

### Biosc 41 Announcements 11/5

- Review of fish
- Quiz covering fish
- Lecture: circulation and gas exchange
- Lab: video (“Your Inner Reptile”), amphibians & reptiles (frog dissection)
  
- Next quiz: tetrapods (all), Wed. 11/12

### Review: Fishes

- Which group of fishes is a basal craniate, but often not grouped as a true “vertebrate”?
- Which groups of fishes are agnathans?
- Which group of fishes are the most primitive gnathostomes?
- Which group of fishes has a heterocercal caudal fin?
- Which fishes have a homocercal caudal fin?
- Type of scales in sharks?

### Review: Fishes

- Oviparous vs ovoviviparous vs viviparous?
- What is the class of ray-finned fishes?
- Lobe-finned fishes? Differences from above?
- Examples of lobe-finned fishes?
- Which group of fishes have an operculum?
- Swim-bladder?

### Review: Fishes

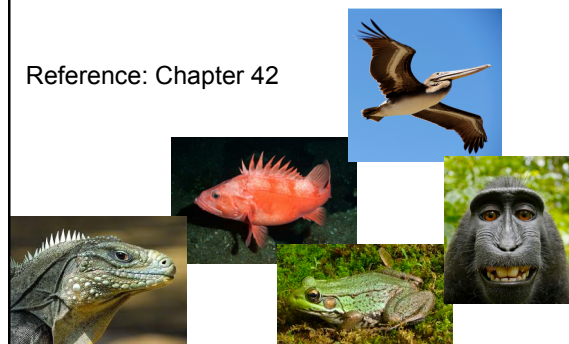
- What organ do chondrichthyans use for buoyancy?
- Most energy-efficient mode of locomotion?
- How do freshwater fish osmoregulate?
- How do seawater fish osmoregulate?

### Quiz 8

1. Which groups of fishes are agnathans? (common names OR scientific names are fine!)
2. What organ do (a) cartilaginous fishes, and (b) bony fishes use for buoyancy?
3. List two ways that fish osmoregulate in freshwater.
4. List two ways that fish osmoregulate in seawater.
5. List two ways in which lobe-finned fishes differ physically from ray-finned fishes.

### Circulation and Gas Exchange

Reference: Chapter 42



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

- O<sub>2</sub> and CO<sub>2</sub> 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 distance
- In small or thin animals, cells can exchange materials directly with the surrounding medium
- In most animals, cells exchange materials with the environment via a fluid-filled circulatory system



### Gastrovascular Cavities

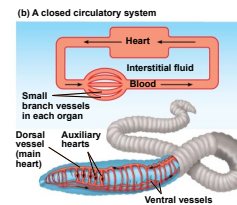
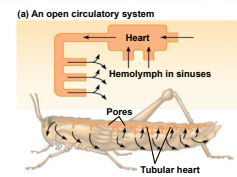
- Some animals lack a circulatory system
- Some cnidarians have elaborate gastrovascular cavities
  - Functions in both digestion and distribution of substances throughout the body
- Body wall enclosing GVC is only two cells thick
- Flatworms have GVC and a flat body to minimize diffusion distances



### Open and Closed Circulatory Systems

- A circulatory system has:
  - Circulatory fluid
  - A set of interconnecting vessels
  - A muscular pump, the **heart**
- Circulatory system connects body tissues with organs that exchange gases, absorb nutrients, dispose wastes
- Circulatory systems can be open or closed and vary in the number of "circuits"

- Arthropods and some molluscs have circulatory fluid called **hemolymph** that bathes organs directly in **open circulation**
- In a **closed circulatory system**, **blood** is confined to vessels and is distinct from interstitial fluid
- Annelids, cephalopods, and vertebrates have closed circulation

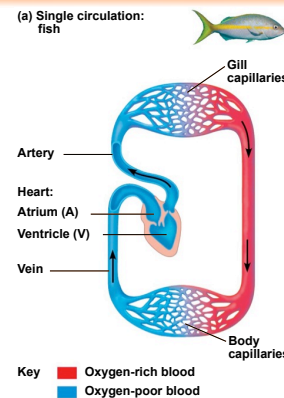


### Organization of Vertebrate Circulatory Systems

- 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; each has one-way blood flow
- **Arteries** branch into **arterioles** and carry blood **away from the heart to capillaries**
- **Capillary beds** are the sites of exchange between blood and interstitial fluid
- **Venules** converge into **veins** and return blood from capillaries **to the heart**

