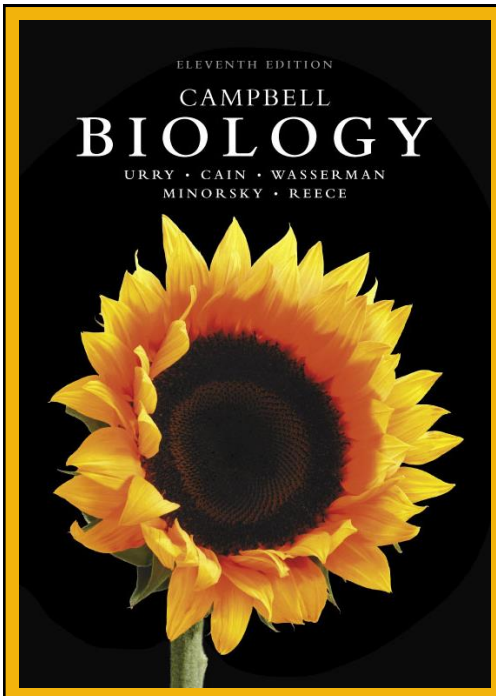


Chapter 42

Circulation and Gas Exchange

Lecture Presentations by
Nicole Tunbridge and
Kathleen Fitzpatrick

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

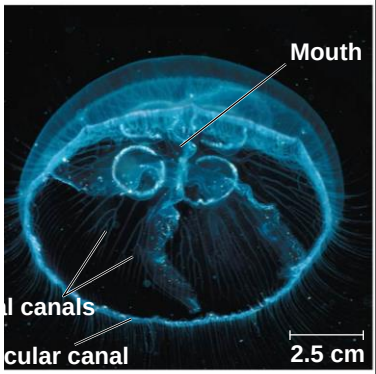
- *Gills* are an example of a specialized exchange system in animals
  - O_2 diffuses from the water into blood vessels
  - CO_2 diffuses from blood into the water
- Internal transport and gas exchange are functionally related in most animals

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

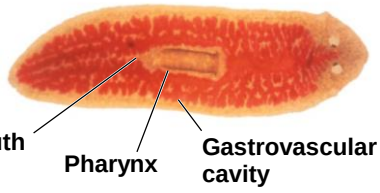
- Small molecules can move between cells and their surroundings by **diffusion**
- Diffusion is only efficient over small distances because the *time it takes to diffuse is proportional to the square of the distance*
- In some animals, many or all cells are in direct contact with the environment
- In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

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

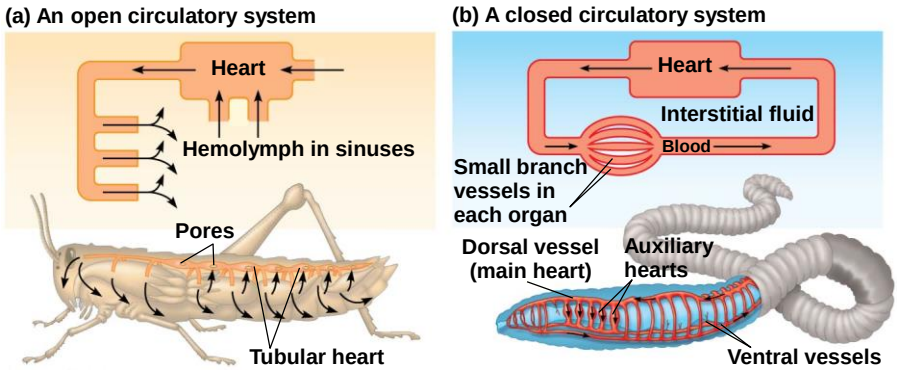


(b) The planarian *Dugesia*, a flatworm

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*

- 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



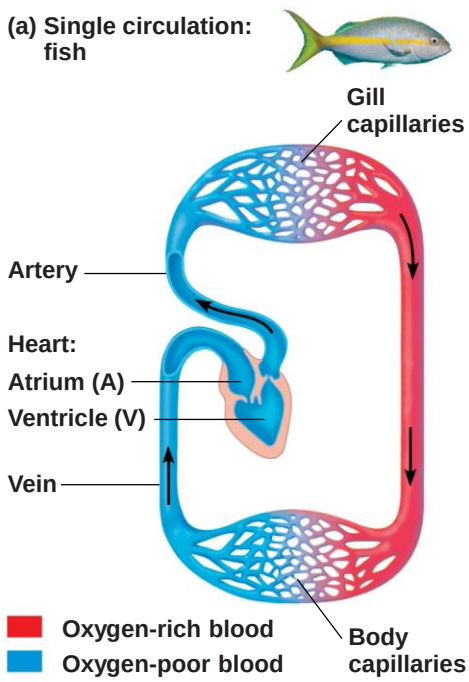
Organization of Vertebrate Circulatory Systems

