Chapter 42: Circulation and Gas Exchange

42.1 Compare and contrast the structure and functions of the major classes of circulatory systems in animals.

42.2 Describe the role of the major structures of the heart during contraction and relaxation.

42.3 Identify the types of blood vessels and their functions in maintaining and regulating blood flow.

42.4 List the components of mammalian blood and their functions in exchange, transport, and defense.

42.5 Compare and contrast the respiratory systems of aquatic animals, insects, and mammals.

42.6 Describe the mechanisms for ventilating bird and human lungs, as well as the feedback pathways regulating human breathing.

42.7 Use examples to describe the adaptive properties of respiratory pigments in gas exchange between body cells and the environment.

This chapter on circulation and gas exchange is rich with material that illustrates important aspects of biology. The movement of materials from the bloodstream into the cells involves all aspects of active and passive transport, a key concept. Gas exchange also involves transport and several other important ideas, including the effect of changes in pH on the protein hemoglobin and its effect on oxygen delivery. Illustrative examples seem to be on every page!

Study Tip: A careful study of Figure 42.1 in your text will give you the overall architecture for how the respiratory and circulatory systems work together to deliver oxygen to the tissues and remove carbon dioxide. At the bottom of the figure the diagram shows O_2 going into the tissues and CO_2 coming out of the tissues.

a. Explain how the tissues use O_2.

b. Where does the constant accumulation of CO_2 originate?

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

LO 42.1: Compare and contrast the structure and functions of the major classes of circulatory systems in animals.

1. Gaining O_2 and nutrients while shedding CO_2 and other waste products occurs with every cell in the body. However, diffusion is rapid only over small distances. Describe two solutions to this problem that are the result of natural selection.

2. Remember from Chapter 41 that you should look at how various animal groups solve the same problem. *Cnidarians*, like the moon jelly in Figure 42.2 in your text, and *planarians* do not have a distinct circulatory system. How have they solved the problem of exchange?

3. Larger animals must have a circulatory system to move fluid between cells and the outside environment. What are the three basic components of a circulatory system?

4. What is *hemolymph*?

5. Contrast *open circulatory systems* with *closed circulatory systems*.

6. Complete the following chart. You will find the anatomical descriptions at the beginning of Concept 42.3, Blood Vessel Structure and Function.

Blood Vessel	Function	Anatomical Description
Artery		
Arteriole		
Vein		
Venule		
Capillary		

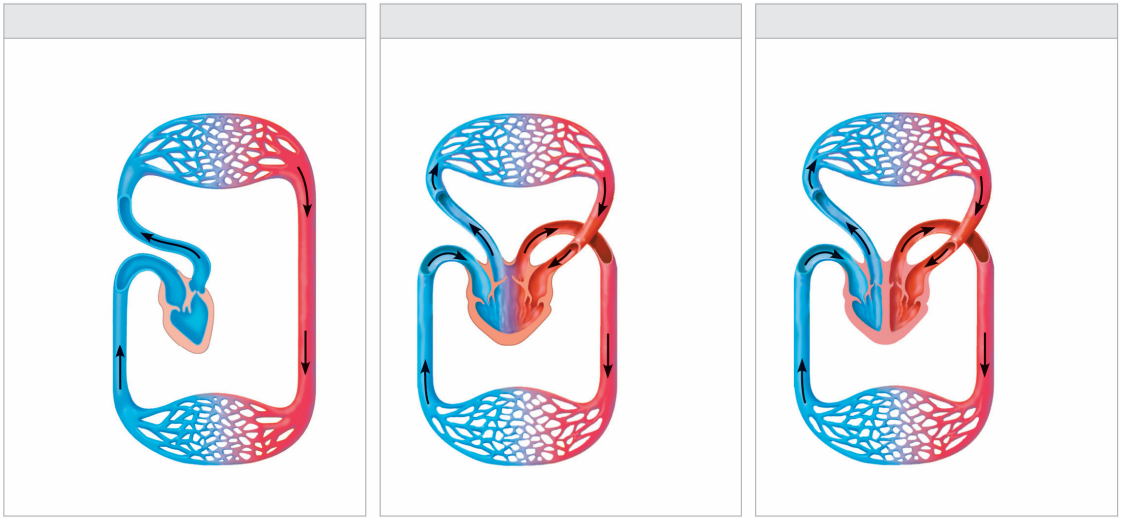
7. a. What is the function of the *atria*?

   b. What is the function of the *ventricles*?