### 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 (gills and body) before returning



### Double Circulation

(b) Double circulation: amphibian

- Amphibians, reptiles, and mammals have **double circulation**
- O<sub>2</sub>-poor and O<sub>2</sub>-rich blood are pumped separately from the right and left sides of the heart
- In amphibians, O<sub>2</sub>-poor blood flows through a pulmocutaneous circuit to pick up O<sub>2</sub> through the lungs and skin

Key: ■ Oxygen-rich blood, ■ Oxygen-poor blood

### Double Circulation

(c) Double circulation: mammals & reptiles

- In reptiles and mammals, O<sub>2</sub>-poor blood flows through the pulmonary circuit to pick up O<sub>2</sub> through the lungs
- O<sub>2</sub>-rich blood delivers O<sub>2</sub> through the **systemic circuit**
- Double circulation maintains higher blood pressure in organs than single circulation

Key: ■ Oxygen-rich blood, ■ Oxygen-poor blood

- Amphibians have a three-chambered heart: two atria and one ventricle
- Reptiles have a three-chambered heart: two atria and one ventricle, partially divided by a septum
- Mammals and birds have a four-chambered heart with two atria and two ventricles
- The left side of the heart pumps and receives only O<sub>2</sub>-rich blood, while the right side receives and pumps only O<sub>2</sub>-poor blood
- Mammals and birds are endotherms and require more O<sub>2</sub> than ectotherms

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

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### The Mammalian Heart: A Closer Look

- The two atria have relatively thin walls and serve to collect blood returning to the heart
- Ventricles have thicker walls and contract much more forcefully

- 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**
- The **heart rate** (pulse) is the number of beats per minute
- The **stroke volume** is the amount of blood pumped in a single contraction
- 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

- Four valves prevent backflow of blood in the heart
- Atrioventricular (AV) valves** separate each atrium and ventricle
- Semilunar valves** control blood flow to the aorta and the pulmonary artery

### Maintaining the Heart's Rhythmic Beat

- The **sinoatrial (SA) node (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)**

- 1 Signals (yellow) from SA node spread through atria.
- 2 Signals are delayed at AV node.
- 3 Bundle branches pass signals to heart apex.
- 4 Signals spread throughout ventricles.

- The pacemaker is regulated by two portions of the nervous system: the **sympathetic** and **parasympathetic** divisions
- The sympathetic division **speeds up** the pacemaker
- The parasympathetic division **slows down** the pacemaker
- Also regulated by hormones and temperature

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

- The epithelial layer that lines blood vessels is called the **endothelium**; it is smooth to minimize resistance
- Capillaries are barely wider than a red blood cell, and have thin walls to facilitate exchange
- Arteries have thicker walls than veins to accommodate high pressure blood pumped from the heart
- In the thinner-walled veins, muscle action pushes blood back to the heart

### Blood Flow Velocity

- Blood flow is slowest in capillary beds, due to high resistance
- Slow flow in capillaries facilitates exchange of materials

### Changes in Blood Pressure During the Cardiac Cycle

- Blood pressure** is the pressure that blood exerts in all directions, including against the walls of blood vessels
- The recoil of elastic arterial walls helps maintain pressure
- Systolic pressure** is the pressure in the arteries during ventricular systole; it is the highest pressure in the arteries
- Diastolic pressure** is the pressure in the arteries during diastole; it is lower than systolic pressure
- A **pulse** is the rhythmic bulging of artery walls with each heartbeat

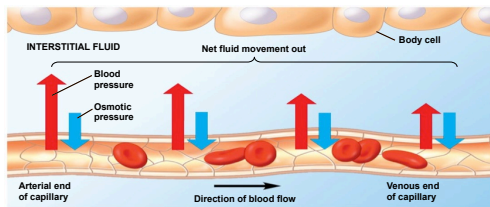
### Regulation of Blood Pressure

- Homeostatic mechanisms regulate arterial blood pressure by altering arteriole diameter
- 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 **decreases blood pressure**