- 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*

- **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**

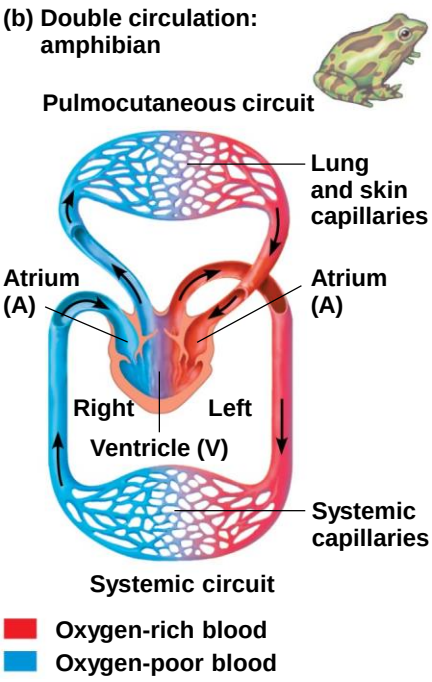
Single Circulation

- 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



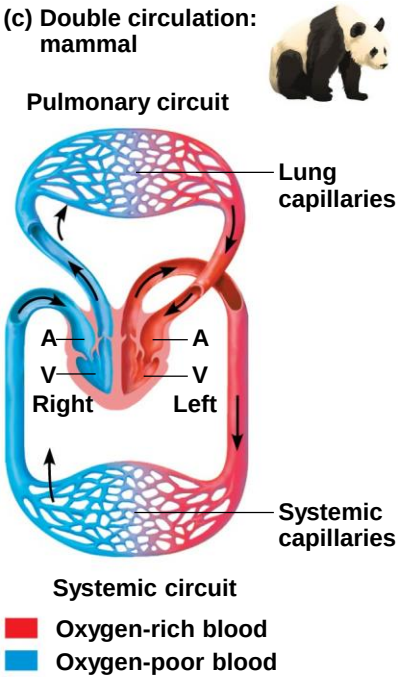
Double Circulation

- 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



- 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

Figure 42.4c



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

Mammalian Circulation

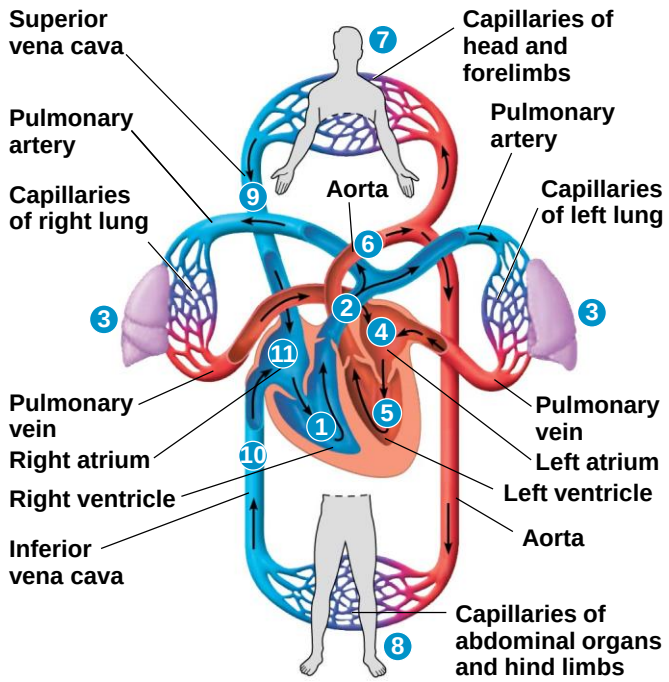
- Contraction of the right ventricle pumps blood to the lungs via the pulmonary arteries
- The blood flows through capillary beds in the left and right lungs and loads O_2 and unloads CO_2
- Oxygen-rich blood returns from the lungs via the pulmonary veins to the left atrium of the heart

- 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

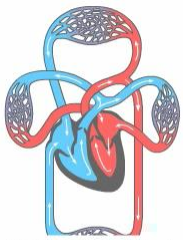
- Further branches lead to capillary beds in the abdominal organs and hind limbs
- O_2 diffuses from blood to tissues, and CO_2 diffuses from tissues to blood
- Capillaries rejoin, forming venules, conveying blood to veins
- Oxygen-poor blood from the head, neck, and forelimbs is channeled into the superior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

- 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

Figure 42.5



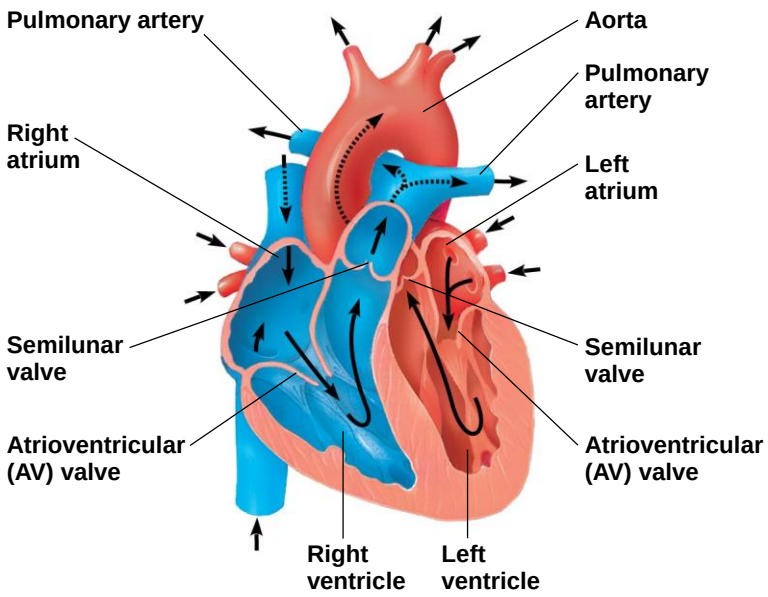
Animation: Path of Blood Flow in Mammals



