Chapter 42: Circulation and Gas Exchange

AP Biology 2013

1

Gas Exchange

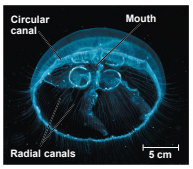
- Unicellular organisms - gas exchange occurs directly with the environment
- Multicellular organisms - direct gas exchange is not possible
- Gills are and example of a gas exchange mechanism
  - O_2 diffuses from water to blood vessels
  - CO_2 diffuses from blood to water

Fig. 42.1

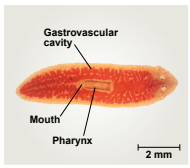
2

Circulatory System and Phylogeny

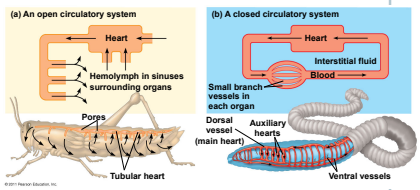
- Transport systems connect the organs of exchange with body cells
- Internal transport systems circulate fluid that provides a link between the aqueous cell environment and the exchange organs (lungs)
- Invertebrate circulation
  - Simple animals (like cnidarians) have a body wall only two cells thick with a gastrovascular cavity (functions in both digestion and distribution of substances throughout the body)
  - More complex animals have either an open or closed circulatory system
    - Both have a circulatory fluid (blood), set of tubes (vessels), and a muscular pump (heart)



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



(b) The planarian *Dugesia*, a flatworm

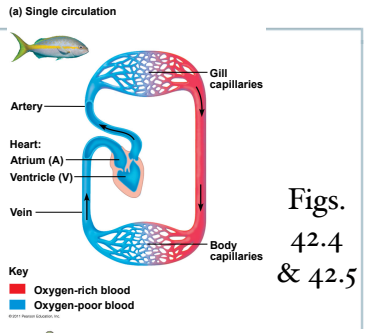


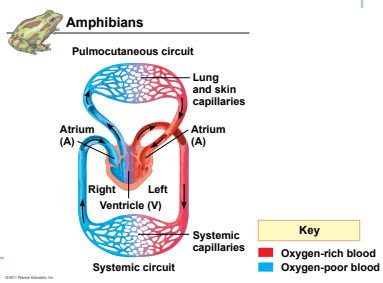
Figs. 42.2 & 42.3

3

Cardiovascular System

- Vertebrates - closed circulatory system called a cardiovascular system
- Blood flows in a closed system consisting of blood vessels and a two to four chambered heart
  - Arteries carry blood to capillaries (site of chemical exchange between blood and intestinal fluid)
  - Veins return blood from capillaries to heart
- Fish - heart has two chambers (one ventricle and one atrium)
  - Blood pumped from ventricle travels to gills where it picks up O_2 and disposes of CO_2
- Amphibians - have a three chambered heart with two atria and one ventricle
  - Ventricle pumps blood into a forked artery and splits the output into pulmocutaneous circuit and systemic circuit



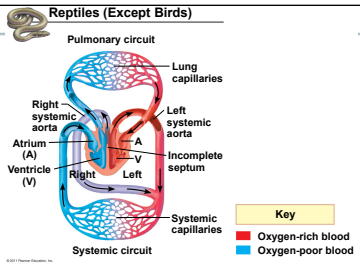


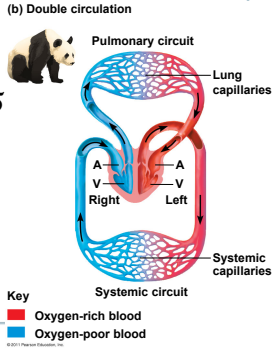
Figs. 42.4 & 42.5

4

Cardiovascular System

- Reptiles - have double circulation with a pulmonary circuit and a systemic circuit
  - Turtles, snakes, and lizards have a three-chambered heart
- Mammals and birds - ventricle is completely divided into separate right and left chambers
  - Left side of the heart pumps and receives only oxygen-rich blood
  - Right side receives and pumps only oxygen-poor blood
  - Four-chambered heart was an essential adaptation of the endothermic way of life





