Circulation and Respiration
Circulatory System: Features and Functions

• All circulatory systems have three major parts
  ▪ The heart: a pump that keeps blood circulating
  ▪ Blood: a liquid that serves as a medium for transport
  ▪ A system of tubes, blood vessels, that conducts the blood throughout the body
Circulatory System: Features and Functions

Two types of circulatory systems are found in animals

**Open circulatory systems**
- Are found in:
  - Many invertebrates, including arthropods and mollusks
- Animals with these systems have one or more simple hearts, vessels, and a space within the body cavity called the hemocoel
- Tissues and organs are bathed with hemolymph

**Closed circulatory systems**
- Are found in:
  - Some invertebrates and mollusks
  - All vertebrates
- Blood is confined in a continuous vascular network with a pumping heart
Circulatory System: Features and Functions

• The vertebrate circulatory system has diverse functions
  ▪ It transports O\textsubscript{2} and CO\textsubscript{2} to and from the tissues
  ▪ It distributes nutrients from the digestive system to body cells
  ▪ It transports waste and toxic substances to the liver
  ▪ It distributes hormones from glands and organs to body cells
  ▪ It regulates body temperature
  ▪ It prevents blood loss by producing blood clots
  ▪ It protects the body against disease
The Vertebrate Heart

• The vertebrate heart consists of muscular chambers capable of strong contractions
  ▪ Atria collect blood and pump it to the ventricles
  ▪ Ventricles circulate blood to the lungs and the rest of the body
The Vertebrate Heart

• The two-chambered heart of fish: the most basic type of heart
  ▪ The hearts of fish have two main contractile chambers: a single atrium and a single ventricle

• Terrestrial vertebrates have increasingly complex and efficient hearts
  ▪ Amphibians and most reptiles have three-chambered hearts
    • An important adaptation in these terrestrial vertebrates is double circulation, which creates two separate circuits of blood
      ▪ The pulmonary circuit directs blood from the heart through the lungs
      ▪ The systemic circuit carries blood between the heart and the rest of the body
The Vertebrate Heart

• Four-chambered hearts consist of two separate pumps
  ▪ Birds, mammals, and some reptiles have four-chambered hearts
  ▪ This type of heart acts like two hearts beating as one
    • The “right heart,” consisting of the right atrium and ventricle, deals with oxygen-poor blood
    • Veins carry blood to the heart, and arteries carry blood away
    • The right ventricle pumps blood to the lungs
    • The “left heart,” consisting of the left atrium and ventricle, deals with oxygen-rich blood
    • The left ventricle pumps blood to the body
The Vertebrate Heart

Blood flows to the right ventricle, from which it is pumped into the lungs.

Veins carry oxygen-poor blood from the body to the right atrium.

Blood picks up oxygen in the lungs and then returns to the left atrium of the heart.

The blood is pumped from the left ventricle into the body.

Blood flows into the left ventricle.
The Vertebrate Heart

• Valves maintain the direction of blood flow
  ▪ Atrioventricular valves allow blood to flow from atria to ventricles, but not the reverse
  ▪ Semilunar valves allow blood to enter the pulmonary artery and aorta when the ventricles contract, but prevent backflow of blood

• Cardiac muscle is present ONLY in the heart
  ▪ Cardiac muscle cells are small and branched and have a striped appearance
    ▪ Cardiac muscle cells are linked to one another by intercalated discs
The Vertebrate Heart

• The coordinated contractions of atria and ventricles produce the cardiac cycle
  ▪ Each heartbeat is a series of coordinated events called the cardiac cycle
  ▪ The cardiac cycle generates the forces measured when blood pressure is taken
    • Systolic pressure is measured during ventricle contraction
    • Diastolic is the minimum pressure in the arteries as the heart rests between contractions
    • Hypertension is high blood pressure
    • Hypotension is low blood pressure
The Vertebrate Heart