8. Explain the difference between single and double circulation.

9. In a circulatory system, exchange occurs in two general places. Blood goes to a respiratory surface (lungs, gills, skin) or to the organs and tissues of the body (systemic circulation). Through which type of blood vessel does exchange actually occur?

10. Look at the following figure. Label the sketches *fish*, *amphibian*, and *mammal*, respectively. Note that each shows blood going to two places, as previously described. Below each sketch, discuss the differences between the groups, focusing on heart chambers, blood flow, and level of oxygen in the blood as it flows through the heart and systemic circuits.



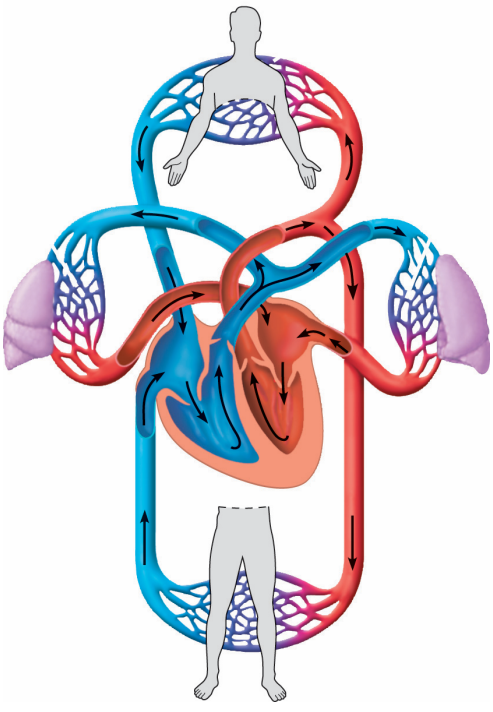
11. Why is a four-chambered heart a key adaptation required for *endothermy*?

12. Use the four-chambered heart of birds and mammals to explain the concept of convergent evolution.

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

LO 42.2: Describe the role of the major structures of the heart during contraction and relaxation.

13. The following figure is vital to your overall understanding of mammalian circulation. Label the following: *aorta*, *pulmonary artery*, *left lung*, *right lung*, *left atrium*, *left ventricle*, *aorta*, *inferior vena cava*, *superior vena cava*, *systemic circulation*, and *pulmonary circulation*. Then reread this section in your book, and trace what is happening from **Point 1** to **Point 11.**



14. Now that you have the anatomy down, it is time to look at how the heart works. Explain each of the following terms.

    cardiac cycle

    systole

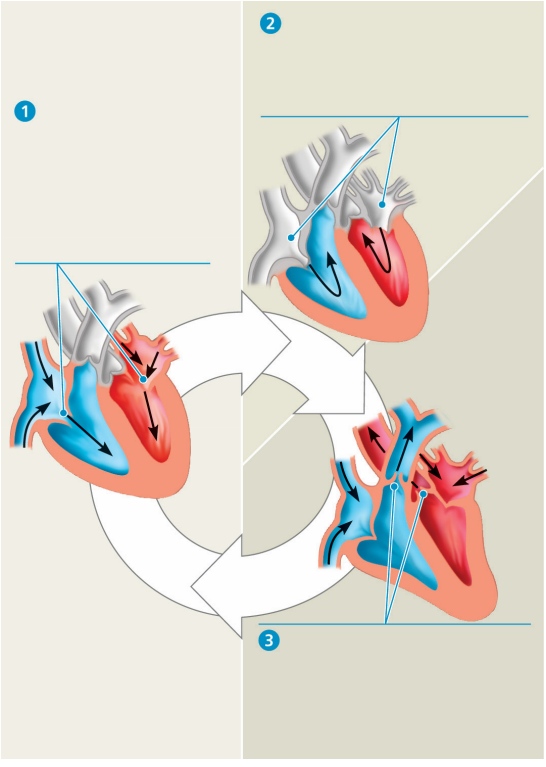
    diastole

    cardiac output (Include the two factors that determine it.)

