each human has approximately 150 million alveoli.
- **Positive pressure ventilation:** mechanism for pumping air used by frogs and other amphibians. Pushes air into lungs.
- **Negative pressure ventilation:** inverse of positive, pulling air into the lungs.
- **Diaphragm:** a thin muscular sheet responsible for the change in volume by creating a downward motion and an expansion of the ribcage.
- **Dead space:** air passages that are not lined by a respiratory surface.

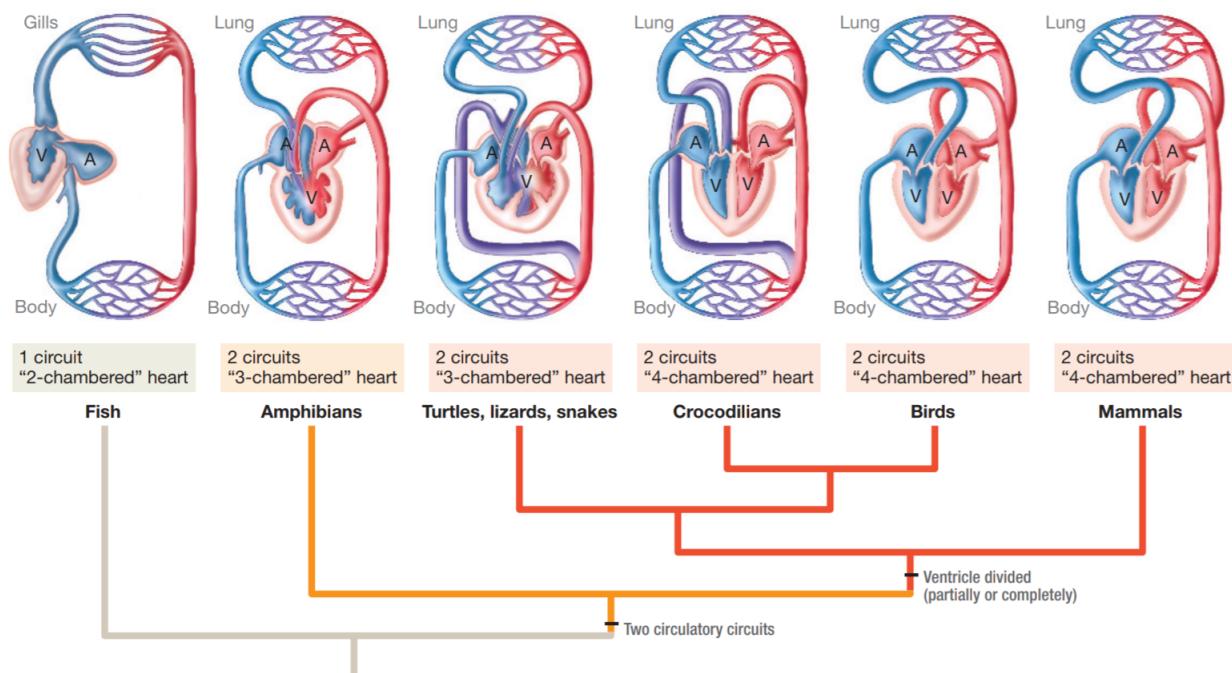
## How are Oxygen and Carbon Dioxide Transported in Blood?

- **Platelets:** cell fragments that act to minimize blood loss from ruptured blood vessels. They do so by releasing material that helps form the blockages known as clots
- **White blood cells:** part of the immune system. They fight infections.
- **Red blood cells:** transport oxygen from the lungs to tissues throughout the body.
- **Hemoglobin:** oxygen-carrying tetramer
- **Heme:** a nonprotein bound to the end of each chain on hemoglobin.
- **Oxygen–hemoglobin equilibrium curve:** a sigmoidal curve from the measurement of each successive oxygen molecule to a subunit of the hemoglobin molecule causes a conformational change in the protein that makes the remaining subunits much more likely to bind oxygen. The phenomenon is called **Cooperative binding**.
- **Bohr shift:** when the oxygen–hemoglobin equilibrium curve shifts to the right. This happens when pH declines or temperature increases.

## Circulation

- **Open circulatory system:** a fluid connective tissue called hemolymph is actively pumped throughout the body in a limited system of vessels.
- **Heart:** organ that pumps hemolymph into vessels that empty into open, fluid-filled spaces
- **Closed circulatory system:** blood flows in a continuous circuit through a series of vessels in the body, under pressure generated by a heart.
- **Arteries:** are tough, thick-walled vessels that take blood away from the heart. Small arteries are called arterioles.
- **Capillaries:** Capillaries are vessels whose walls are just one cell thick, allowing exchange of gases and other molecules between blood and tissues. Networks of capillaries are called capillary beds.
- **Veins:** Veins are thin-walled vessels that return blood to the heart. Small veins are called venules.
- **Aorta:** a large artery that blood is injected into by the heart.
- **Valves:** thin flaps of tissue that prevent any backflow of blood.
- **Lymphatic system:** a collection of thin-walled, branching tubules called lymphatic vessels that permeate all tissues
- **Lymph:** interstitial fluid that enters the lymphatic ducts.
- **Atrium:** thin-walled chamber that receives blood.
- **Ventricle:** thick-walled chamber that generates force to push blood.