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

Figure 42.6



- 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**

Figure 42.7_1

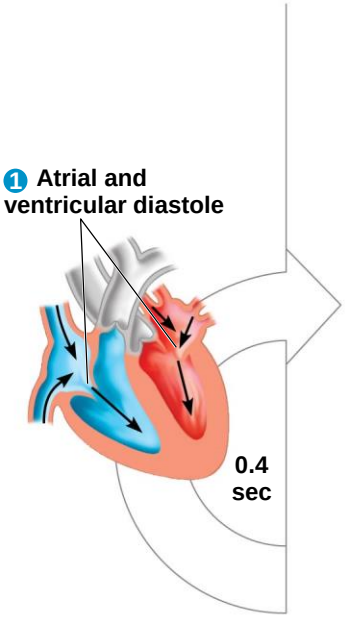


Figure 42.7_2

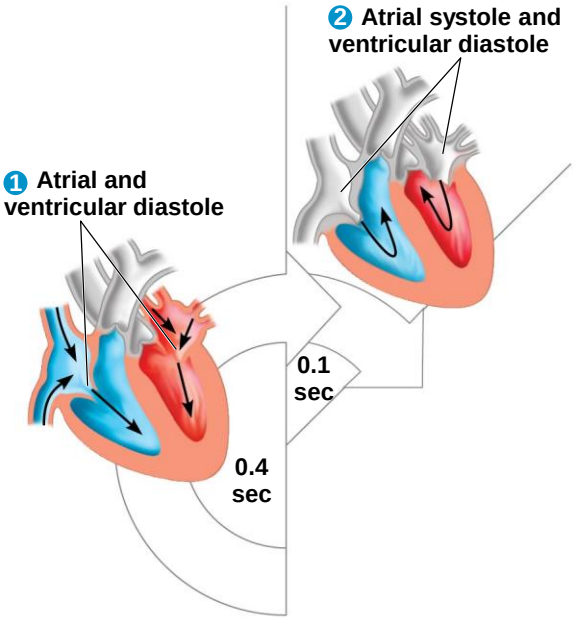
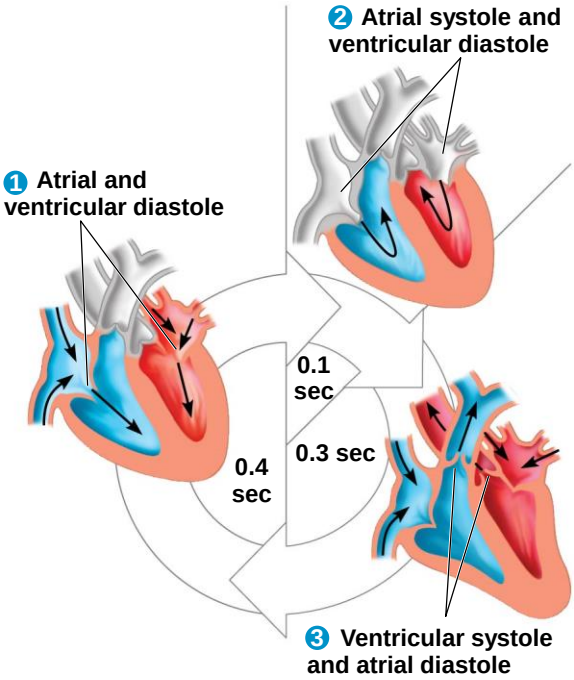