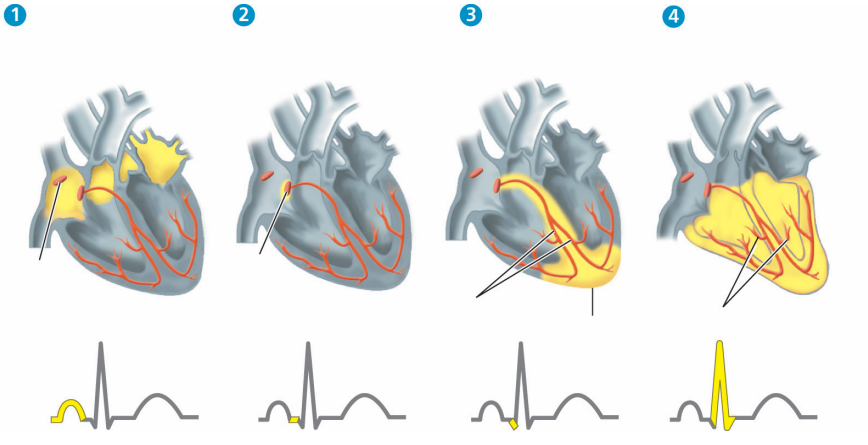
15. Explain the specific roles of the *atrioventricular valves* and the *semilunar valves*.

16. What is a *heart murmur*?

17. Heartbeat rhythm is maintained by electric impulses that are generated from modified cells found in the wall of the right atrium, called the *sinoatrial (SA) node or pacemaker*. Label this figure of the cardiac cycle and then explain the cycle at each blue number.



18. Label the figure below and then explain the four steps to control of the heart rhythm. During which step do the atria contract? The ventricles? Include this information on the figure.



19. The cells of the heart's pacemaker will respond to inputs to regulate heart rate. List three inputs that alter heart rate and describe a specific example of each.

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

LO 42.3: Identify the types of blood vessels and their functions in maintaining and regulating blood flow.

You should have provided anatomical descriptions of all blood vessels types in the chart with question 6.

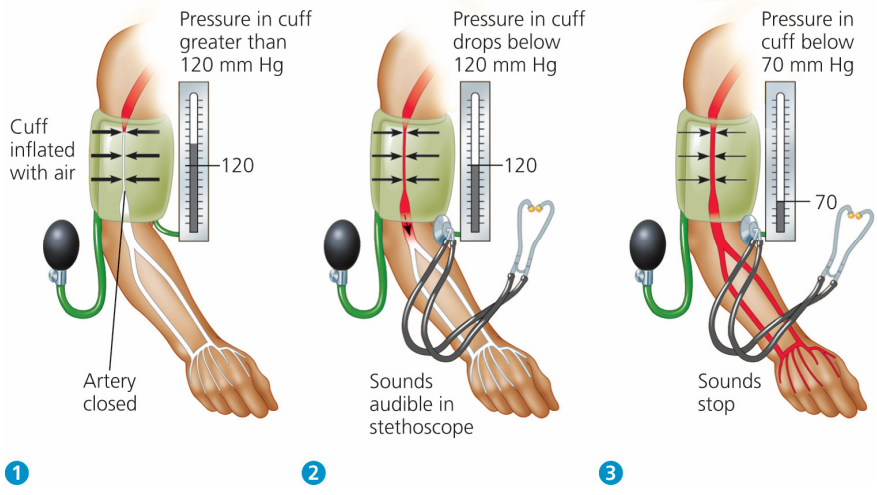
20. How do structure and function correlate in the *capillaries*?

21. What anatomical feature of the *veins* maintains a unidirectional flow of blood back toward the heart?

22. As blood vessel diameter decreases, *blood velocity* will _____.

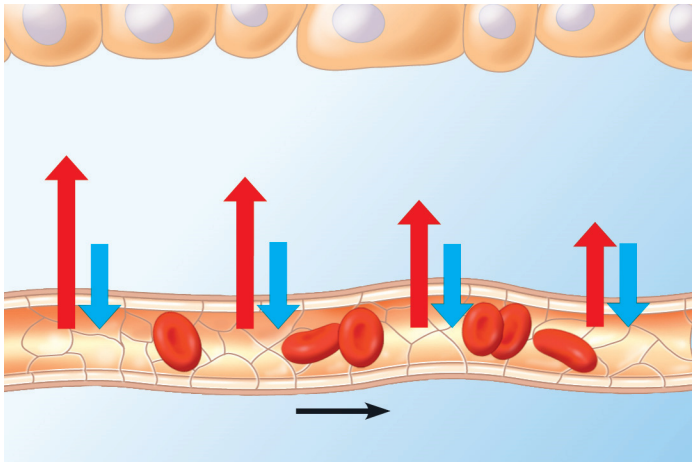
23. Why does blood *slow* as it moves from arteries to arterioles to capillaries? Why is this important?

