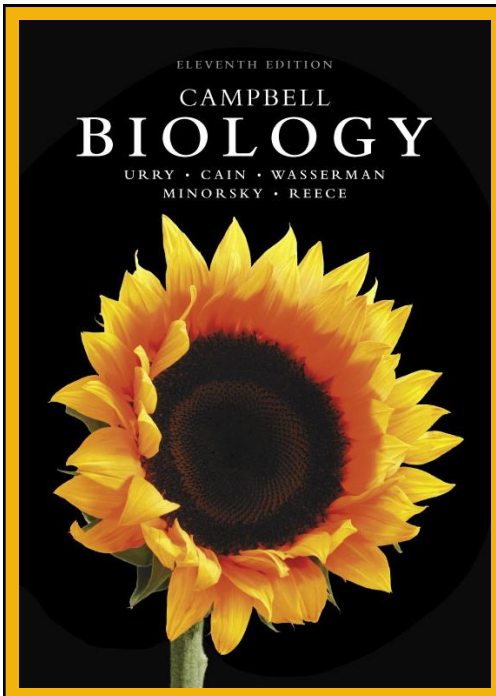

Chapter 42

Circulation and Gas Exchange

Lecture Presentations by
Nicole Tunbridge and
Kathleen Fitzpatrick

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Trading Places

- Every organism must exchange substances with its environment
- Exchanges ultimately occur at the cellular level by crossing the plasma membrane
- In unicellular organisms, these exchanges occur directly with the environment
- For most cells of multicellular organisms, direct exchange with the environment is not possible

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- *Gills* are an example of a specialized exchange system in animals
  - O_2 diffuses from the water into blood vessels
  - CO_2 diffuses from blood into the water
- Internal transport and gas exchange are functionally related in most animals

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Concept 42.1: Circulatory systems link exchange surfaces with cells throughout the body

- Small molecules can move between cells and their surroundings by **diffusion**
- Diffusion is only efficient over small distances because the *time it takes to diffuse is proportional to the square of the distance*
- In some animals, many or all cells are in direct contact with the environment
- In most animals, cells exchange materials with the environment via *a fluid-filled circulatory system*

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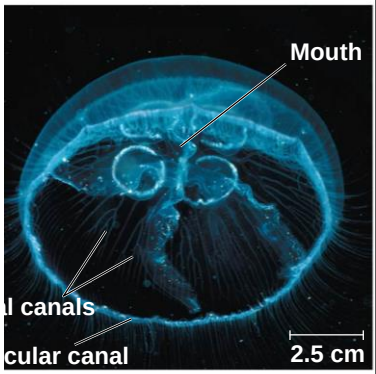
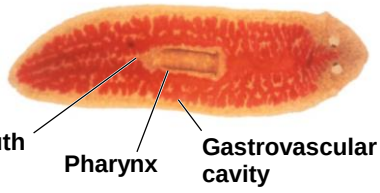
Gastrovascular Cavities

- Some animals do not have a circulatory system
- Some cnidarians (لواسع) have elaborate gastrovascular cavities that function in both digestion and distribution of substances
- The body wall that encloses the gastrovascular cavity is only two cells thick
- Flatworms have a gastro-vascular cavity and a flat body that minimizes diffusion distances



(a) The moon jelly *Aurelia*, a cnidarian



(b) The planarian *Dugesia*, a flatworm

Open and Closed Circulatory Systems

- A circulatory system has
  - *A circulatory fluid*
  - *A set of interconnecting vessels*
  - *A muscular pump, the* ***heart***
- The circulatory system connects the fluid that surrounds cells with the organs that exchange gases, absorb nutrients, and dispose of wastes
- Circulatory systems can be *open* or *closed*

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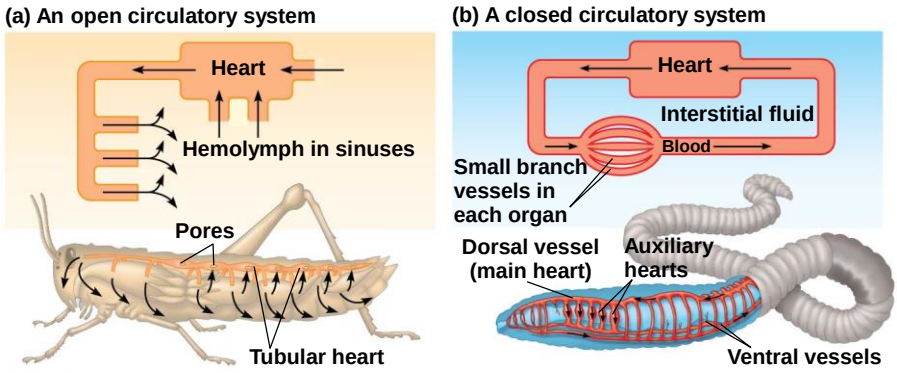
- In insects, other arthropods, and some molluscs, circulatory fluid called **hemolymph** bathes the organs directly in an **open circulatory system**
- In a **closed circulatory system**, **blood** is confined to vessels and is distinct from the interstitial fluid
- Vertebrates have closed circulatory systems



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Organization of Vertebrate Circulatory Systems

- Humans and other vertebrates have a closed circulatory system called the **cardiovascular system**
- The three main types of blood vessels are *arteries*, *veins*, and *capillaries*
- Blood flow is *one way in these vessels*

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- **Arteries** الشرايين branch into **arterioles** and carry blood away from the heart to **capillaries**
- Networks of capillaries called **capillary beds** are the sites of chemical exchange between the blood and interstitial fluid
- **Venules** converge into **veins** الأوردة and return blood from capillaries to the heart
- *Arteries and veins are distinguished by the direction of blood flow, not by O_2 content*
- Vertebrate hearts contain two or more chambers
- Blood enters through an **atria** and is pumped out through **ventricles**

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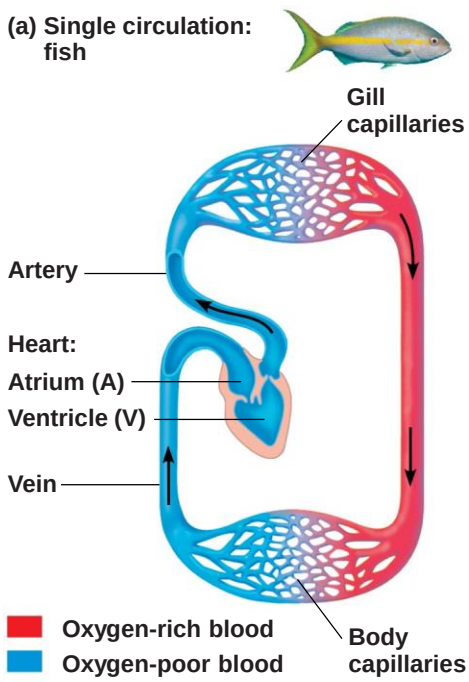
Single Circulation

- Bony fishes, rays, and sharks have single circulation with a two-chambered heart
- In **single circulation**, blood leaving the heart passes through two capillary beds before returning