• Electrical impulses coordinate the sequence of heart chamber contractions
  ▪ The contraction of the heart is initiated and coordinated by a pacemaker
    • The sinoatrial node (SA node) is the heart’s pacemaker and initiates a wave of contraction
      ▪ It is made up of a cluster of specialized heart muscle cells that produce spontaneous electrical signals at a regular rate
    • The atrioventricular node (AV node) channels the contraction impulse
    • The impulse is then conducted to other parts of the heart
  ▪ When the pacemaker fails, fibrillation can occur
The Vertebrate Heart

• The nervous system and hormones influence heart rate
  ▪ The parasympathetic nervous system decreases heart rate
  ▪ The sympathetic nervous system increases heart rate
  ▪ Hormones can have differing effects on heart rate

• The brain does NOT regulate the heart
  ▪ A person’s heart could still work on its own, despite brain damage
The Vertebrate Heart

- Heart valves maintain the direction of blood flow
- If the heart valves degenerate, blood will "backslide" against pressure from:
  - A ventricle to an atrium
  - From the pulmonary artery back into the right ventricle
  - From the aorta back into the left ventricle
  - From the left atrium back into the pulmonary vein
Blood

• Blood has two major components
  ▪ Plasma: a liquid which makes up about 55–60% of the blood
  ▪ The cell-based component includes red and white blood cells and platelets
Blood

- **Plasma:** primarily water in which proteins, salts, nutrients, and wastes are dissolved
  - Plasma is approximately 90% water
  - It contains molecules of dissolved proteins, hormones, nutrients, ions, and wastes
  - Plasma contains three major plasma proteins
    - Albumins
    - Globulins
    - Fibrinogen

- The cell-based components of blood are formed in bone marrow
  - All three cell-based components of the blood originate from cells in the bone marrow
Blood: Red Blood Cells

- Red blood cells carry oxygen from the lungs to the tissues
  - Red blood cells are called erythrocytes
    - These make up 99% of the total cellular component in the blood
  - Red blood cells contain hemoglobin that transports $O_2$ from the lungs to the tissue
- Negative feedback regulates red blood cell numbers
  - Erythropoietin is produced by the kidney in response to oxygen deficiency and stimulates the production of red blood cells
    - A person who injects extra erythropoietin or takes the hormone as an oral pill will have an increased number of red blood cells in the blood
Blood: Red Blood Cells

- Red blood cells carry oxygen from the lungs to the tissues

- Causes of low oxygen levels in the blood
  - Loss of blood
  - High altitude (oxygen is less available)
  - Insufficient hemoglobin
  - Conditions affecting gas exchange
    - Respiratory problems
    - Heart failure

- Anemia
  - Inadequate number of erythrocytes
Blood: Red Blood Cells

Erythropoietin production by kidney

Stimulates

Red blood cell production in the bone marrow

Causes

Restored oxygen level

Inhibits
Blood: White Blood Cells

• White blood cells defend the body against disease
  ▪ White blood cells are called leukocytes
    • There are five types of leukocytes
    • These cells make up 1% of the total cellular component of blood
  ▪ Monocytes, a type of white blood cell, turn into macrophages that can engulf bacteria
Blood: Platelets

• Platelets: cell fragments that aid in blood clotting
  ▪ Platelets are pieces of large cells called megakaryocytes

• Blood clotting plugs damaged blood vessels
  ▪ Blood clotting is a complex process that involves a variety of proteins
  ▪ When the process is completed, a clot forms
  ▪ Hemophilia is a genetic disorder
    • Those affected lack a protein called clotting factor
Blood

• Oxygenated (oxygen-rich) blood has a bright cherry-red color

• Deoxygenated (oxygen-poor) blood has a maroon-red color which appears blue through the skin
  ▪ When blood is drawn from the body, it is taken from a vein, so the color of the blood will be a dark red
    • It will not be bluish as it is not being seen through the skin
Blood Vessels

- Blood circulates through the body within a network of vessels
  - Blood leaving the heart travels from arteries to arterioles to capillaries to venules to veins and back to the heart
Blood Vessels