24. Use this figure to explain how a *sphygmomanometer* is used to measure blood pressure. Number and explain the three key "listening points" involved in determining blood pressure.



25. If the blood pressure is reported as 110/80, what is the diastolic pressure?

26. Explain the exchange of fluid at the two ends of a capillary by annotating this figure. Include these terms in your discussion: *interstitial fluid*, *osmotic pressure*, and *blood pressure*.



27. Why does the presence of blood proteins tend to pull fluid back into the capillaries?

28. The capillaries "leak" about 4 L of fluid each day. How is this returned to the blood?

29. What is *lymph*? Is it more like blood or more like interstitial fluid?

30. We don't have a second heart to pump lymph. What keeps lymph moving along?

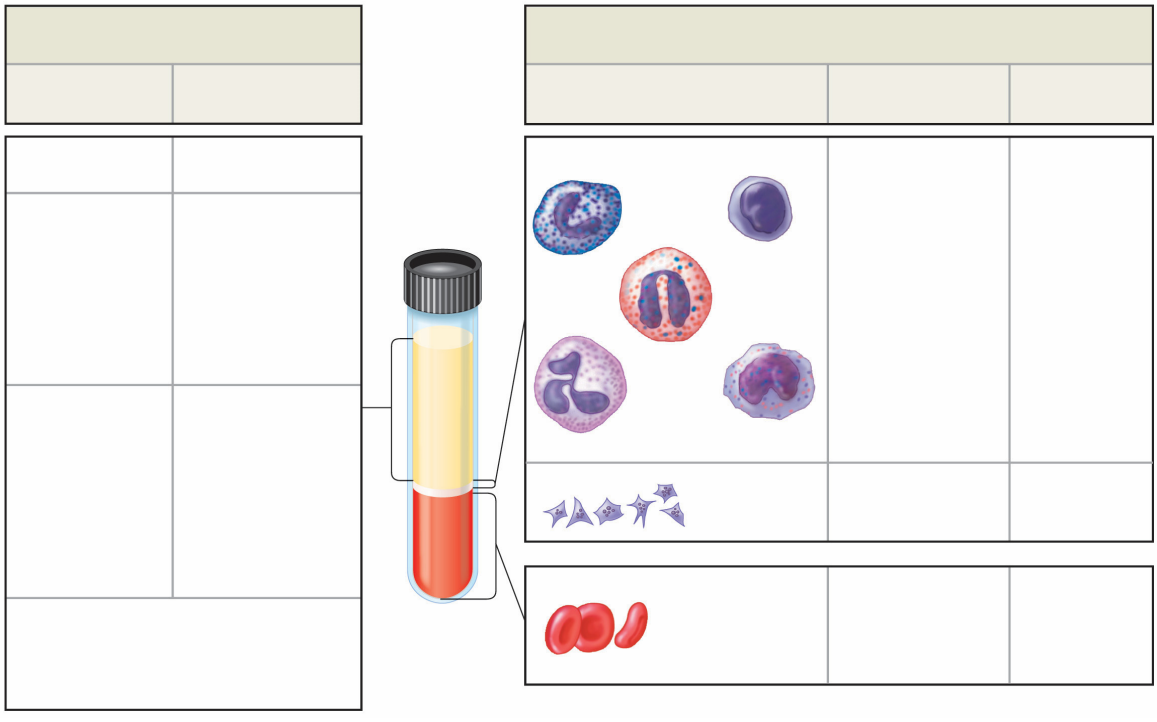
31. Name three places you have *lymph nodes*. What are two functions of these nodes?

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

LO 42.4: List the components of mammalian blood and their functions in exchange, transport, and defense.

32. Blood separates into two components, a liquid matrix called _____ and the *cellular elements*.

33. Label *plasma* and *cellular elements* on the following figure. What is the relative percentage of each? Note this on the figure. Then, name each type of cell and give its function. Finally, list the four major constituents of plasma. What are their functions?



34. Describe three ways in which the structure of an *erythrocyte* enhances its function, which is to transport oxygen. This is an excellent example of how structure and function are interrelated.