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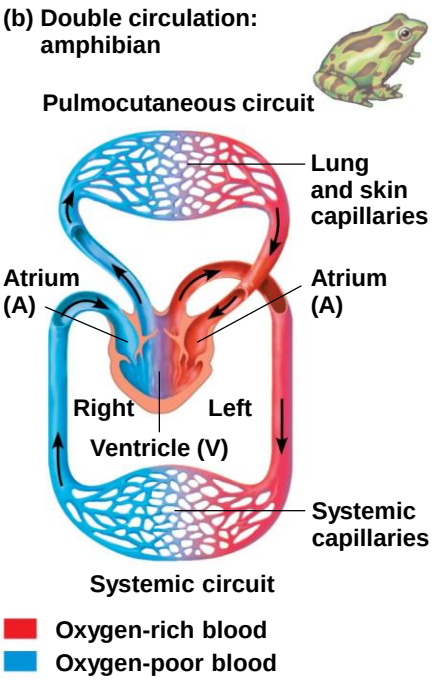
Double Circulation

- Amphibians, reptiles, and mammals have **double circulation**
- Oxygen-poor and oxygen-rich blood are pumped separately from the right and left sides of the heart



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- In reptiles and mammals, oxygen-poor blood flows through the pulmonary circuit to pick up oxygen through the lungs
- In amphibians, oxygen-poor blood flows through a pulmocutaneous circuit to pick up oxygen through the lungs and skin
- Oxygen-rich blood delivers oxygen through the systemic circuit

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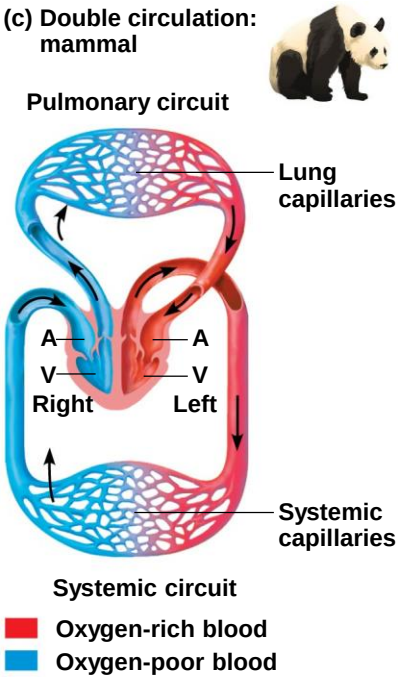
Figure 42.4c



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Concept 42.2: Coordinated cycles of heart contraction drive double circulation in mammals

- The mammalian cardiovascular system meets the body's continuous demand for O_2

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Mammalian Circulation

- Contraction of the right ventricle pumps blood to the lungs via the pulmonary arteries
- The blood flows through capillary beds in the left and right lungs and loads O_2 and unloads CO_2
- Oxygen-rich blood returns from the lungs via the pulmonary veins to the left atrium of the heart

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- Oxygen-rich blood flows into the left ventricle and is pumped out to body tissues via the systemic circuit
- Blood leaves the left ventricle via the aorta, which conveys blood to arteries leading throughout the body
- The first branches are the coronary arteries, supplying the heart muscle

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- Further branches lead to capillary beds in the abdominal organs and hind limbs
- O_2 diffuses from blood to tissues, and CO_2 diffuses from tissues to blood
- Capillaries rejoin, forming venules, conveying blood to veins
- Oxygen-poor blood from the head, neck, and forelimbs is channeled into the superior vena cava

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- The inferior vena cava drains blood from the trunk and hind limbs
- The two venae cavae empty their blood into the right atrium from which the oxygen-poor blood flows into the right ventricle

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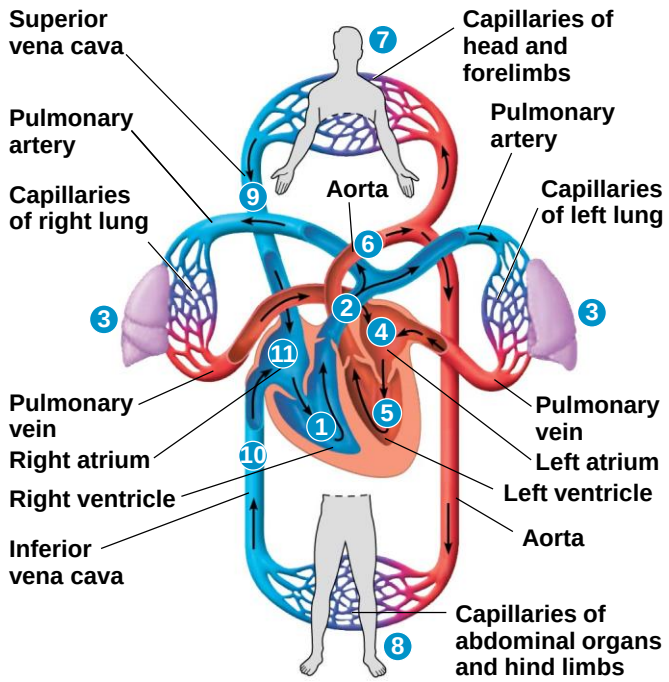
Figure 42.5



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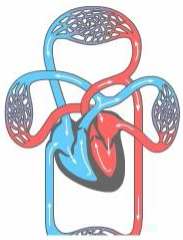
Animation: Path of Blood Flow in Mammals



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The Mammalian Heart: *A Closer Look*

- The human heart is about the size of a clenched fist and consists mainly of cardiac muscle
- The two atria have relatively thin walls and serve as collection chambers for blood returning to the heart
- The ventricles have thicker walls and contract much more forcefully

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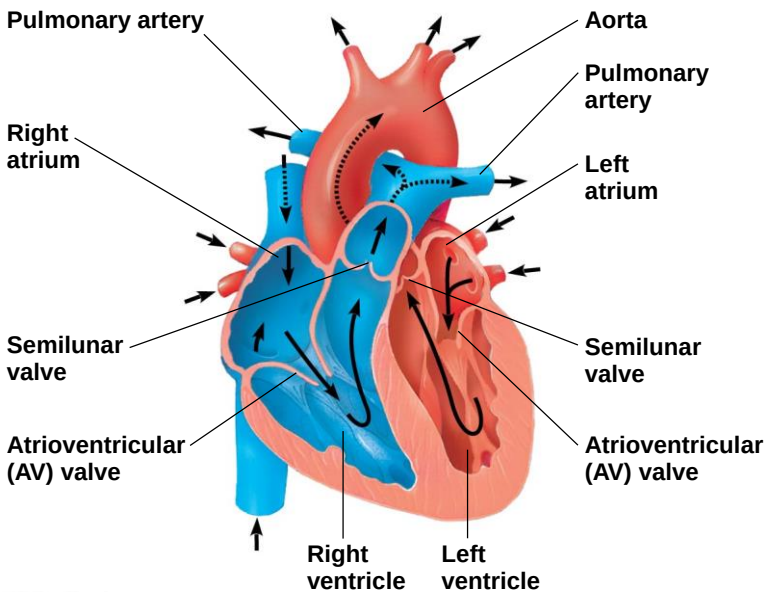
Figure 42.6