Figs. 42.4 & 42.5

5

Double Circulation

- Depends on anatomy and pumping cycle of the heart
- Structure and function of the human circulatory system can serve as a model for exploring mammalian circulation in general
- Heart valves - dictate one-way flow of blood through the heart
- Pattern of flow:
  - Blood flow begins with the right ventricle pumping blood into the lungs (loads O_2 and unloads CO_2)
  - Oxygen-rich blood then enters the left atrium and is pumped to the body tissues by the left ventricle
  - Blood returns to the heart through the right atrium

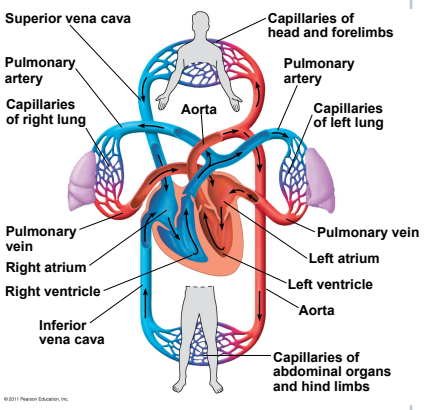
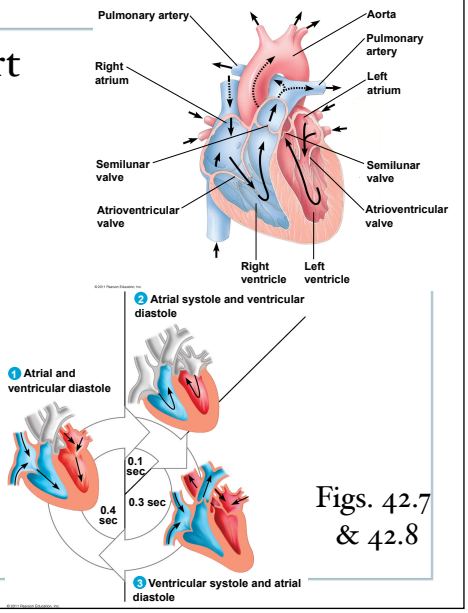


Fig. 42.6

6

Mammalian Heart

- Contract and relaxes in a rhythmic cycle called the cardiac cycle
  - Systole - contraction/ pumping phase
  - Diastole - relaxation/ filling phase
- Heart rate is called the pulse (beats per minute)
- Cardiac output - volume of blood pumped into the systemic circulation per minute



Figs. 42.7 & 42.8

7

Heart Rhythm

- Some muscle cells are self-excitable (contract without any signal from the nervous system)
- Sinoatrial (SA) node (pacemaker) - sets the rate and timing at which all cardiac muscle cells contract (influenced by nerves, hormones, body temperature, and exercise)
  - Impulses from the SA node travel to the atrioventricular (AV) node
    - Impulse is delayed at the AV node and then travels to the Purkinje fibers that make the ventricles contract
- Impulses can be recorded by an electrocardiogram (ECG or EKG)

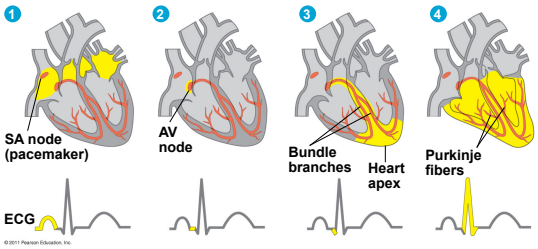


Fig. 42.9

8

Blood Circulation

- Same physical properties that govern water flowing through a pipe govern blood circulation.
- All blood vessels are built of similar tissues and have three similar layers
- Structural differences in arteries, veins, and capillaries correlate with different functions
  - Arteries have thicker walls to accommodate high pressure blood pumped from the heart
  - Veins have thinner walls because blood flows back to the heart as a result of muscle contraction