Figure 42.7_3



- 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

- 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

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

Figure 42.8_1

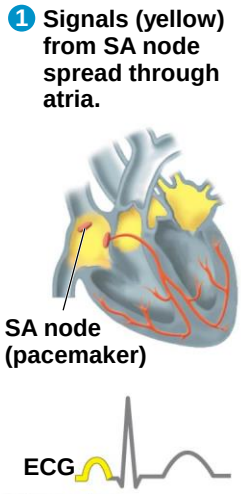


Figure 42.8_2

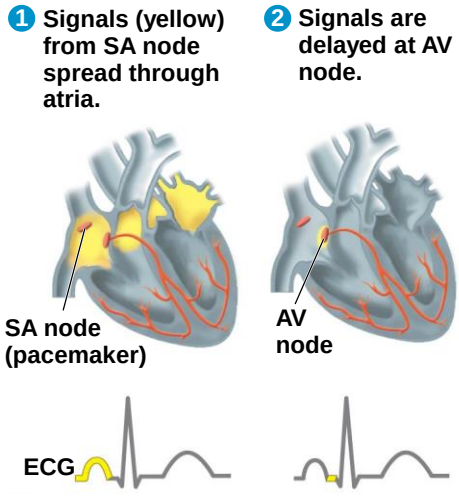


Figure 42.8_3

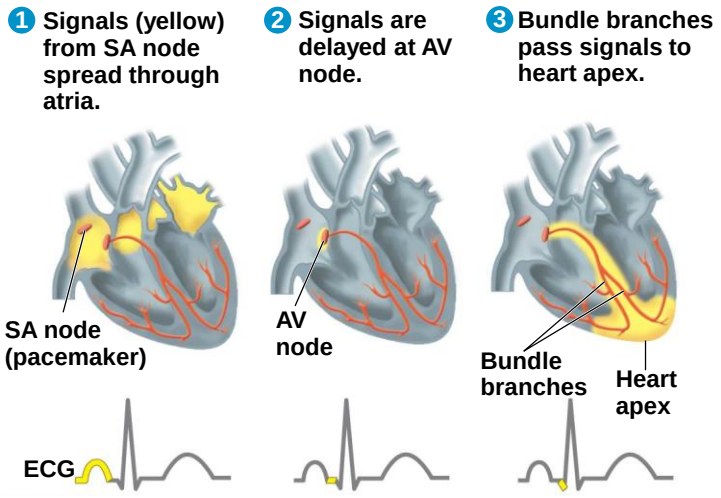
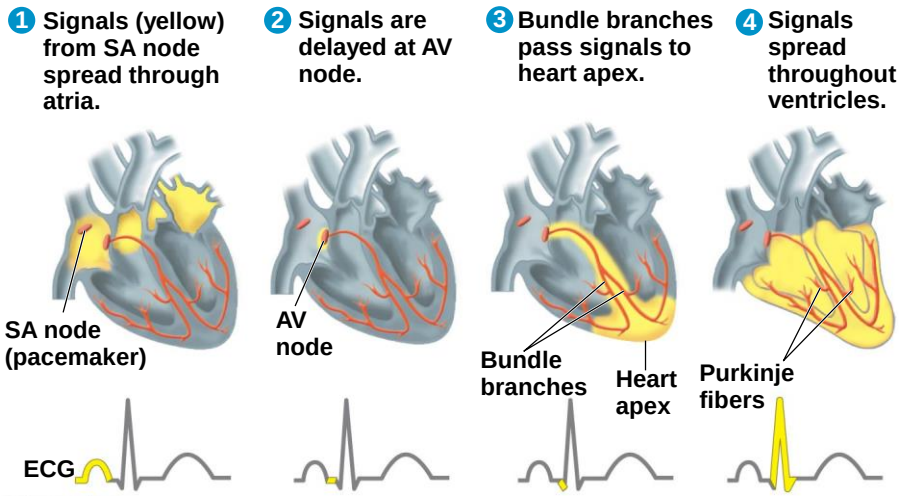


Figure 42.8_4



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

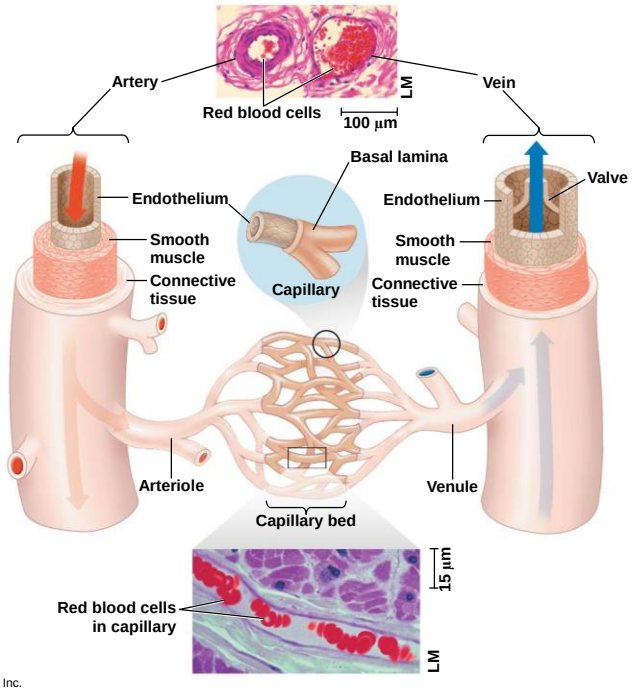
- The vertebrate circulatory system relies on blood vessels that exhibit a close match of structure and function