• Blood vessels are composed of a variety of tissues

• Arteries and arterioles carry blood away from the heart
  - The walls of arteries are thicker and have elastic tissue to withstand high pressure
  - Arteries branch into smaller arterioles
Blood Vessels

• Capillaries allow exchange of nutrients and wastes
  ▪ Arterioles branch into capillaries
    • These tiny vessels are a single cell thick for easy diffusion
  ▪ These vessels exchange materials between blood and the fluid that bathes body cells, called interstitial fluid
    • Substances diffuse through the capillary walls
    • High pressure in the capillaries causes them to leak fluid, which drains to the lymphatic system
Blood Vessels

• Veins and venules carry blood back to the heart
  ▪ They provide a low-resistance pathway for blood flow back to the heart
    • Veins are thin-walled vessels that are more expandable than arteries
    • Veins contain valves to prevent the backflow of blood
  ▪ Blood pressure in veins is low, but breathing and the contraction of skeletal muscles helps return blood to the heart
Blood Vessels

• Arterioles control the distribution of blood flow
  - The muscular walls of the arterioles control blood flow
  - The flow is influenced by nerves, hormones, and other chemicals released from nearby tissues
  - Muscles called precapillary sphincters further control blood flow
The Lymphatic System

• The lymphatic system is composed of organs and vessels that eventually feed into the circulatory system

  ▪ This system has a variety of functions

    • Return excess interstitial fluid to the bloodstream
    • Transport fats from the small intestine to the bloodstream
    • Filter aged blood cells and debris from the blood
    • Defend the body by exposing bacteria and viruses to white blood cells
The Lymphatic System

• Lymphatic vessels resemble the capillaries and veins of the circulatory system
  ▪ These vessels are highly permeable and “dead-end” in the extracellular fluid surrounding body cells
  ▪ Lymphatic vessels have one-way valves, as in veins
The Lymphatic System

• The lymphatic system returns interstitial fluid to the blood
  ▪ Blood capillaries leak fluid into the extracellular spaces
    • The fluid is forced into lymphatic capillaries, which transport it back to the circulatory system
      ▪ This transport is extremely important to the body, and malfunctions can cause serious health problems
The Lymphatic System

• The lymphatic system transports fats from the small intestine to the blood

• Lymphatic organs help defend the body
  ■ Organs of the lymphatic system are important in the immune response
  ■ The thymus, tonsils, lymph nodes, and spleen are all involved
Gas Exchange

• The exchange of gases supports cellular respiration
  ▪ Respiration is the process by which organisms exchange gases with the environment
    • Oxygen is taken in and carbon dioxide is released

• Gas exchange through cells and tissues relies on diffusion
  ▪ All animal respiratory systems meet three requirements that facilitate the diffusion of $O_2$ and $CO_2$
    • The respiratory surface must be moist
    • The respiratory surfaces are thin
    • Respiratory surfaces must have a large surface area
  ▪ The movement of air across the respiratory surface is called bulk flow
Respiratory Adaptations Minimize Diffusion Distances

• Relatively inactive animals may lack specialized respiratory organs

• Some animals in moist environments lack specialized respiratory structures
  ▪ Sponges live in aquatic environments and use ciliated cells to create a current of water from which they can absorb gases
  ▪ Sea jellies, corals, and anemones have thin skin that allows gas exchange by diffusion
    • Flatworms also have thin skin and a large surface for diffusion
  ▪ Other animals, such as earthworms, combine skin surface with complex circulation for delivery to cells
Respiratory Adaptations Minimize Diffusion Distances

• Respiratory systems and circulatory systems often work together to facilitate gas exchange

  ▪ Air or water moves past respiratory surfaces by bulk flow
  ▪ Oxygen and carbon dioxide are exchanged by diffusion
  ▪ Gases are transported to tissues by bulk flow
  ▪ Gases are exchanged with tissues and the circulatory system by diffusion
Respiratory Adaptations Minimize Diffusion Distances