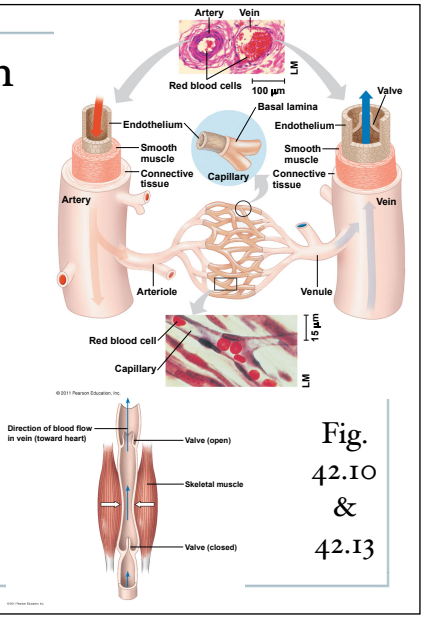
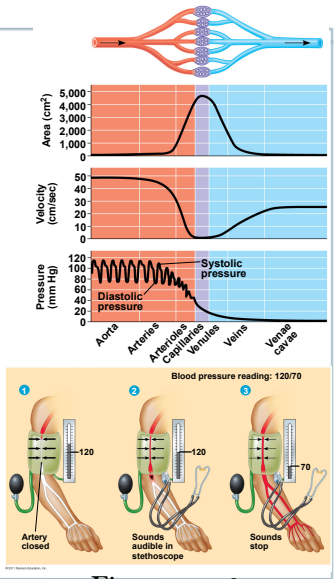


Fig. 42.10 & 42.13

9

Blood Circulation

- Velocity of blood flow varies in the circulatory system
  - Slowest in the capillary beds because of high resistance and large total cross-sectional area
- Blood pressure is the hydrostatic pressure that blood exerts against the wall of a vessel
  - Systolic pressure is the pressure in the arteries during ventricular systole (highest pressure in the arteries)
  - Diastolic pressure is the pressure in the arteries during diastole (lower than systolic pressure)
  - Determined by cardiac output and resistance

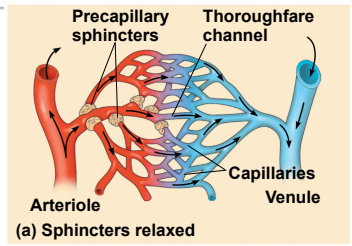


Figs. 42.11 & 42.12

10

Capillaries

- Usually filled to capacity
- Two mechanisms that regulate distribution of blood in capillary beds:
  - One mechanism involves contraction of smooth muscles in the wall of an arteriole to constrict the vessel
  - Second involves precapillary sphincters to control the flow of blood between arterioles and venules
- Critical exchange of substances between the blood and interstitial fluid takes place in the thin endothelial wall of the capillaries



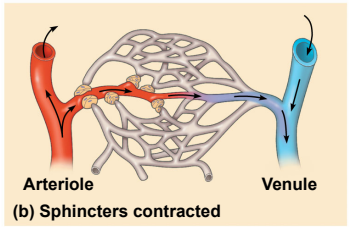


Fig. 42.14

11

Capillaries

- Difference between blood pressure and osmotic pressure drives fluid out of the capillaries at the arteriole end and into the capillaries at the venule end
- The lymphatic system returns fluid from the body from the capillary beds and also aids in defense
- Fluid directly reenters circulation at the venous end of the capillary bed and indirectly through the lymphatic system

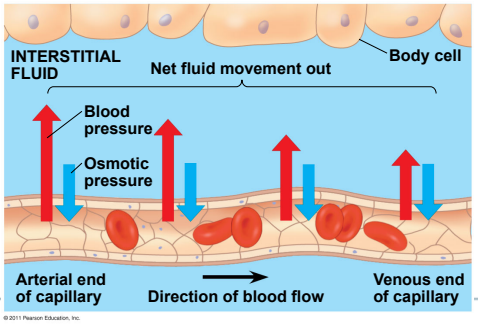


Fig. 42.15

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Lymphatic System

- Returns fluid that leaks out from the capillary beds
- Fluid (called lymph) reenters the circulation directly at the venous end of the capillary bed and indirectly through the lymphatic system which drains into veins in the neck
- Valves in the lymph vessels prevent the backflow of fluid
- Lymph nodes filter lymph and help in body defenses