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- The heart contracts and relaxes in a rhythmic cycle called the **cardiac cycle**
- The contraction, or pumping, phase is called **systole**
- The relaxation, or filling, phase is called **diastole**

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Figure 42.7_1

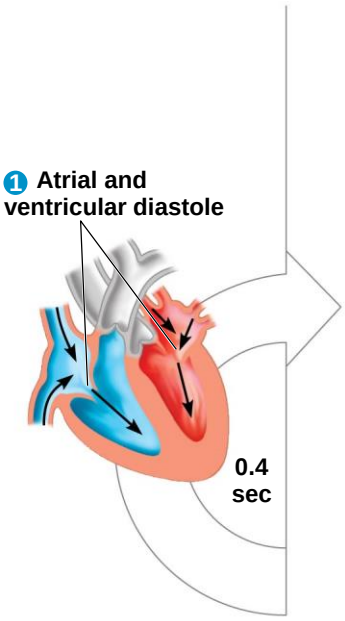

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Figure 42.7_2

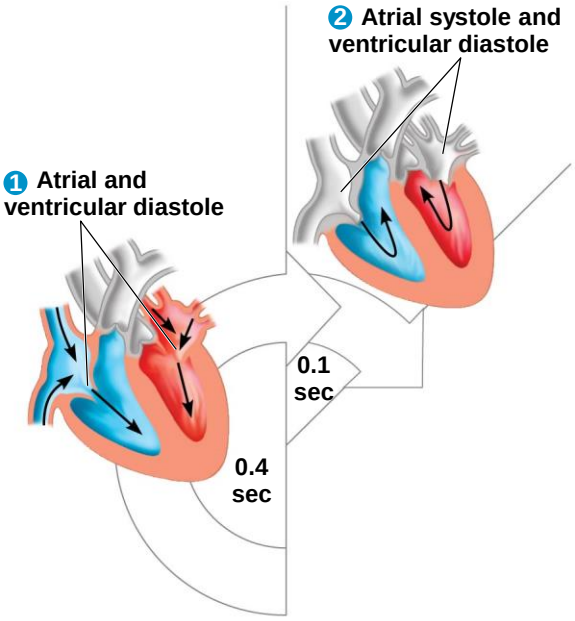

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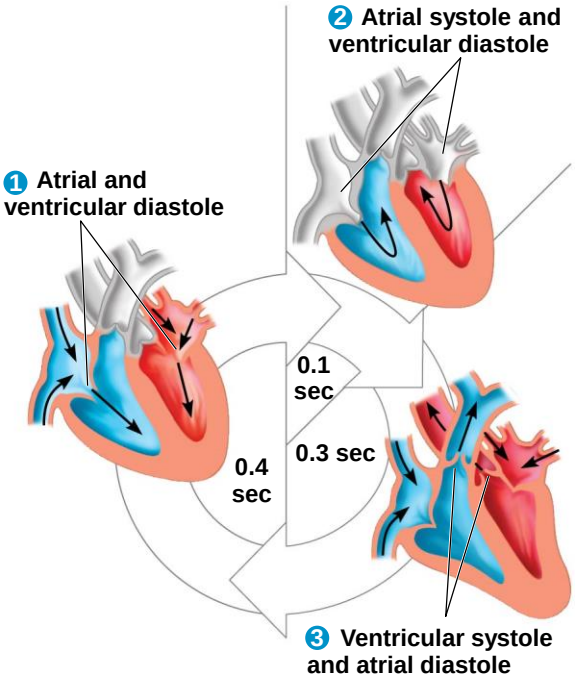
Figure 42.7_3



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- The **cardiac output** is the volume of blood pumped into the systemic circulation per minute and depends on both the heart rate and stroke volume
- The **heart rate** is the number of beats per minute
- The **stroke volume** is the amount of blood pumped in a single contraction

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- Four valves prevent backflow of blood in the heart
- The **atrioventricular (AV) valves** separate each atrium and ventricle
- The **semilunar valves** control blood flow to the aorta and the pulmonary artery
- The “lub-dup” sound of a heart beat is caused by the recoil of blood against the AV valves (lub) then against the semilunar (dup) valves
- Backflow of blood through a defective valve causes a **heart murmur** نفخة قلبية

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Maintaining the Heart's Rhythmic Beat

- Some cardiac muscle cells are autorhythmic, meaning they contract without any signal from the nervous system
- The **sinoatrial (SA) node**, or *pacemaker*, sets the rate and timing at which cardiac muscle cells contract
- Impulses that travel during the cardiac cycle can be recorded as an **electrocardiogram (ECG** or **EKG)**
- Impulses from the SA node travel to the **atrioventricular (AV) node**
- Here, the impulses are delayed and then travel to the Purkinje fibers that make the ventricles contract