- Fainting is caused by inadequate blood flow to the head
- Animals with long necks need very high systolic pressure to pump blood against gravity!
- Blood is moved through veins by smooth and skeletal muscle contraction, and expansion of the vena cava with inhalation
- One-way valves in veins prevent backflow of blood

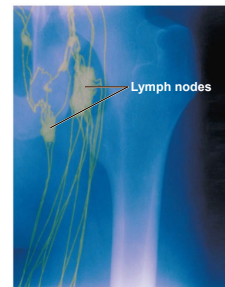


- Exchange of substances between blood and interstitial fluid occurs across the thin endothelial walls of capillaries
- The difference between blood pressure and osmotic pressure drives fluids across capillary walls
- Most blood proteins and all blood cells are too large to pass through the endothelium



### Fluid Return by the Lymphatic System

- The **lymphatic system** returns fluid that leaks from capillary beds (**lymph**), and drains into veins in the neck
- Valves in lymph vessels prevent backflow (**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 immune defense



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

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

### Blood Composition and Function

- Blood in vertebrates is **connective tissue** made of several kinds of cells suspended in a liquid matrix called **plasma**

Plasma 55%		Separated blood elements	Cellular elements 45%		
Constituent	Major functions		Cell type	Number per $\mu\text{L}$ ( $\text{mm}^3$ ) of blood	Functions
Water	Solvent		Leukocytes (white blood cells)	5,000–10,000	Defense and immunity
Ions (electrolytes) Sodium Potassium Calcium Magnesium Chloride Bicarbonate	Osmotic balance, pH buffering, and regulation of membrane permeability		Basophils Lymphocytes		
Plasma proteins Albumin Immunoglobulins (antibodies) Apolipoproteins Fibrinogen	Osmotic balance, pH buffering Defense Lipid transport Clotting		Eosinophils Neutrophils Monocytes		
Substances transported by blood			Platelets	250,000–400,000	Blood clotting
Nutrients (glucose, lipids, vitamins) Waste products of metabolism Respiratory gases ( $\text{O}_2$ and $\text{CO}_2$ ) Hormones			Erythrocytes (red blood cells)	5,000,000–6,000,000	Transport of $\text{O}_2$ and some $\text{CO}_2$

### 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
- Particular 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

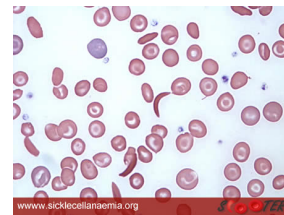
### Cellular Elements

- 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, involved in clotting

### Erythrocytes

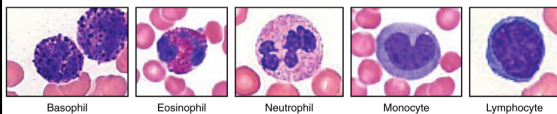
- Red blood cells, or **erythrocytes**, are the most numerous blood cells
- Contain **hemoglobin (Hb)**, the iron-containing protein that transports  $O_2$
- Each molecule of Hb binds up to four molecules of  $O_2$
- In mammals, mature erythrocytes lack nuclei and mitochondria

- Sickle-cell disease** is caused by abnormal hemoglobin proteins that form aggregates
- The aggregates can deform an erythrocyte into a sickle shape
- Sickled cells can rupture or block blood vessels



### Leukocytes

- There are five major types of white blood cells (**leukocytes**): basophils, eosinophils, neutrophils, monocytes and lymphocytes
- Function in defense either by phagocytizing bacteria and debris or mounting immune responses against foreign substances
- They are found both in and outside the circulatory system



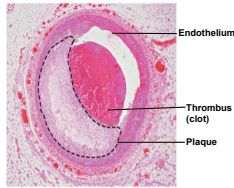
### Stem Cells and the Replacement of Cellular Elements

- Erythrocytes, leukocytes, and platelets all develop from a common source of **stem cells** in the red marrow of bones, especially ribs, vertebrae, sternum, and pelvis
- The hormone **erythropoietin (EPO)** stimulates erythrocyte production when  $O_2$  delivery is low
- Physicians can use recombinant EPO to treat people with conditions such as anemia