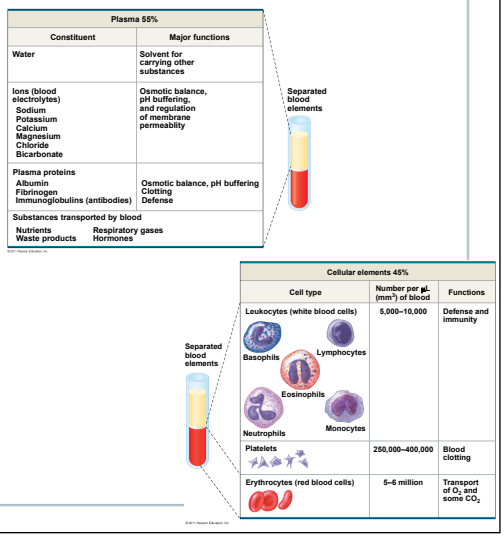
Fig. 42.16

13

Blood

Fig. 42.17

- Connective tissue with cells suspended in plasma
- Consists of several kinds of cells (45% of blood)
  - Red blood cells (transport oxygen)
  - White blood cells (defense)
  - Platelets (involved in clotting)
- Blood plasma is about 90% water with solutes like inorganic salts in the form of dissolved ions (electrolytes)
  - Plasma also contains proteins which influence pH, osmotic pressure, and viscosity. These proteins also function in lipid transport, immunity, and blood clotting.



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Blood Cells

- Erythrocytes - red blood cells (transport oxygen)
- Leukocytes - white blood cells (defense)
  - Monocytes, neutrophils, basophils, eosinophils, and lymphocytes
  - Function by phagocytizing bacteria and debris by producing antibodies
- Stem cells help to replace worn out cells throughout an animal's life
  - All blood cells develop from a common source

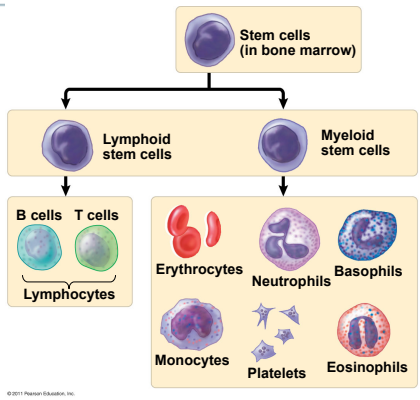

Fig. 42.16

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Clotting

- When the endothelium of a blood vessel is damaged the mechanism of clotting begins
- A cascade of reactions converts fibrinogen to fibrin forming a clot

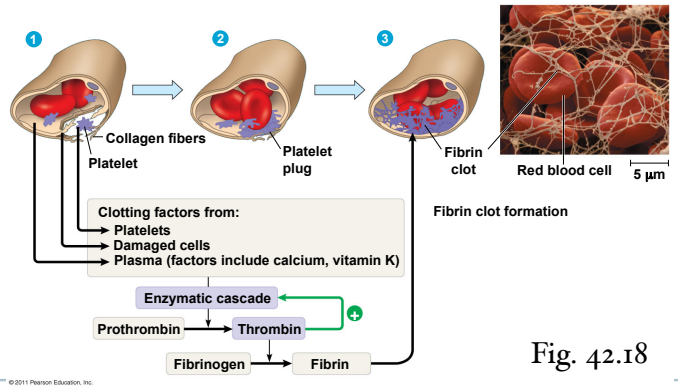

Fig. 42.18

16

Cardiovascular Disease

- Disorders of the heart and blood vessels (account for more than half of the deaths in the U.S.)
- Atherosclerosis - caused by buildup of cholesterol within arteries
- Hypertension - high blood pressure (promotes atherosclerosis and increased risk of heart attack or stroke)
- Heart attack (myocardial infarction) - death of cardiac muscle tissue resulting from a blockage of one or more coronary arteries
- Stroke - death of nervous tissue in the brain usually from a rupture or blockage of arteries in the brain