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

- 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

Figure 42.9



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

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

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

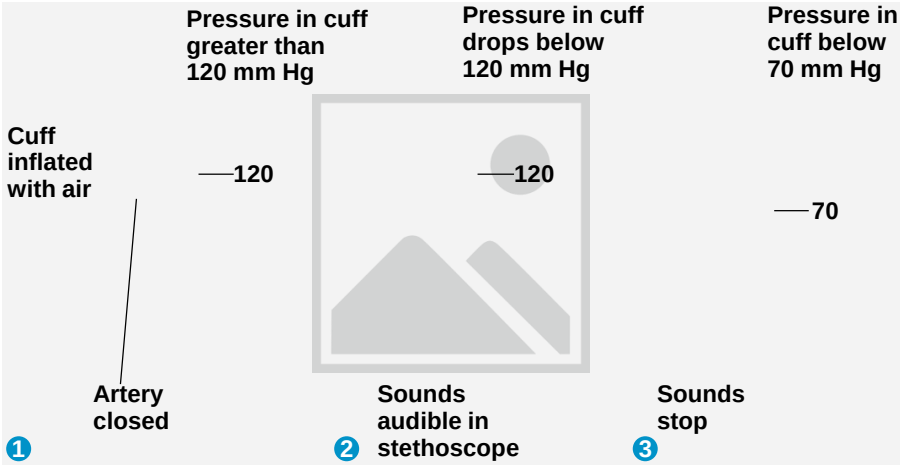
Regulation of Blood Pressure

- 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

Blood Pressure and Gravity

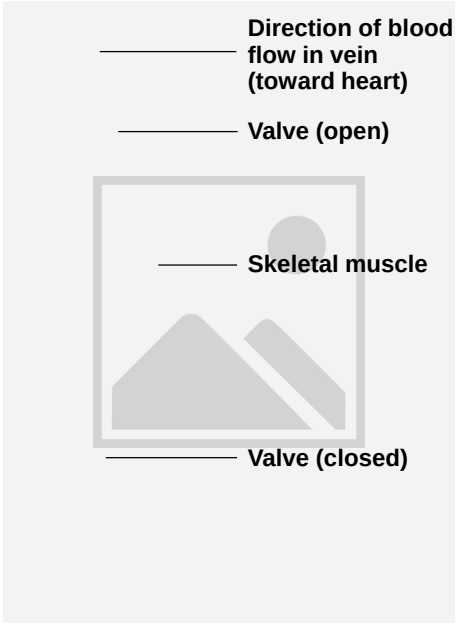
- Blood pressure is generally measured for an artery in the arm at the same height as the heart
- Blood pressure for a healthy 20-year-old human at rest is about 120 mm Hg at systole and 70 mm Hg at diastole
- Gravity has a significant effect on blood pressure

Figure 42.11



- 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

Figure 42.12

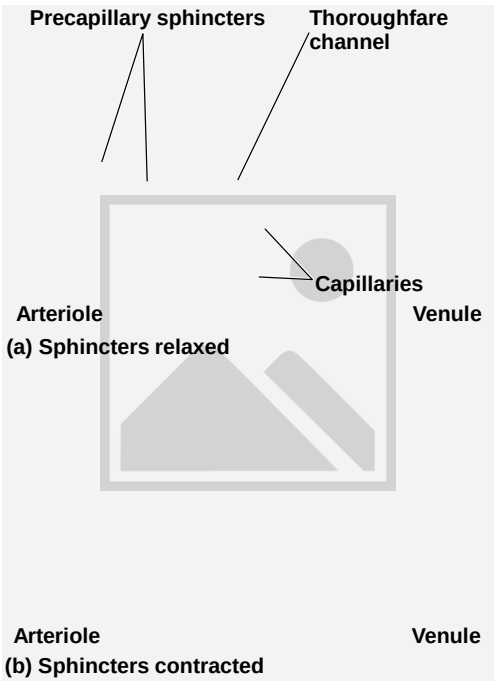


Capillary Function

- 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

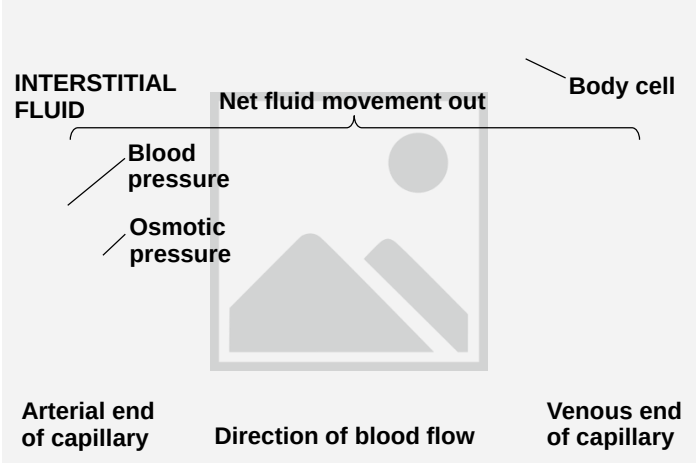
- Two mechanisms regulate distribution of blood in capillary beds
  - Constriction or dilation of arterioles that supply capillary beds
  - Precapillary sphincters that control flow of blood between arterioles and venules
- Blood flow is regulated by nerve impulses, hormones, and other chemicals