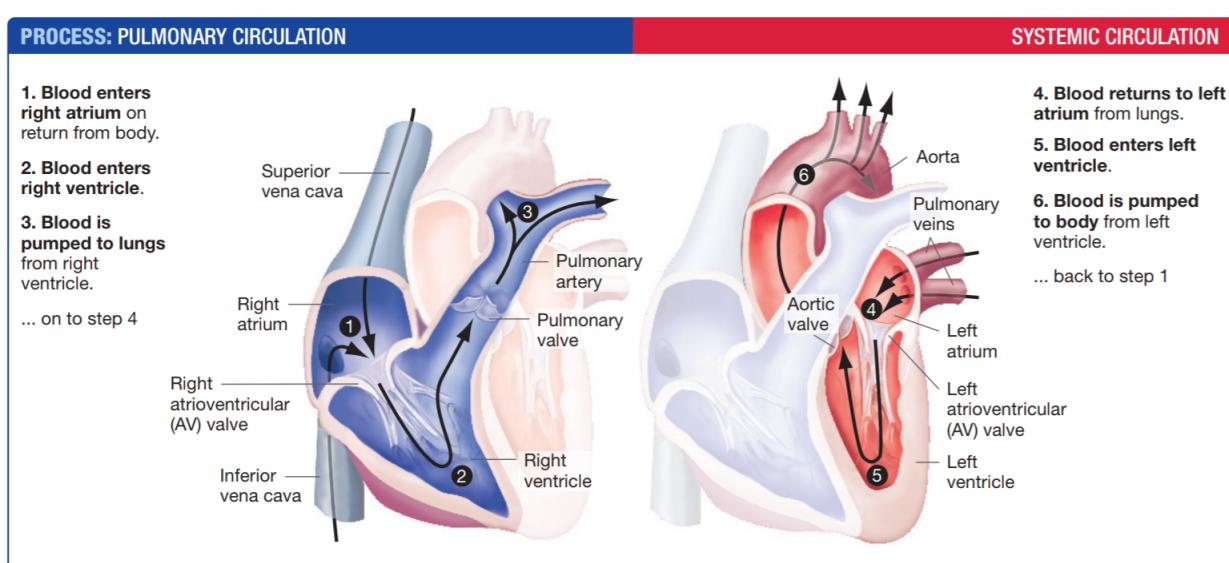
- **Pulmonary artery:** carries blood to the lungs.
- **Pulmonary veins:** return freshly oxygenated blood to the heart.
- **Pulmonary circuit:** takes blood to the lungs and gills.
- **Systemic circuit:** takes blood to the body.