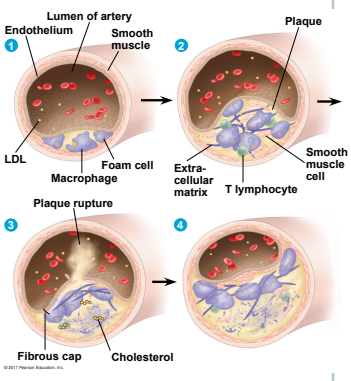

Fig. 42.20

17

Gas Exchange

- Supplies oxygen for cellular respiration and disposes of carbon dioxide
- Animals require large, moist, respiratory surfaces for the adequate diffusion of respiratory gasses between the cells at the respiratory medium (either air or water)

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Gills

- Outfoldings of the body surface specialized for gas exchange
- In some invertebrates the gills have a simple shape and are distributed all over the body
- Segmented worms have flaplike gills that extend over body segments
- Clams and crayfish are restricted to a local body region

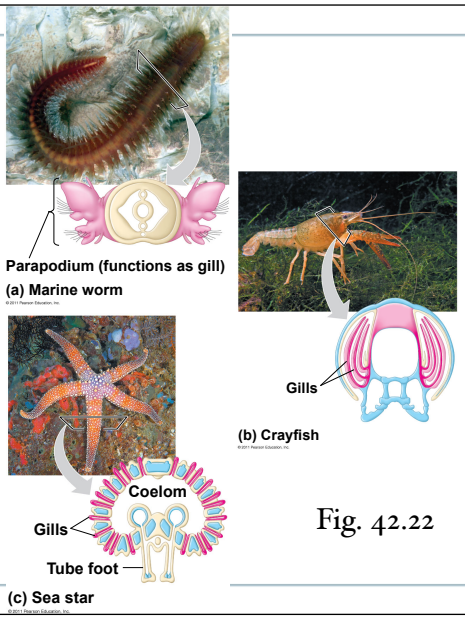

Fig. 42.22

19

Gills

- Effectiveness of gas exchange in some gills (including fish)
  - Increased by ventilation and countercurrent flow of blood and water

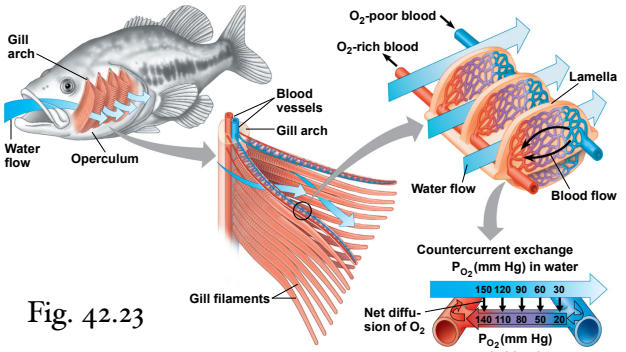

Fig. 42.23

20

Tracheal Systems

- Insects have a tracheal system that consists of tiny branching tubes that penetrate the body
- The tubes supply oxygen directly to the body cells