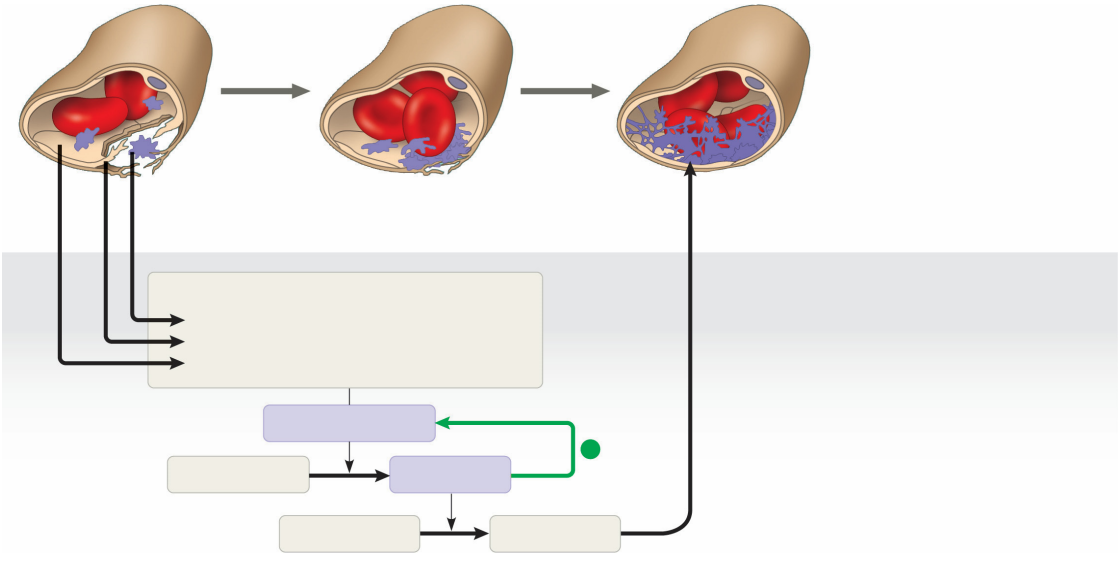
35. What is the role of *hemoglobin*? What mineral is required to make it?

36. How does *sickle-cell disease* affect the ability of the respiratory system to deliver oxygen and remove waste? (An excellent explanation on sickle-cell disease is found in the Make Connections feature on page 502.)

37. Where are *blood stem cells* found?

38. What is *erythropoietin (EPO)*? What will stimulate its production?

39. Blood clotting involves a pathway of several steps. It begins when *platelets* begin to form a plug in the blood vessel wall, and damaged platelets release a chemical that initiates a clotting cascade. Focus on what happens to the plasma protein *prothrombin* and *fibrinogen* when this cascade begins. Complete the blocks on this figure, beginning with the release of clotting factors.



40. What causes the development of a *plaque* in *atherosclerosis*?

    a. Compare a *heart attack* (myocardial infarction) to a *stroke*.

    b. Compare the function and health impacts of *LDLs* to *HDLs*.

    c. What is *hypertension* and how does it harm blood vessels?

Concept 42.5 Gas exchange occurs across specialized respiratory surfaces

LO 42.5: Compare and contrast the respiratory systems of aquatic animals, insects, and mammals.

41. What is meant by the *partial pressure* of a gas?

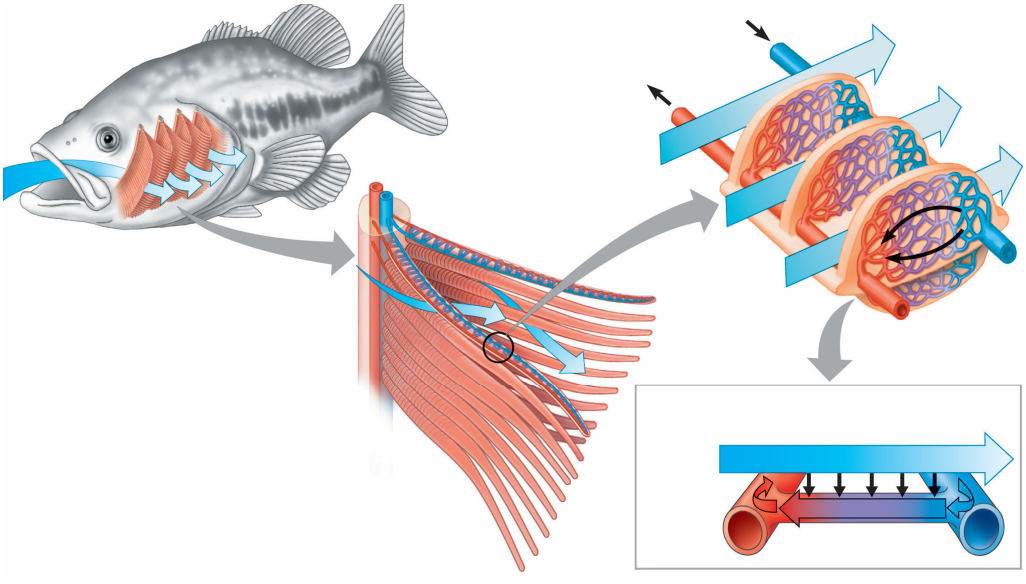
42. Mountain climbers are acutely aware that an increase in elevation causes a reduction in atmospheric pressure. Calculate the partial pressure of oxygen if the air pressure is 520 mm Hg. Show work! (You will find the solution at the end of this chapter).