**Figure 42.23** As Vertebrate Circulatory Systems Evolved, the Number of Atria and Ventricles Increased.

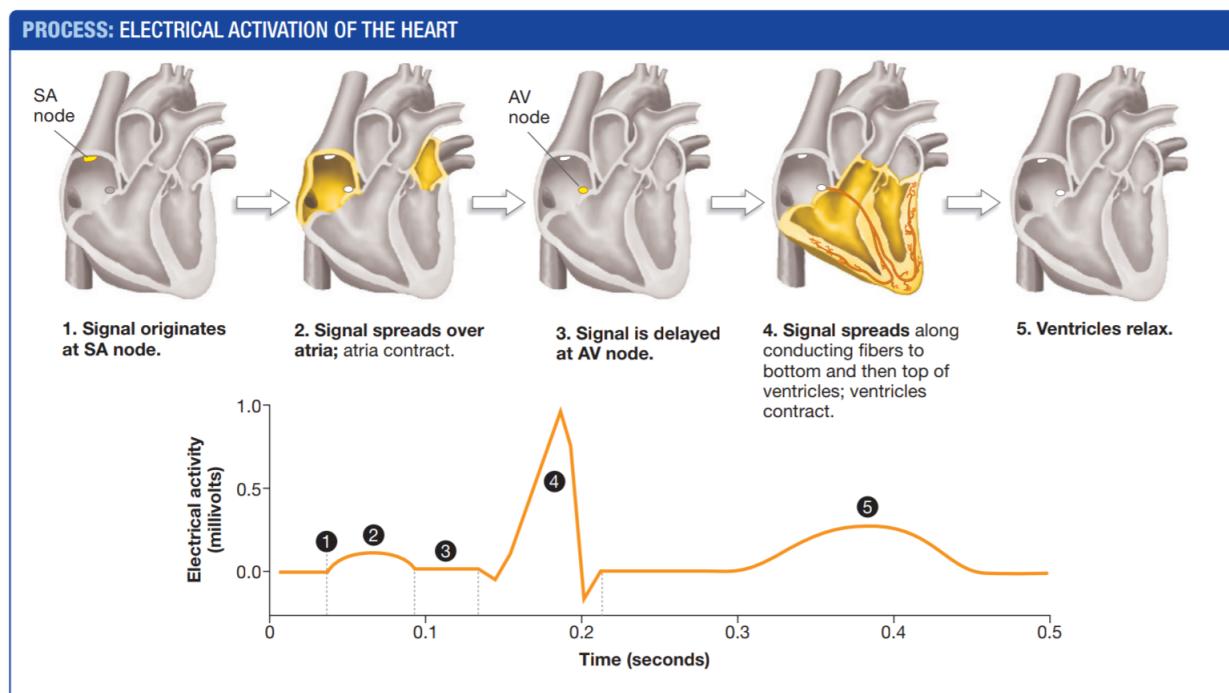
"A" denotes the atria—chambers that receive blood coming into the heart from the body and the gills or lungs.  
"V" denotes the ventricles—chambers that pump blood out to the gills or lungs and the body.

- **Venae cavae:** two large veins, called the inferior (lower) and superior (upper) venae cavae. Blood low in oxygen returns to the heart via these veins.



**Figure 42.24** The Human Heart Maintains Separation of Oxygenated and Deoxygenated Blood.  
Blood flows through the chambers in the sequence shown.

- **Heart murmur:** backflow that reduces the heart's efficiency.
- **Pacemaker cells:** initiate contraction in the vertebrate heart.
- **Sinoatrial (SA) node:** region of the right atrium.
- **Intercalated discs:** connects cardiac muscle cells by joining end to end with other branching cardiac muscle cells.
- **Electrocardiogram**



**Figure 42.26 Sequential Electrical Activation Leads to Coordinated Contraction of the Human Heart.**  
The rate and strength of contractions control the pressure in the heart chambers and arteries.

- **Systole:** the contraction phases of the atria.
- **Diastole:** the relaxation phases of the atria.
- **Cardiac cycle:** consists of one diastole and one systole for both atria and ventricles.
- **Systolic blood pressure:** blood pressure measured in the systemic arterial circulation at the peak of ventricular ejection into the aorta.
- **Diastolic blood pressure:** blood pressure measured just before ventricular ejection is called the
- **Hypertension:** people with blood pressures consistently higher than 140/90 mm Hg.
- **Baroreceptors:** pressure-sensing receptors that detect changes in blood pressure.
- **Arteriosclerosis:** a condition where blood vessels harden and lose elasticity.
- **Myocardial infarction:** arteries that deliver blood to the heart muscle become completely blocked, causing heart attack.

## Chapter 42: Review

### The Respiratory and Circulatory System

- Animal gas exchange involves ventilation, exchange of gases between the environment and the blood, and exchange of gases between blood and tissues.
- Animal circulation involves transportation of gases, nutrients, wastes, and other substances throughout the body.

### Air and Water as Respiratory Media

- As media for exchanging oxygen and carbon dioxide, air and water are dramatically different.
- Compared with water, air contains much more oxygen and is much less dense and viscous. As a result, terrestrial animals have to process a much smaller volume of air to extract the same amount of O<sub>2</sub>, and the amount of work required to do so is less than in aquatic animals.
- Both terrestrial and aquatic animals pay a price for exchanging gases: Land-dwellers lose water to evaporation; freshwater animals lose ions and gain excess water; marine animals gain ions and lose water.

### Organs of Gas Exchange

- The structure of gills, tracheae, lungs, and other gas exchange organs minimizes the cost of ventilation while maximizing the diffusion rates of O<sub>2</sub> and CO<sub>2</sub>.
- Consistent with predictions made by Fick's law of diffusion, respiratory epithelia tend to be extremely thin and to be folded to increase surface area.
- In fish gills, countercurrent exchange ensures that the differences in O<sub>2</sub> and CO<sub>2</sub> partial pressures between water and blood are favorable for gas exchange over the entire length of the ventilatory surface.
- Insect tracheae carry air directly to and from tissues.
- In bird lungs, structural adaptations lead to a high ratio of useful ventilatory space to dead space.
- Breathing rate is regulated to keep the carbon dioxide content of the blood stable during rest and exercise.