Figure 42.13



- 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

Figure 42.14

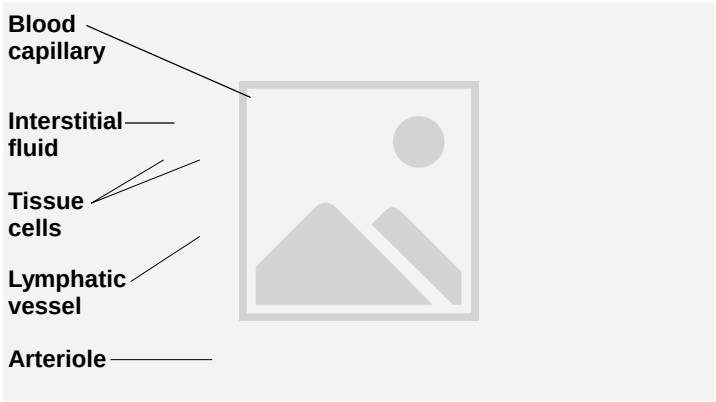


Fluid Return by the Lymphatic System

- 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

- 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

Figure 42.15



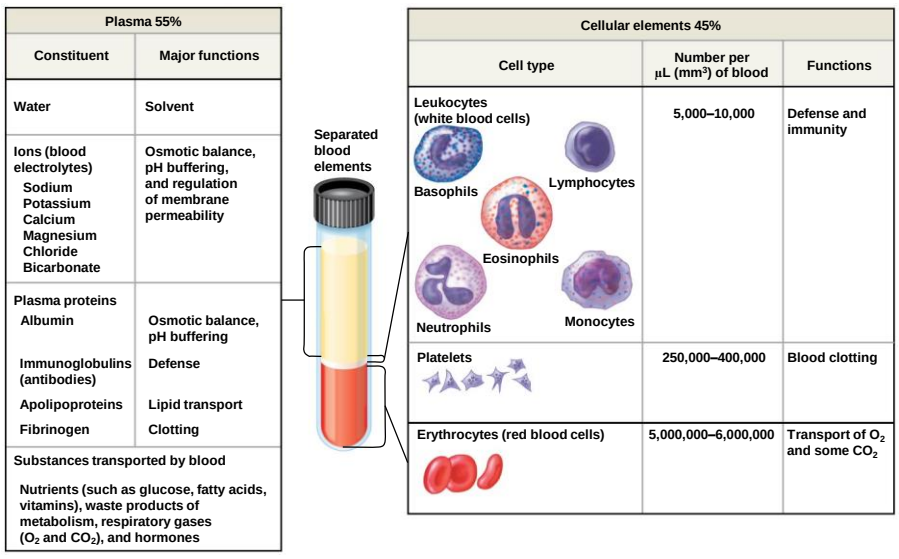
Concept 42.4: Blood components function in exchange, transport, and defense

- 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

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

Figure 42.16



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

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

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

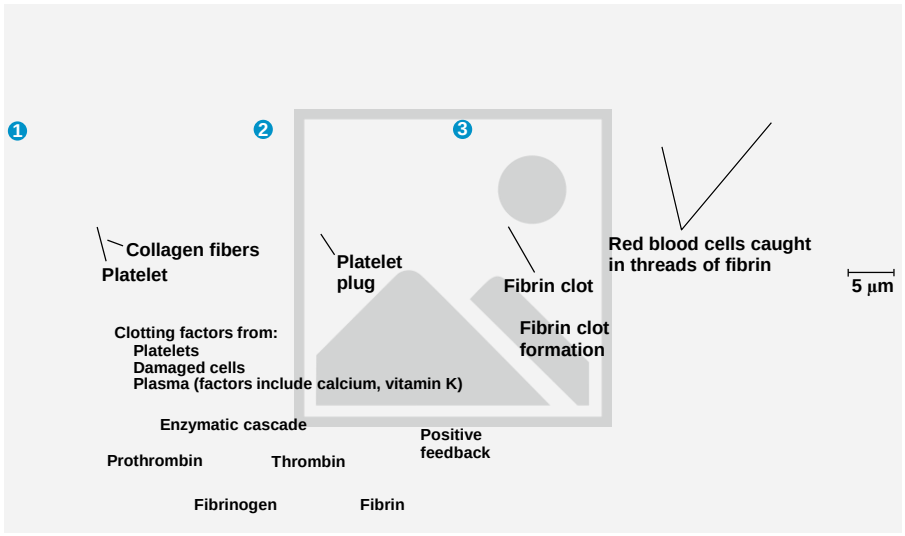
Leukocytes

- 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

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

Figure 42.18



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

Atherosclerosis, Heart Attacks, and Stroke

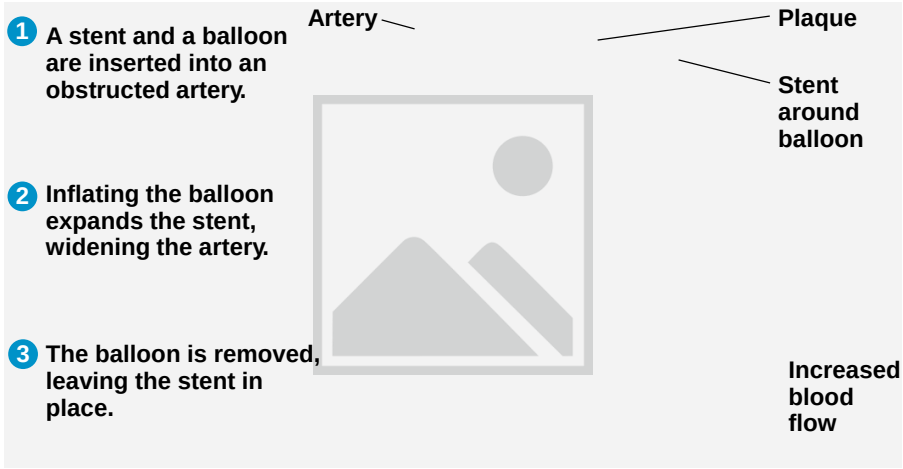
- One type of cardiovascular disease, **atherosclerosis**, is caused by the buildup of fatty deposits (plaque) within arteries
- Cholesterol is a key player in the development of atherosclerosis