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Figure 42.8_1

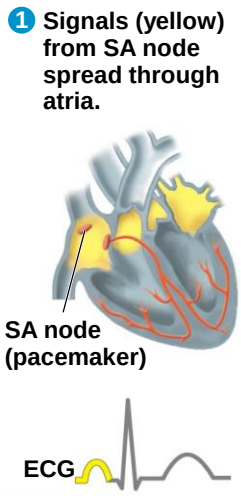

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Figure 42.8_2

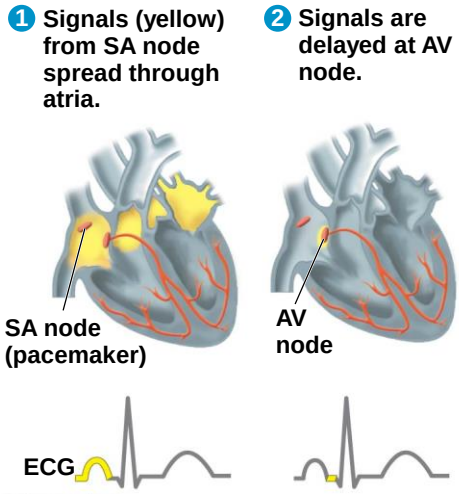

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Figure 42.8_3

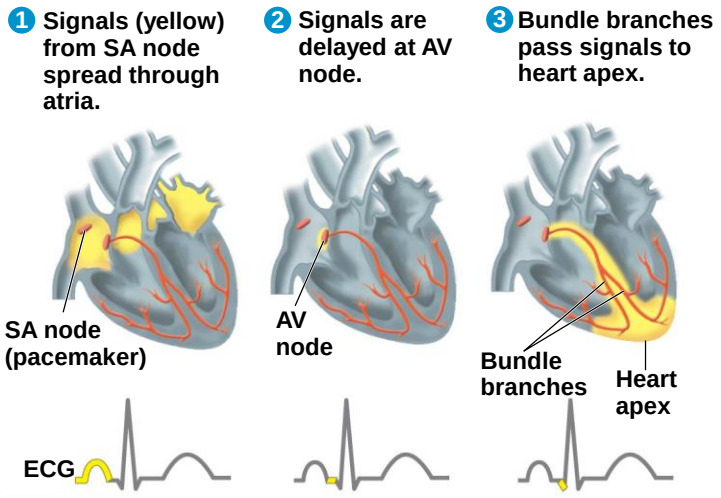

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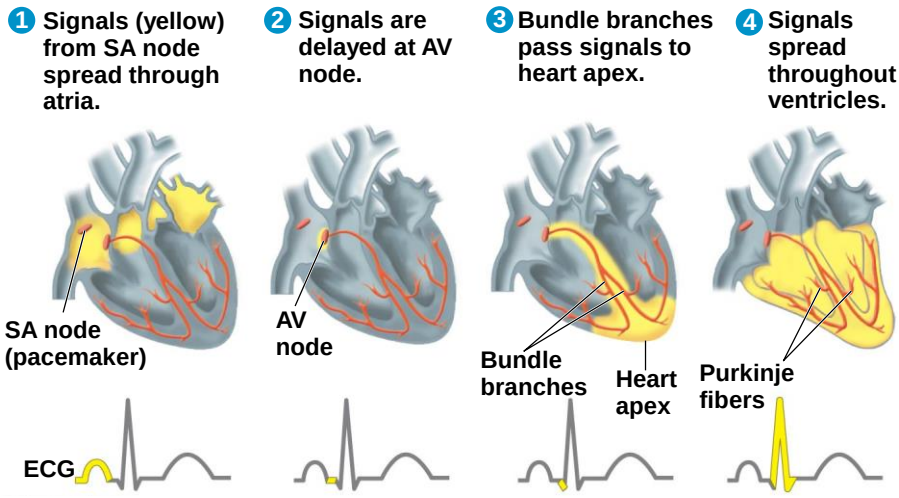
Figure 42.8_4



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Concept 42.3: Patterns of blood pressure and flow reflect the structure and arrangement of blood vessels

- The vertebrate circulatory system relies on blood vessels that exhibit a close match of structure and function

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Blood Vessel Structure and Function

- All blood vessels contain a central lumen lined with an epithelial layer that lines blood vessels
- This **endothelium** is smooth and minimizes resistance
- Capillaries are only slightly wider than a red blood cell
- Capillaries have thin walls, the endothelium plus its basal lamina, to facilitate the exchange of materials

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- Arteries and veins have an endothelium, smooth muscle, and connective tissue
- Arteries have thick, elastic walls to accommodate the high pressure of blood pumped from the heart
- In the thinner-walled veins, blood flows back to the heart mainly as a result of muscle action
- Unlike arteries, veins contain valves to maintain unidirectional blood flow

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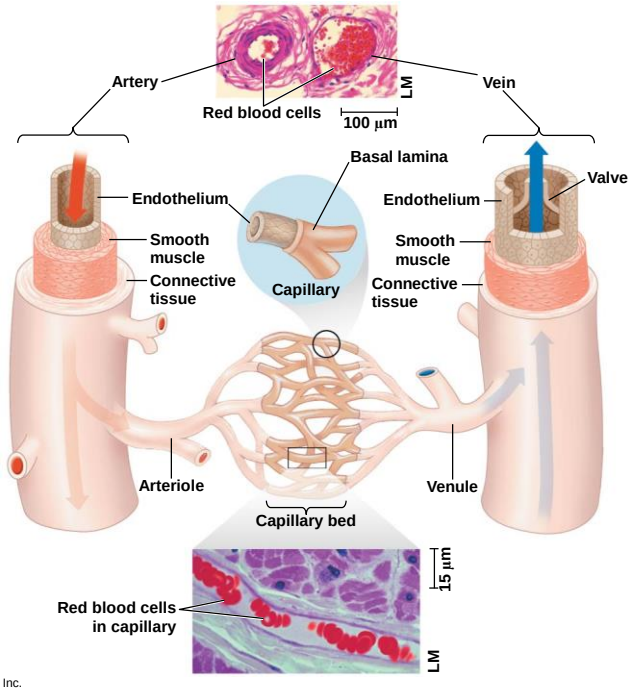
Figure 42.9



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Blood Flow Velocity

- Physical laws governing movement of fluids through pipes affect blood flow and blood pressure
- Velocity of blood flow is slowest in the capillary beds as a result of the high resistance and large total cross-sectional area
- Blood flow in capillaries is necessarily slow for exchange of materials

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Blood Pressure

- Blood flows from areas of higher pressure to areas of lower pressure
- Blood pressure is a force exerted in all directions, including against the walls of blood vessels
- The recoil of elastic arterial walls plays a role in maintaining blood pressure
- The resistance to blood flow in the narrow diameters of tiny capillaries and arterioles dissipates much of the pressure

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Changes in Blood Pressure During the Cardiac Cycle

- **Systolic pressure** is the pressure in the arteries during ventricular systole; it is the highest pressure in the arteries
- A **pulse** is the rhythmic bulging of artery walls with each heartbeat
- **Diastolic pressure** is the pressure in the arteries during diastole; it is lower than systolic pressure

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Regulation of Blood Pressure

- Homeostatic mechanisms regulate arterial blood pressure by altering the diameter of arterioles
- **Vasoconstriction** is the contraction of smooth muscle in arteriole walls; it increases blood pressure
- **Vasodilation** is the relaxation of smooth muscles in the arterioles; it causes blood pressure to fall

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Blood Pressure and Gravity

- Blood pressure is generally measured for an artery in the arm at the same height as the heart
- Blood pressure for a healthy 20-year-old human at rest is about 120 mm Hg at systole and 70 mm Hg at diastole
- Gravity has a significant effect on blood pressure

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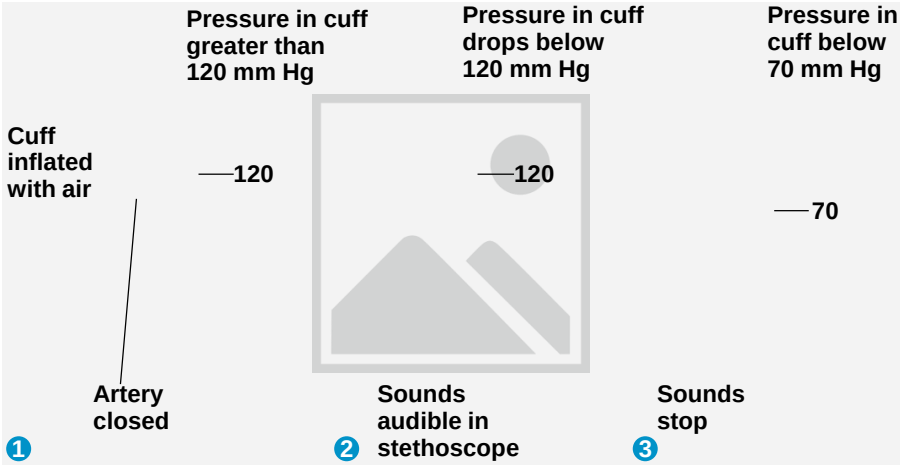
Figure 42.11



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- Fainting is caused by inadequate blood flow to the head
- Animals with long necks require a very high systolic pressure to pump blood a great distance against gravity
- Because blood pressure is low in veins, one-way valves in veins prevent backflow of blood
- Return of blood is also enhanced by contraction of smooth muscle in venule walls and skeletal muscle contraction