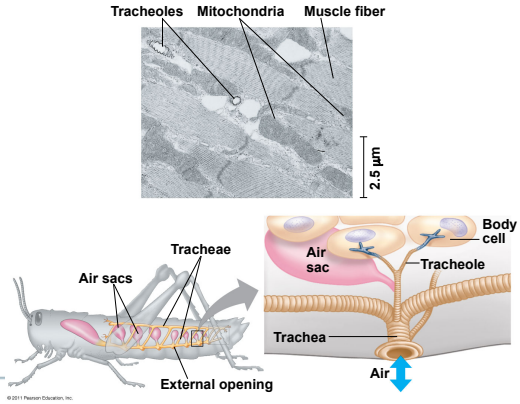

Fig. 42.24

21

Lungs

- Spiders, land snails, and most terrestrial vertebrates have internal lungs
- System of branching ducts that conveys air to the lungs
- Air passes through the nostrils passes through the pharynx, trachea, bronchi, bronchioles, and alveoli (where gas exchange occurs)

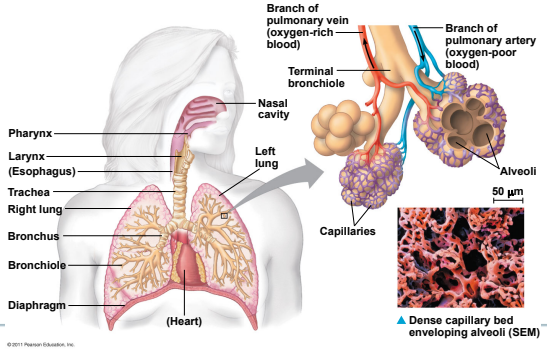

Fig. 42.25

22

Breathing

- Ventilation of the lungs
- Amphibians ventilate by positive pressure breathing which forces air down the lungs
- Mammals ventilate lungs by negative pressure breathing (pulls air into the lungs)
  - Lung volume increases as the rib muscles and diaphragm contract

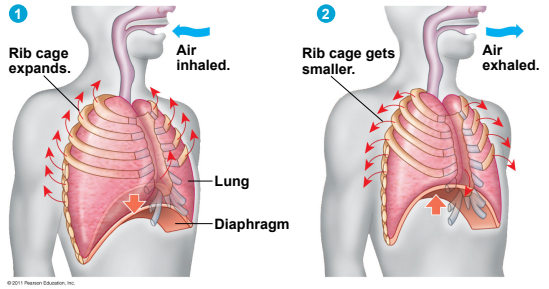

Fig. 42.28

23

Breathing

- Birds
  - Also have air sacs that function as bellows which keep air flowing through the lungs
- Air passes through the lungs in one direction only (every exhalation completely renews the lungs)

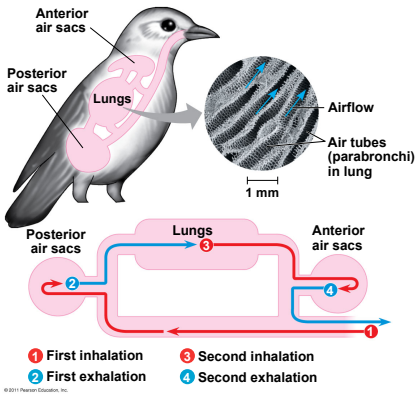

Fig. 42.27

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Control of Breathing

- Main breathing control centers are in two regions of the brain (medulla oblongata and the pons)
- Medulla regulates the rate and depth of breathing in response to pH changes in the cerebrospinal fluid
  - Adjusts breathing rate and depth to match metabolic demands
- Sensors in the aorta and carotid arteries monitor O_2 and CO_2 concentrations in the blood and exert a secondary control