- **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

Figure 42.19

- 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

Figure 42.20



- 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

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

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

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

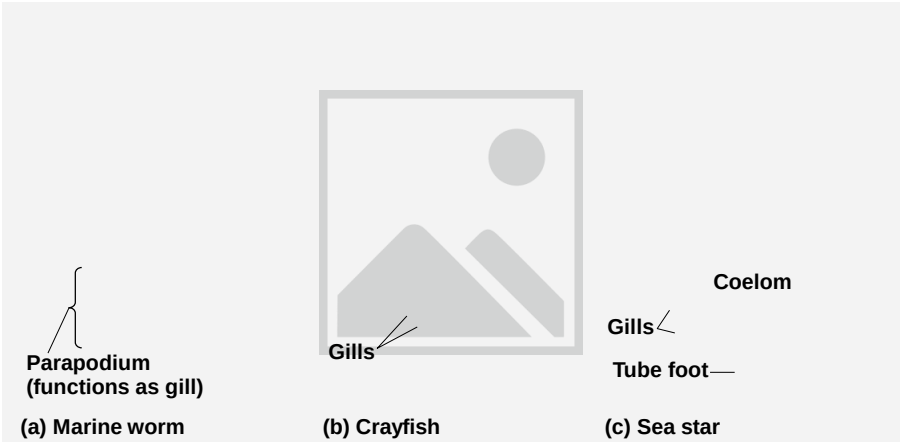
Respiratory Surfaces

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

Gills in Aquatic Animals

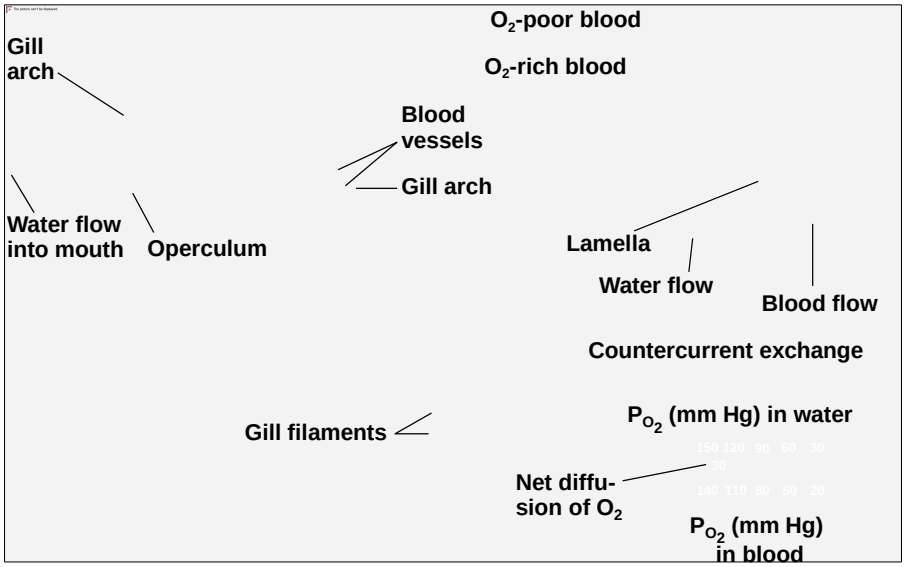
- Gills are outfoldings of the body that create a large surface area for gas exchange
- **Ventilation** moves the respiratory medium over the respiratory surface
- Aquatic animals move through water or move water over their gills for ventilation