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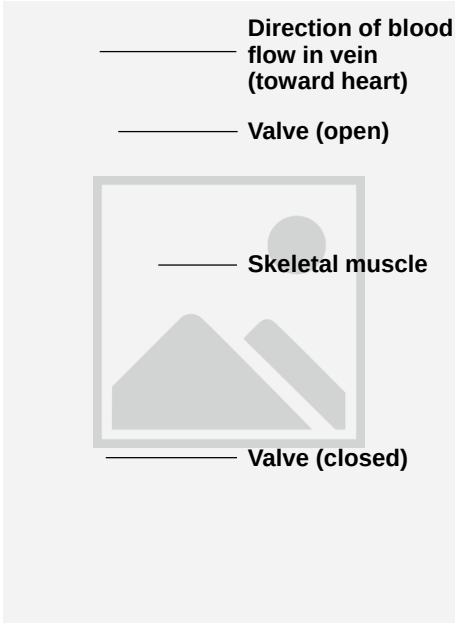
Figure 42.12



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Capillary Function

- Blood flows through only 5–10% of the body's capillaries at any given time
- Capillaries in major organs are usually filled to capacity
- Blood supply varies in many other sites

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- Two mechanisms regulate distribution of blood in capillary beds
  - Constriction or dilation of arterioles that supply capillary beds
  - Precapillary sphincters that control flow of blood between arterioles and venules
- Blood flow is regulated by nerve impulses, hormones, and other chemicals

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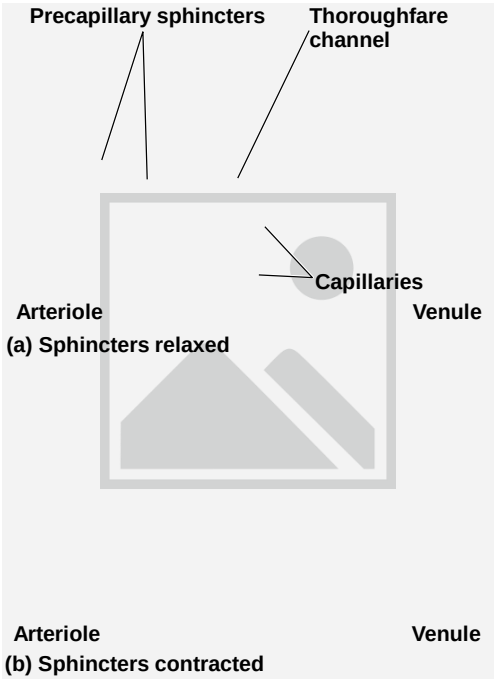
Figure 42.13



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- The exchange of substances between the blood and interstitial fluid takes place across the thin endothelial walls of the capillaries
- Blood pressure tends to drive fluid out of capillaries, and blood proteins tend to pull fluid back
- These proteins are responsible for much of the blood's osmotic pressure
- On average, there is a net loss of fluid from capillaries

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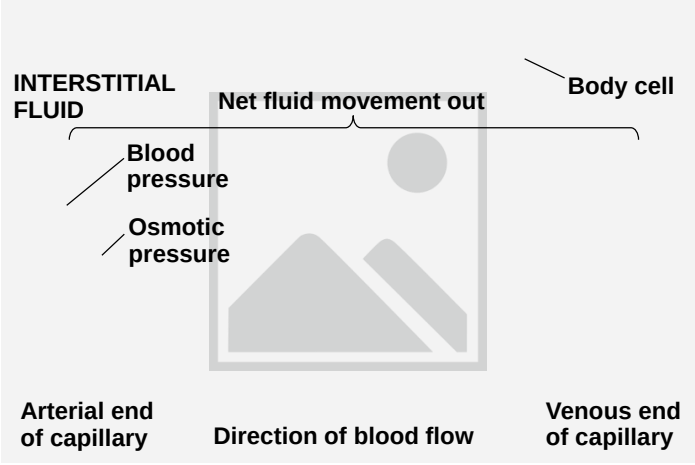
Figure 42.14



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Fluid Return by the Lymphatic System

- The **lymphatic system** returns fluid that leaks out from the capillary beds
- Fluid lost by capillaries is called **lymph**
- The lymphatic system drains into veins in the neck
- Valves in lymph vessels prevent the backflow of fluid

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- Edema is swelling caused by disruptions in the flow of lymph
- **Lymph nodes** are organs that filter lymph and play an important role in the body's defense
- When the body is fighting an infection, lymph nodes become swollen and tender

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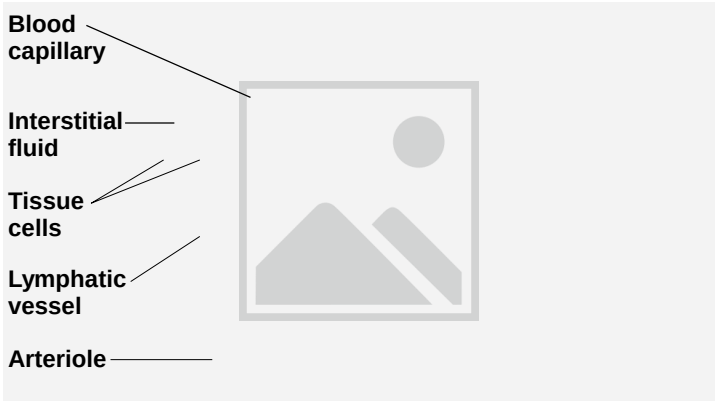
Figure 42.15



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Concept 42.4: Blood components function in exchange, transport, and defense

- With open circulation, the fluid is continuous with the fluid surrounding all body cells
- The closed circulatory systems of vertebrates contain a more highly specialized fluid called blood

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Blood Composition and Function

- Blood in vertebrates is a connective tissue consisting of several kinds of cells suspended in a liquid matrix called **plasma**
- Cells and cell fragments occupy about 45% of the volume of blood

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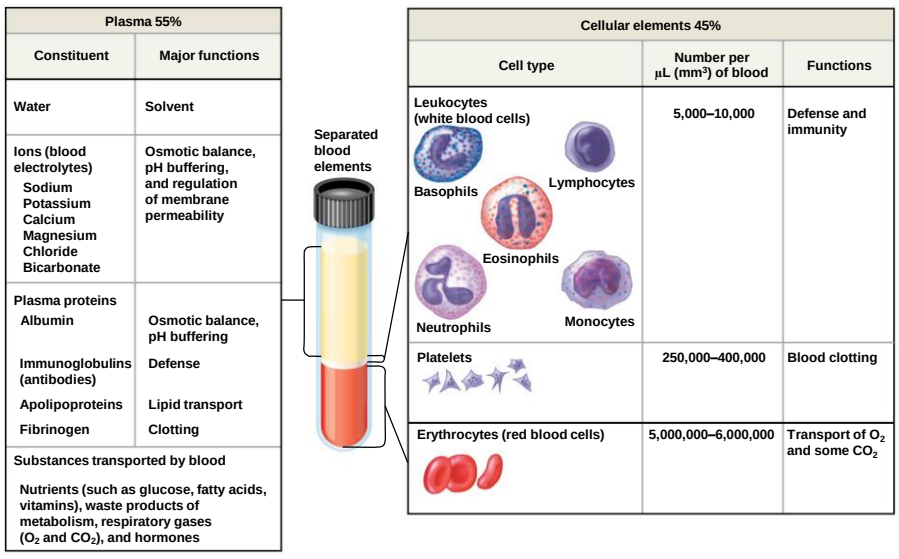
Figure 42.16