### How are Oxygen and Carbon Dioxide Transported in Blood?

- The tendency of hemoglobin to give up oxygen varies as a function of the PO<sub>2</sub> in surrounding tissue in a sigmoidal fashion. As a result, a relatively small change in tissue PO<sub>2</sub> causes a large change in the amount of oxygen released from hemoglobin.
- Oxygen binds less tightly to hemoglobin when pH is low. Because CO<sub>2</sub> reacts with water to form carbonic acid, the existence of high CO<sub>2</sub> partial pressures in exercising muscle tissues lowers their pH and makes oxygen less likely to stay bound to hemoglobin and more likely to be unloaded into tissues.

- The CO<sub>2</sub> that diffuses into red blood cells from tissues is rapidly converted to carbonic acid by the enzyme carbonic anhydrase. The protons that are released as carbonic acid dissociates bind to deoxygenated hemoglobin. In this way, hemoglobin acts as a buffer that takes protons out of solution and prevents large fluctuations in blood pH.

## Circulation

- In many animals, blood or hemolymph moves through the body via a circulatory system consisting of a pump (heart) and vessels.
- In open circulatory systems, overall pressure is low and tissues are bathed directly in hemolymph.
- In closed circulatory systems, blood is contained in vessels that form a continuous circuit. Containment of blood allows higher pressures and flow rates, as well as the ability to direct blood flow accurately to tissues that need it the most.
- In organisms with a closed circulatory system, a lymphatic system collects excess fluid that leaks from the capillaries and returns it to the circulation.
- In amphibians and some reptiles, blood from the pulmonary and systemic circuits may be mixed in the single ventricle.
- In mammals and birds, a four-chambered heart pumps blood into two circuits, which separately serve the lungs and the rest of the body. Crocodilians have a similar heart with a bypass vessel that can shunt blood from the pulmonary to the systemic circuit.
- In vertebrates, the cardiac cycle is controlled by electrical signals that originate in the heart itself.
- Heart rate, cardiac output, and constriction of both arterioles and veins are regulated by chemical signals and by electrical signals from the brain.
- Cardiovascular disease is the leading cause of death in humans.

## Chapter 43:Nervous System

1. Principles of Electric Signaling
2. Dissecting Action Potential
3. The Synapse
4. The Vertebrate Nervous System
  - Review

### Principles of Electric Signaling

- Nerve net
- Central nervous system (CNS)
- Sensory neurons
- Interneurons
- Motor neurons
- Nerves
- Peripheral nervous system
- Reflex
- Cell body
- Dendrites
- Axons
- Electrical potential
- Membrane Potential
- Resting potential
- Ion channel
- Leak channels
- Equilibrium potential
- Action potential
- Three-Phase Signal
  - Depolarization

- Repolarization
- Hyperpolarization
- Excitable membranes

## Dissecting Action Potential

- Voltage-gated channels
- Voltage clamping
- Patch clamping
- Neurotoxins
- Action potential propagation
- Refractory state
- Oligodendrocytes
- Schwann cells
- Glia
- Schwann cells
- Glia
- Myelin sheath
- Node of Ranvier
- Multiple sclerosis (MS)

## The Synapse

- Synapses
- Neurotransmitters
- Synaptic cleft
- Synaptic vesicles
- Presynaptic neuron
- Postsynaptic cell
- Ligand-gated channels
- Second messengers

- Excitatory postsynaptic potentials (EPSPs)
- Inhibitory postsynaptic potentials (IPSPs)
- Summation
- Axon hillock

## The Vertebrate Nervous System

- Afferent division
- Efferent division
- Somatic nervous system
- Autonomic nervous system
  - Parasympathetic nervous system
  - Sympathetic nervous system
- Enteric nervous system
- General Anatomy of the Human Brain
  - Cerebrum
  - Cerebellum
  - Diencephalon
  - Brain stem
  - Frontal lobe
  - Parietal lobe
  - Occipital lobe
  - Temporal lobe
  - Corpus callosum
  - Hippocampus
- Optogenetics
- Synaptic plasticity
- Neurogenesis

### Chapter 43: Review

#### Principles of Electric Signaling

- Most neurons have a cell body, multiple short dendrites that receive signals from other cells, and a single axon that transmits electrical signals to other neurons or to effector cells in glands or muscles.
- Studies of the squid giant axon established that neurons have a resting potential maintained by the sodium–potassium pump and potassium leak channels. When  $\text{Na}^+/\text{K}^+$ -ATPase hydrolyzes ATP, it transports 3  $\text{Na}^+$  out of the cell and 2  $\text{K}^+$  in.

#### Dissecting Action Potential

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#### The Synapse

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#### The Vertebrate Nervous System

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