43. A gas always diffuses from a region of _____ partial pressure to a region of _____ partial pressure.

44. Gas exchange with water as the respiratory medium is much more demanding than exchange with the air. What are three reasons for this?

45. There are several requirements for a respiratory surface. It must be *moist*, have a *large surface area*, and be *thin*. What four different organs satisfy these requirements?

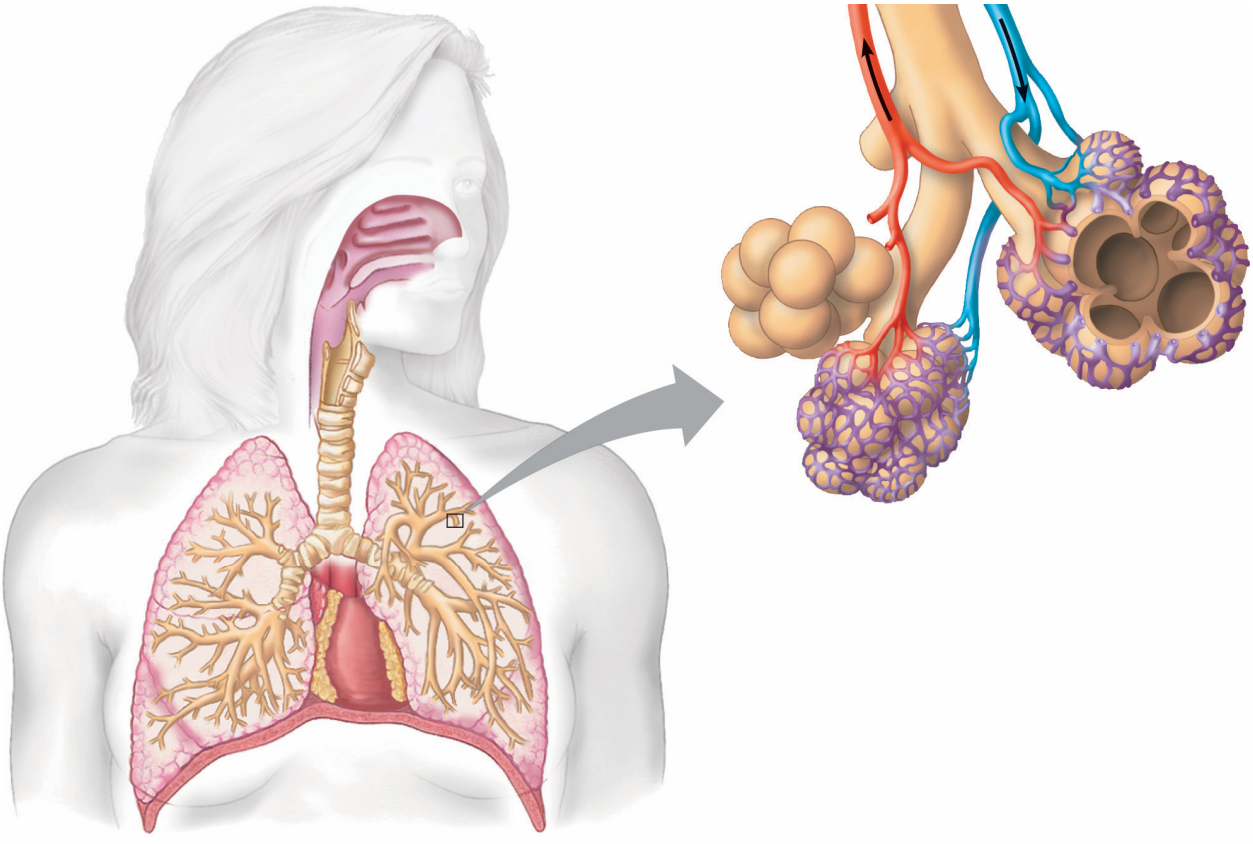
46. *Gills* serve as the respiratory organ in many aquatic animals. Figure 42.22 in your text uses arrows to show the flow of water. The most significant part of this figure is the portion that shows the countercurrent flow of water and blood. Study carefully the paragraph that describes *countercurrent exchange*, and then label this figure to explain how oxygen is taken up over the length of a capillary.