Plasma 55%

Constituent	Major functions
Water	Solvent
Ions (blood electrolytes) Sodium Potassium Calcium Magnesium Chloride Bicarbonate	Osmotic balance, pH buffering, and regulation of membrane permeability
Plasma proteins	
Albumin	Osmotic balance, pH buffering
Immunoglobulins (antibodies)	Defense
Apolipoproteins	Lipid transport
Fibrinogen	Clotting
Substances transported by blood	
Nutrients (such as glucose, fatty acids, vitamins), waste products of metabolism, respiratory gases (O_2 and CO_2), and hormones	

Separated blood elements

Cellular elements 45%

Cell type	Number per μL (mm^3) of blood	Functions
Leukocytes (white blood cells) Basophils Lymphocytes Eosinophils Neutrophils Monocytes	5,000–10,000	Defense and immunity
Platelets	250,000–400,000	Blood clotting
Erythrocytes (red blood cells)	5,000,000–6,000,000	Transport of O_2 and some CO_2

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Plasma

- Plasma contains inorganic salts as dissolved ions, sometimes called electrolytes
- Plasma proteins influence blood pH and help maintain osmotic balance between blood and interstitial fluid
- Certain plasma proteins function in lipid transport, immunity, and blood clotting
- Plasma is similar in composition to interstitial fluid, but plasma has a much higher protein concentration

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Cellular Elements

- Suspended in blood plasma are two types of cells:
  - Red blood cells (erythrocytes) transport O_2
  - White blood cells (leukocytes) function in defense
- **Platelets** are fragments of cells that are involved in clotting

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Erythrocytes

- Red blood cells, or **erythrocytes**, are the most numerous blood cells
- They contain **hemoglobin**, the iron-containing protein that transports O_2
- Each molecule of hemoglobin binds up to four molecules of O_2
- In mammals, mature erythrocytes lack nuclei and mitochondria

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Leukocytes

- There are five major types of white blood cells, or **leukocytes**
- They function in defense either by phagocytizing bacteria and debris or by mounting immune responses against foreign substances
- They are found both in and outside of the circulatory system

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Blood Clotting

- Coagulation is the formation of a solid clot from liquid blood
- A cascade of complex reactions converts inactive fibrinogen to fibrin, forming a clot
- A blood clot formed within a blood vessel is called a **thrombus** and can block blood flow

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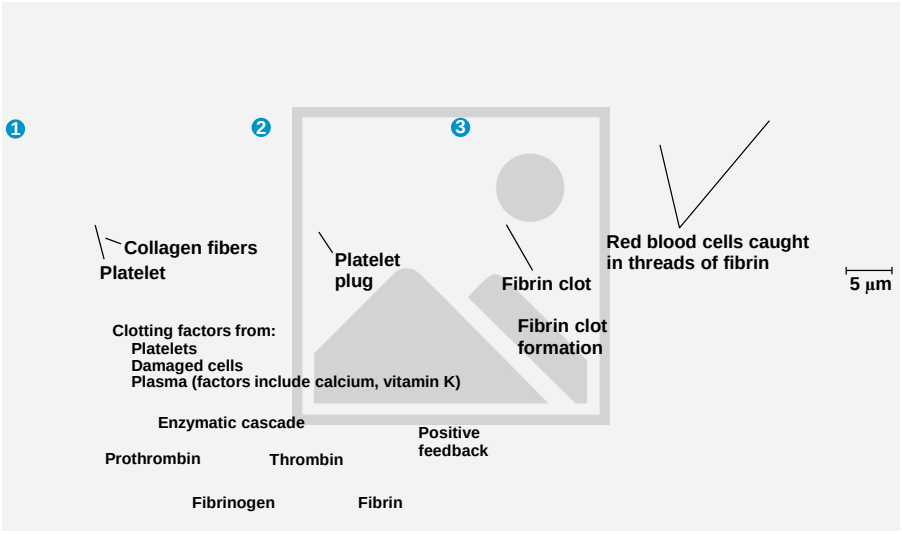
Figure 42.18



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Cardiovascular Disease

- Cardiovascular diseases are disorders of the heart and the blood vessels
- These diseases range in seriousness from minor disturbances of vein or heart function to life-threatening disruptions of blood flow to the heart or brain

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Atherosclerosis, Heart Attacks, and Stroke

- One type of cardiovascular disease, **atherosclerosis**, is caused by the buildup of fatty deposits (plaque) within arteries
- Cholesterol is a key player in the development of atherosclerosis

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- **Low-density lipoprotein (LDL)** delivers cholesterol to cells for membrane production
- **High-density lipoprotein (HDL)** scavenges excess cholesterol for return to the liver
- Risk for heart disease increases with a high LDL to HDL ratio
- Inflammation is also a factor in cardiovascular disease

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Figure 42.19

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- A **heart attack**, or myocardial infarction, is the damage or death of cardiac muscle tissue resulting from blockage of one or more coronary arteries
- A **stroke** is the death of nervous tissue in the brain, usually resulting from rupture or blockage of arteries in the head
- Angina pectoris is chest pain caused by partial blockage of the coronary arteries

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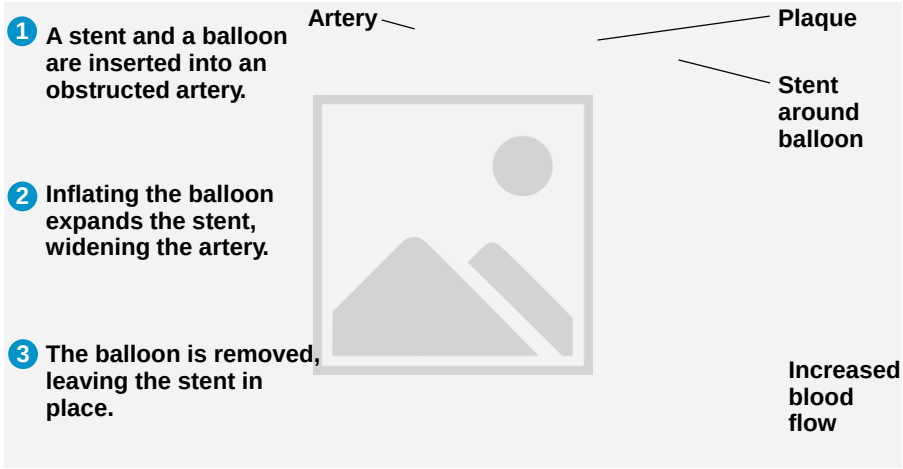
Figure 42.20



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- Inflammation plays a role in atherosclerosis and thrombus formation
- Aspirin inhibits inflammation and reduces the risk of heart attacks and stroke
- **Hypertension**, or high blood pressure, also contributes to heart attack and stroke, as well as other health problems
- Hypertension can be controlled by dietary changes, exercise, and/or medication

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Concept 42.5: Gas exchange occurs across specialized respiratory surfaces