Figure 42.21



- 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

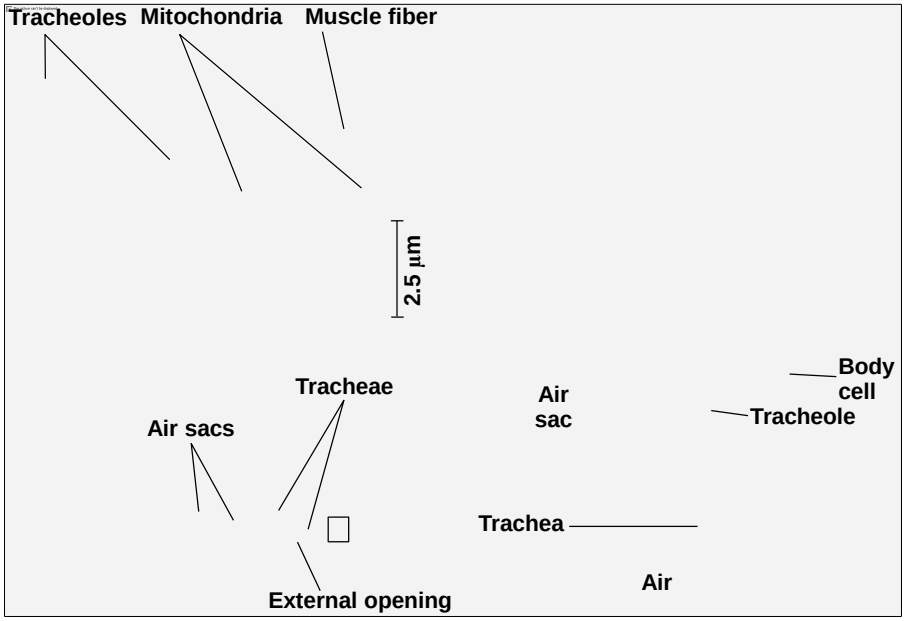
Figure 42.22



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

Figure 42.23



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

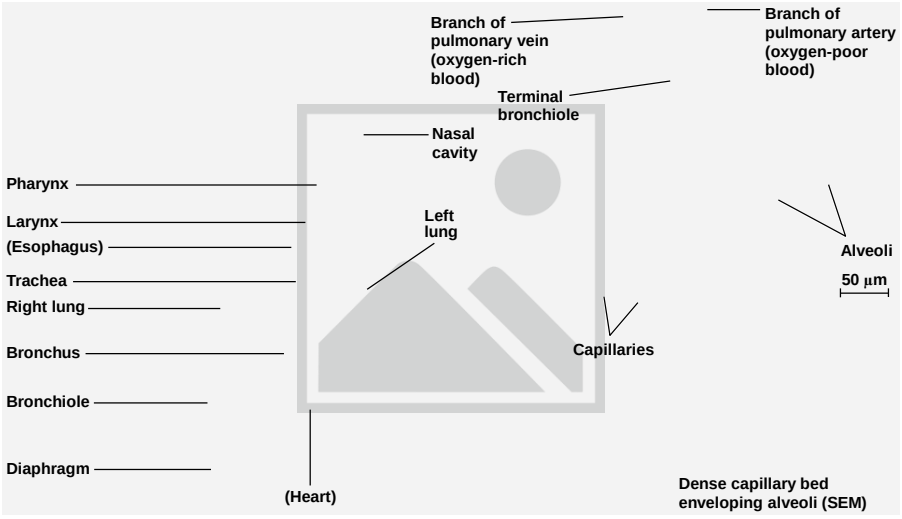
Mammalian Respiratory Systems: A Closer Look

- 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

- 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

- 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

Figure 42.24



- 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

Concept 42.6: Breathing ventilates the lungs

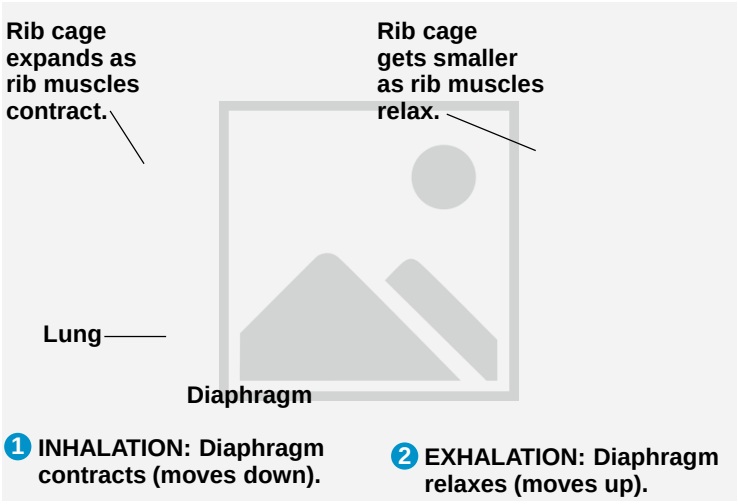
- The process that ventilates the lungs is **breathing**, the alternate inhalation and exhalation of air

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

- 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

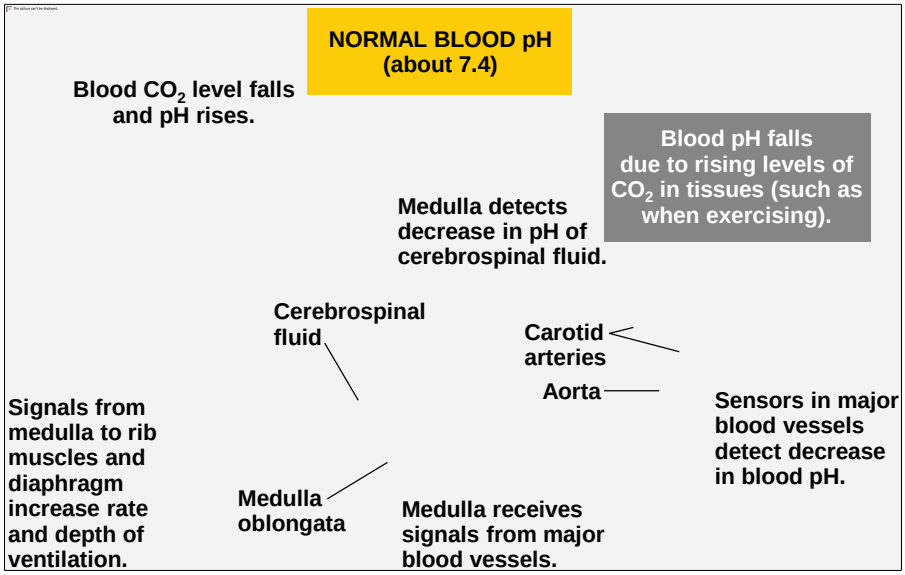
Figure 42.27



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

Figure 42.28



BioFlix: Gas Exchange