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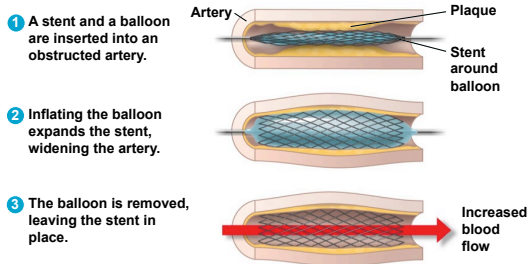
### Cardiovascular Diseases: Atherosclerosis, Heart Attacks, and Stroke

- **Atherosclerosis**, is caused by 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 (bad)
  - **High-density lipoprotein (HDL)** scavenges excess cholesterol for return to the liver (good)
  - Risk for heart disease increases with a high LDL to HDL ratio; inflammation is also a factor



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

Figure 42.20



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### Risk Factors and Treatment of Cardiovascular Disease

- High LDL/HDL ratio increases cardiovascular disease risk
- LDL can be decreased by exercise and avoiding smoking and trans fats
- Drugs called statins reduce LDL and heart attack risk
- Inflammation contributes to atherosclerosis and clots
- Aspirin inhibits inflammation, reduces cardiovascular risk
- **Hypertension** (high blood pressure) also contributes to heart attack and stroke, but can be controlled by dietary changes, exercise, and/or medication

### Concept 42.5: Gas exchange occurs across specialized respiratory surfaces

- **Gas exchange** supplies  $O_2$  for cellular respiration and disposes of  $CO_2$
- **Partial pressure** is the pressure exerted by a particular gas in a mixture of gases in air or liquid
- Gases undergo net diffusion from a region of higher partial pressure to a region of lower partial pressure

### Respiratory Media

- Animals can use air or water as the  $O_2$  source (respiratory medium)
- In a given volume, less  $O_2$  is available in water than air
- Obtaining  $O_2$  from water requires greater efficiency than air breathing

## Respiratory Surfaces

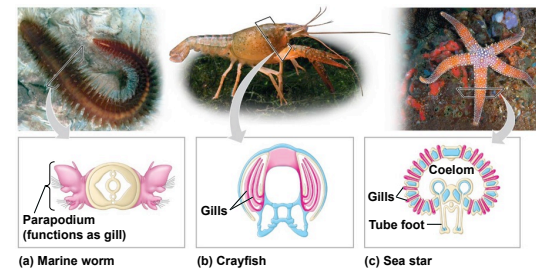
- Animals require large, moist respiratory surfaces for exchange of gases between their cells and the respiratory medium, either air or water
- Gas exchange across respiratory surfaces takes place by diffusion
- Respiratory surfaces vary by animal and can include the **skin, gills, tracheae, and lungs**

## 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

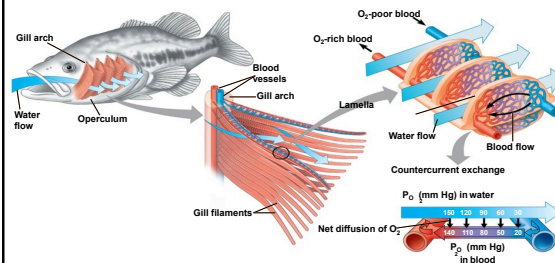


Figure 42.21



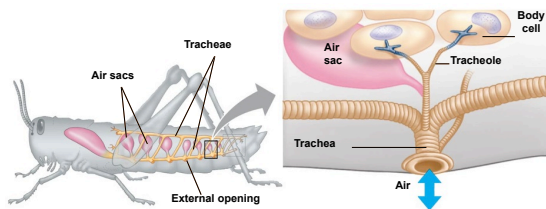
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- Fish gills use **countercurrent exchange**, where blood flows opposite to water passing over gills
- In fish gills, more than 80% of the  $O_2$  dissolved in the water is removed as water passes over the respiratory surface