- **Gas exchange** is the uptake of O_2 from the environment and the discharge of CO_2 to the environment

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Partial Pressure Gradients in Gas Exchange

- **Partial pressure** is the pressure exerted by a particular gas in a mixture of gases
- Partial pressures also apply to gases dissolved in liquids such as water
- O_2 is much less soluble in water than in air

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Respiratory Media

- Breathing air is relatively easy and need not be very efficient
- In a given volume, there is less O_2 available in water than in air
- Obtaining O_2 from water requires greater efficiency than air breathing

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Respiratory Surfaces

- Gas exchange across respiratory surfaces takes place by diffusion
- Respiratory surfaces vary by animal and can include the skin, gills, tracheae, and lungs

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Gills in Aquatic Animals

- Gills are outfoldings of the body that create a large surface area for gas exchange
- **Ventilation** moves the respiratory medium over the respiratory surface
- Aquatic animals move through water or move water over their gills for ventilation

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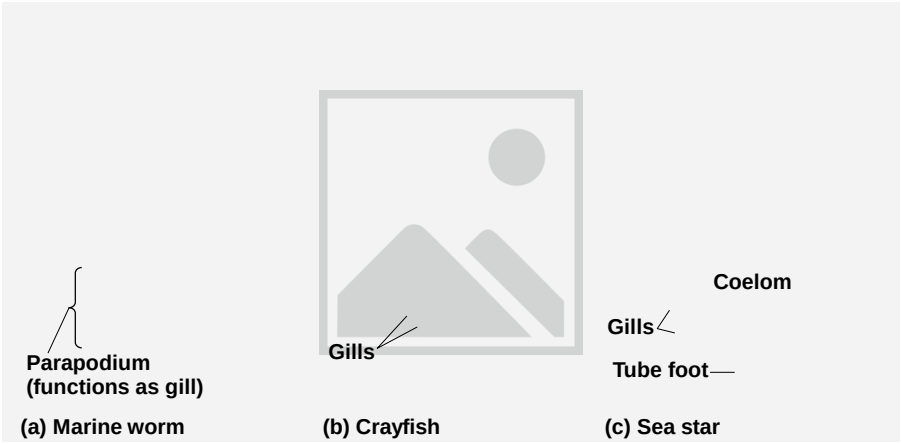
Figure 42.21



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- Fish gills use a **countercurrent exchange** system, where blood flows in the opposite direction to water passing over the gills
- Blood is always less saturated with O_2 than the water it meets
- In fish gills, more than 80% of the O_2 dissolved in the water is removed as water passes over the respiratory surface

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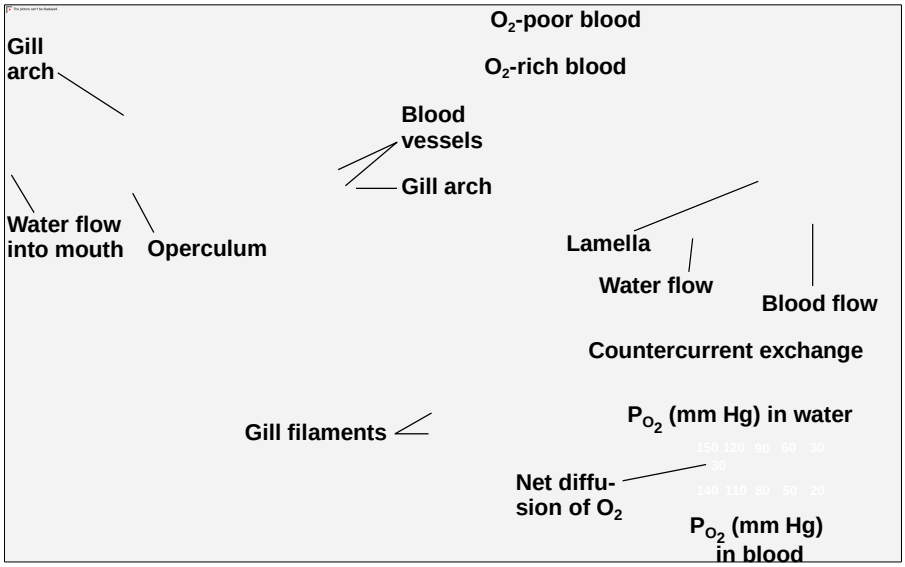
Figure 42.22



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Tracheal Systems in Insects

- The **tracheal system** of insects consists of a network of branching tubes throughout the body
- The tracheal tubes supply O_2 directly to body cells
- The respiratory and circulatory systems are separate
- Larger insects must ventilate their tracheal system to meet O_2 demands

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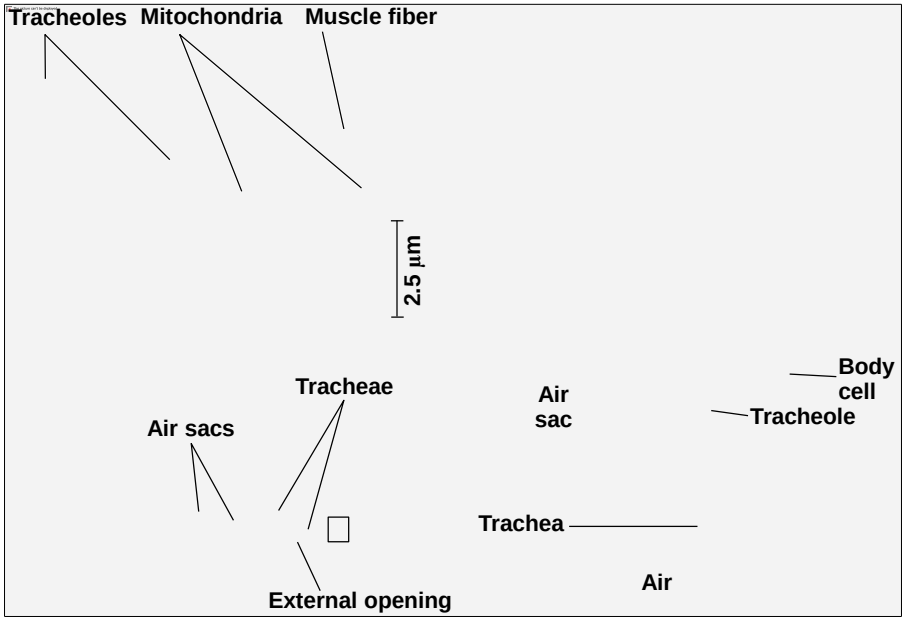
Figure 42.23



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Lungs

- **Lungs** are an infolding of the body surface
- The circulatory system (open or closed) transports gases between the lungs and the rest of the body
- The size and complexity of lungs correlate with an animal's metabolic rate

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Mammalian Respiratory Systems: A Closer Look

- A system of branching ducts conveys air to the lungs
- Air inhaled through the nostrils is filtered, warmed, humidified, and sampled for odors
- The pharynx directs air to the lungs and food to the stomach
- Swallowing moves the **larynx** upward and tips the epiglottis over the glottis in the pharynx to prevent food from entering the **trachea**, or windpipe