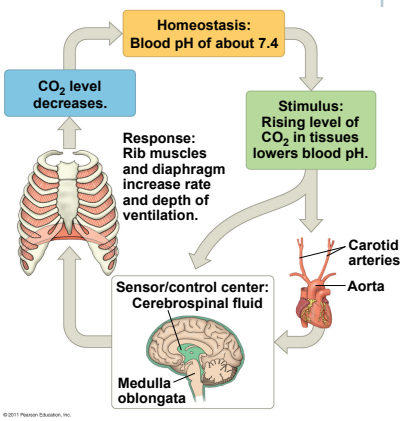

Fig. 42.29

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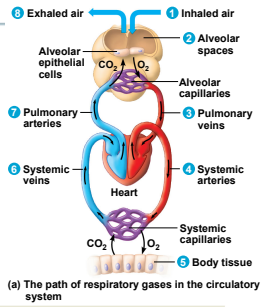
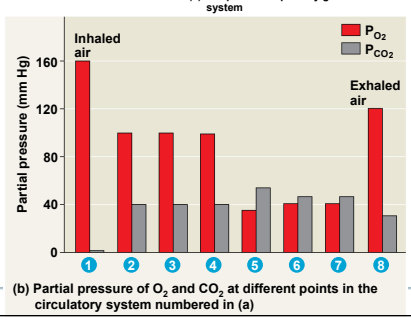
Gas Transport

- Gasses diffuse down pressure gradients in the lungs and other organs
- Diffusion of a gas depends on differences in quantity called partial pressure
- Gases always diffuse from a region of high partial pressure to a region of low partial pressure
- In the lungs and tissues, O_2 and CO_2 diffuse from where their partial pressures are higher to where they are lower



(a) The path of respiratory gases in the circulatory system

Fig. 42.30



(b) Partial pressure of O_2 and CO_2 at different points in the circulatory system numbered in (a)

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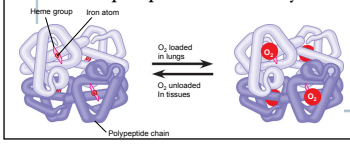
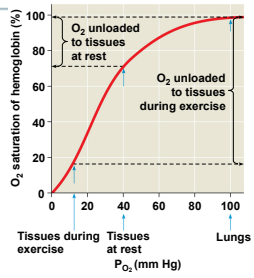
Gas Transport

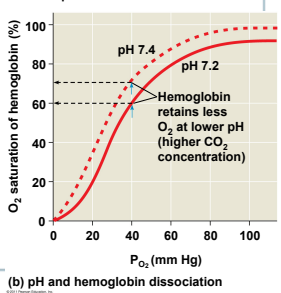
- Respiratory pigments are the proteins that transfer oxygen
- Hemoglobin is the respiratory pigment in almost all vertebrates
  - Contained in erythrocytes
  - Must reversibly bind O_2 when loading in the lungs and unloading at the other body tissues
  - Binding of O_2 to one subunit of hemoglobin increases the O_2 affinity in the other subunits
  - Drop in pH lowers affinity for O_2





(a) P_{O_2} and hemoglobin dissociation at pH 7.4

Fig. 42.31



(b) pH and hemoglobin dissociation

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Gas Transport

- Hemoglobin also helps in the transport of CO_2
- Also assists in buffering
- Carbon from respiring cells diffuses into the blood plasma and then into erythrocytes and is ultimately released in the lungs

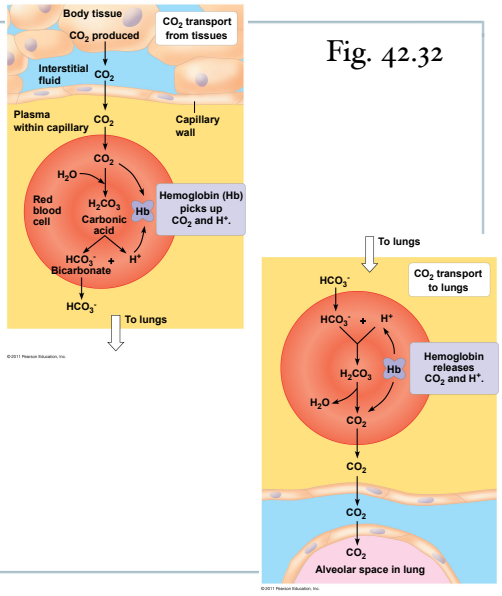

Fig. 42.32

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Helpful Adaptations

- Migratory and diving mammals have adaptations that allow them to perform extraordinary feats
- Extreme O_2 consumption of the antelope-like pronghorn allows it to run at high speeds over long distances
- Deep-diving air breathers have to stockpile O_2 and deplete it slowly

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