## Tracheal Systems in Insects

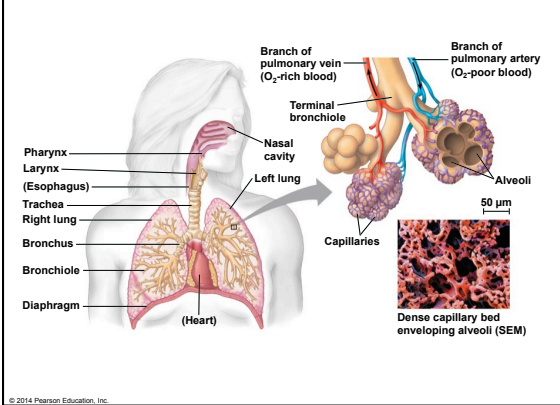
- The **tracheal system** of insects is a network of branching tubes
- Tracheal tubes supply  $O_2$  directly to body cells
- Respiratory and circulatory systems are separate



## Lungs

- Lungs** are an infolding of the body surface; the circulatory system transports gases between lungs and the body
- Lung size and complexity correlate with metabolic rate
- Air passes through the pharynx, larynx, trachea, bronchi, and bronchioles to **alveoli**, where gas exchange occurs
- $O_2$  diffuses through the moist epithelium into capillaries (secretions called **surfactants** coat the surface of alveoli)
- $CO_2$  diffuses from capillaries across epithelium into alveoli for exhalation from body
- Alveoli lack cilia and are susceptible to contamination

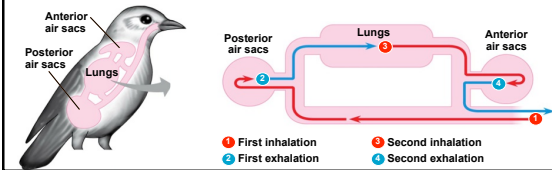
Figure 42.24



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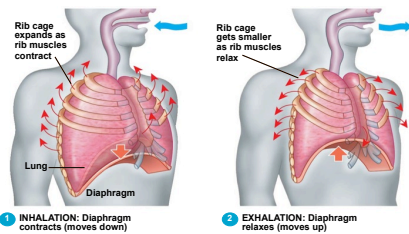
### Concept 42.6: Breathing ventilates the lungs

- The process that ventilates the lungs is **breathing**, the alternate inhalation and exhalation of air
- Amphibians ventilate by **positive pressure breathing**, which forces air down the trachea
- Ventilation in birds is highly efficient; air passes through the lungs in one direction only



### How a Mammal Breathes

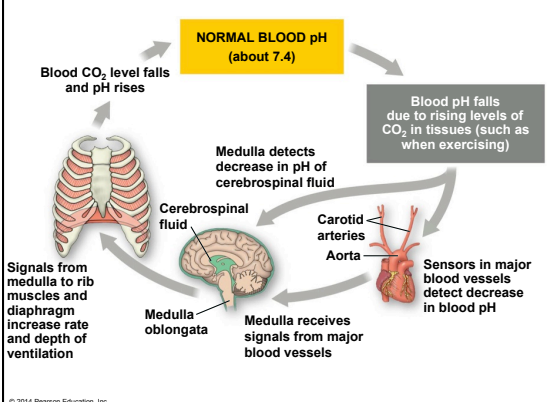
- Mammals ventilate lungs by **negative pressure breathing**, which pulls air into the lungs
- Lung volume increases as rib muscles and **diaphragm** contract
- After exhalation, a **residual volume** of air remains in the lungs



### Control of Breathing in Humans

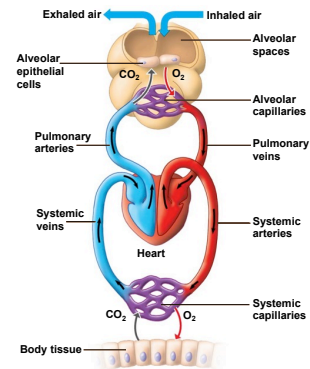
- In humans, breathing is usually regulated by involuntary mechanisms
- The breathing control centers are found in the **medulla oblongata** of the brain
  - Regulates the rate and depth of breathing
  - In response to pH changes in cerebrospinal fluid

Figure 42.28



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### Coordination of Circulation and Gas Exchange



**Two video resources posted on Angel:**

- BioFlix- gas exchange in lungs
  
- Khan Academy- blood flow through the heart
  - <https://www.khanacademy.org/science/health-and-medicine/human-anatomy-and-physiology/heart-introduction/v/flow-through-the-heart>