• Gills facilitate gas exchange in aquatic environments
  ▪ Gills are adapted to have a large surface area
  ▪ Fish create a continuous current over their gills by pumping water into their mouths and ejecting it through the operculum
  ▪ Fish exchange gases by countercurrent exchange
Respiratory Adaptations Minimize Diffusion Distances

• Terrestrial animals have internal respiratory structures
  ▪ Natural selection has favored structures whose thin membranes are protected, supported, and kept moist
  ▪ Insects respire using tracheae
    • Openings called spiracles open into tracheae, which deliver air to body cells
  ▪ Terrestrial vertebrates respire using lungs
    • Lungs are chambers containing moist respiratory surfaces that are protected within the body
    • Amphibians use a combination of methods to exchange gases (gills, skin, lungs)
  ▪ Reptiles have a waterproof skin, so they rely completely on their lungs, which have a large surface area
  ▪ Bird lungs have special adaptations that allow exceptional gas exchange
    • Air sacs serve as reservoirs for air
The Human Respiratory System

• The human respiratory system can be divided into two parts
  ▪ The conducting portion
  ▪ The gas-exchange portion

• The conducting portion carries air to the gas-exchange portion
The Human Respiratory System

• The conducting portion of the respiratory system carries air to the lungs
  - The conducting portion consists of many different structures
    • The upper parts include the pharynx, larynx, epiglottis, and esophagus
      - If the larynx gets clogged, the Heimlich maneuver can be used to dislodge the clog
    • The vocal cords are within the larynx
      - As air passes through them, different sounds can be made
    • Air travels from the larynx through the trachea, and then into the internal parts of the conducting portion, which includes the bronchi and bronchioles
      - Bronchioles lead to the alveoli
The Human Respiratory System

• Air is inhaled actively and exhaled passively
  ▪ Breathing occurs in two stages: inhalation and exhalation
    • During inhalation, the diaphragm is contracted, which pulls it downward
      ▪ This draws air into the lungs
    • During exhalation, the diaphragm is relaxed and moves upward
      ▪ This pushes air out of the lungs
The Human Respiratory System

• Breathing rate is controlled by the respiratory center of the brain
  - The respiratory center is in the medulla
  - Signals are provided by the concentration of carbon dioxide levels in the blood
    - These can increase or decrease the breathing rate
Gas Exchange in the Human Respiratory System

• Gas exchange occurs in the alveoli
  ▪ Alveoli are sacs covered with capillaries
  ▪ They contain a single layer of epithelial cells
    • Surfactant prevents the collapse of alveoli
  ▪ The respiratory membrane consists of the alveolar wall and the capillary wall
    • Gases only need to diffuse a short distance
Gas Exchange in the Human Respiratory System

- Oxygen (O$_2$) and carbon dioxide (CO$_2$) are transported in blood using different mechanisms
  - Blood picks up O$_2$ and transports it to body tissues and also picks up CO$_2$ for transport to the lungs
    - Both gases diffuse down their concentration gradients
    - Nearly all the O$_2$ in blood is carried by hemoglobin
  - CO$_2$ is transported in the blood in three ways by various mechanisms
    - Dissolved in the plasma (10%)
    - Bound to hemoglobin (20%)
    - Most is transported in the plasma as bicarbonate (70%)
Gas Exchange

• If any part of the heart would be blocked, gas exchange would not occur properly

• When gas exchange does not properly occur:
  ▪ Blood will not carry oxygen to the parts of the body that need it to carry out life processes
  ▪ The lungs will not receive the carbon dioxide needed to be released from the body
  ▪ The lungs will not be able to give the blood oxygen needed to be carried to other parts of the body
The Brain and Respiration

• The medulla part of the brain is the respiratory control center
  ▪ If this part of the brain would be damaged, breathing would become irregular, even if there was no damage to the lungs, trachea, bronchi, or any other respiratory organ

• When a person runs, he will start gasping for breath or breathing faster before he has reached his endurance level
  ▪ The brain make the person breathe faster before he is low on oxygen or has too much carbon dioxide