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- Air passes through the pharynx, larynx, trachea, **bronchi**, and **bronchioles** to the alveoli, where gas exchange occurs
- Exhaled air passes over the vocal cords in the larynx to create sounds
- Cilia and mucus line the epithelium of the air ducts and move particles up to the pharynx
- This “mucus escalator” cleans the respiratory system and allows particles to be swallowed into the esophagus

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- Gas exchange takes place in **alveoli**, air sacs at the tips of bronchioles
- Oxygen diffuses through the moist film of the epithelium and into capillaries
- Carbon dioxide diffuses from the capillaries across the epithelium and into the air space

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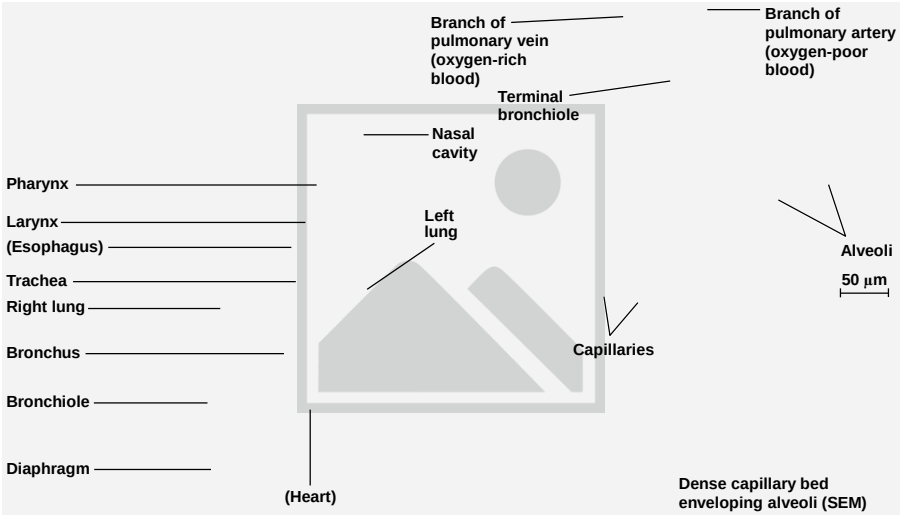
Figure 42.24



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- Alveoli lack cilia and are susceptible to contamination
- Secretions called **surfactants** coat the surface of the alveoli
- Preterm babies lack surfactant and are vulnerable to respiratory distress syndrome; treatment is provided by artificial surfactants

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Concept 42.6: Breathing ventilates the lungs

- The process that ventilates the lungs is **breathing**, the alternate inhalation and exhalation of air

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How a Mammal Breathes

- Mammals ventilate their lungs by **negative pressure breathing**, which pulls air into the lungs
- Lung volume increases as the rib muscles and **diaphragm** contract

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- The **tidal volume** is the volume of air inhaled with each breath
- The maximum tidal volume is the **vital capacity**
- After exhalation, a **residual volume** of air remains in the lungs

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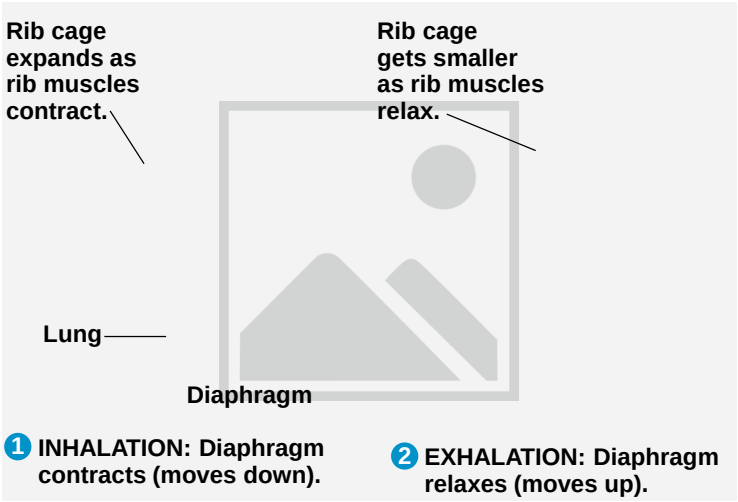
Figure 42.27



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Control of Breathing in Humans

- Breathing is regulated by involuntary mechanisms
- The breathing control centers are found in the medulla oblongata of the brain
- The medulla regulates the rate and depth of breathing in response to pH changes in the cerebrospinal fluid

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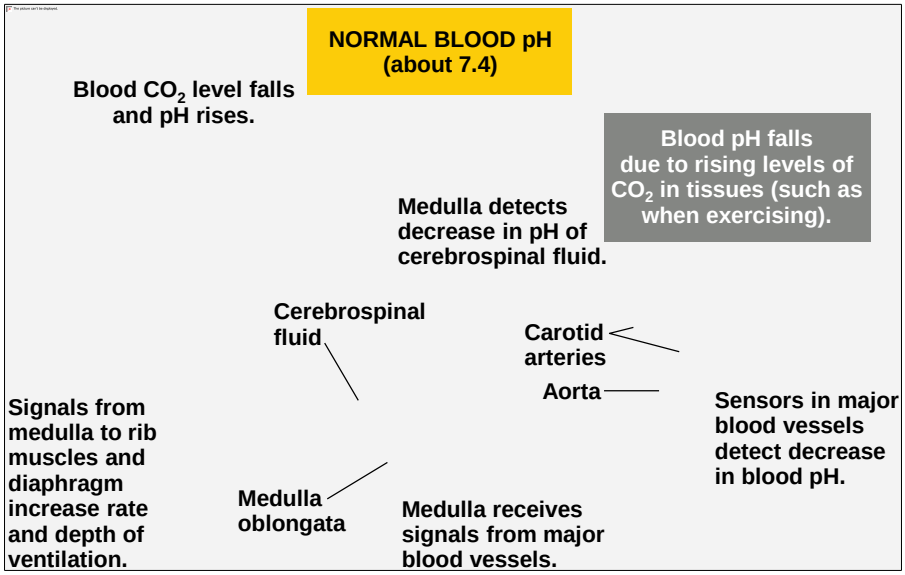
Figure 42.28



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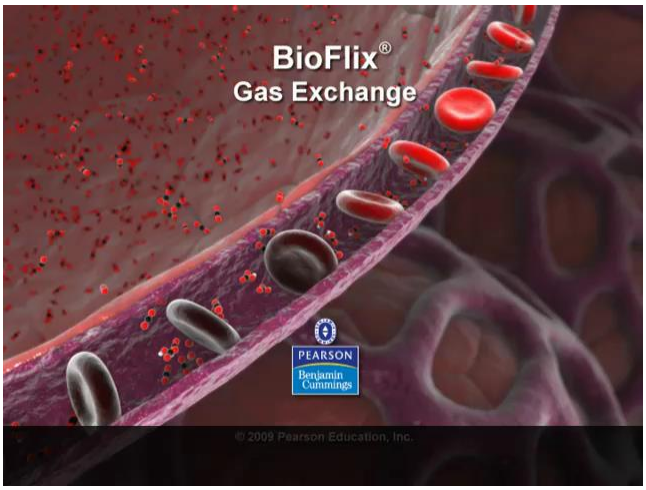
BioFlix: Gas Exchange



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