47. Consider this question to see if you understand the advantage of a *countercurrent exchange* system. Without countercurrent exchange, what would be the maximum absorption percentage if O_2 simply diffused from water to blood in the gills? (See Figure 42.22 in your text.)

48. What is the most common respiratory structure among terrestrial animals? What groups have this system?

49. Let's look at the anatomy of a mammalian respiratory system. On this figure, label each of the following structures and explain its function or describe it: *pharynx*, *larynx*, *trachea*, *left and right lungs*, *left and right bronchi*, *bronchioles*, and *alveoli*.

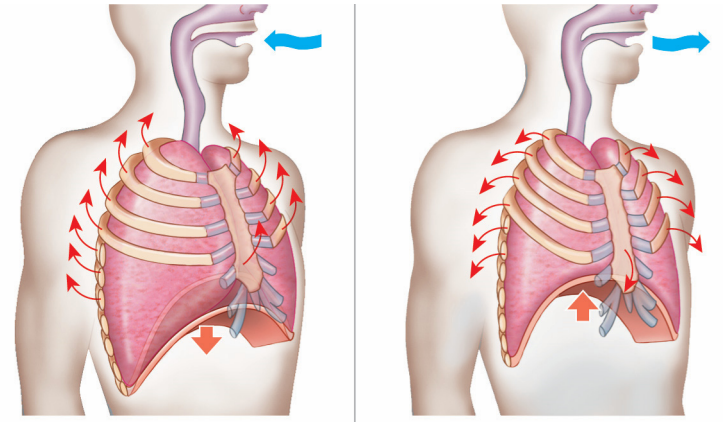


50. Explain the function of a *surfactant* in the lungs and its relationship to *respiratory distress syndrome*. (What would it feel like to discover something that would save the lives of 10,000 infants in a year just in the United States? No wonder Mary Ellen Avery won the National Medal of Science!)

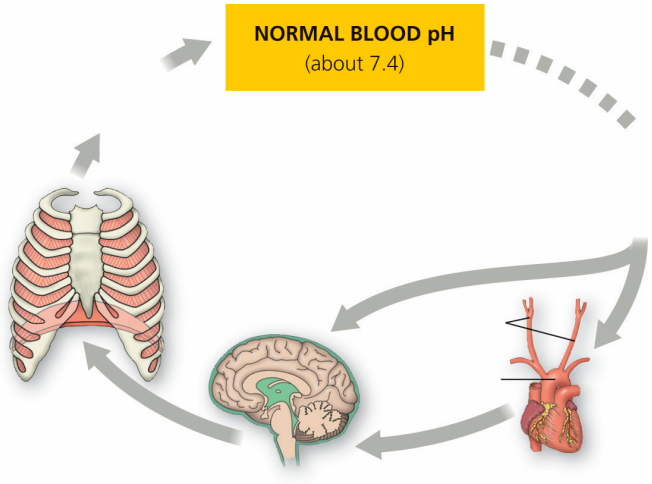
Concept 42.6 Breathing ventilates the lungs

LO 42.6: Describe the mechanisms for ventilating bird and human lungs, as well as the feedback pathways regulating human breathing.

51. Use the following sketch to explain how *negative pressure breathing* occurs in mammals.



52. It always surprises our students to discover that their increased respiration rate during exercise is not controlled by oxygen monitoring but by the monitoring of CO_2. Use the figure below to explain the homeostatic control of breathing.



53. Write out the equation that shows the formation of carbonic acid and the bicarbonate ion. How does this explain blood pH change as CO_2 increases?

54. Read carefully to answer this question: In general, what has a greater effect on the rate of respiration, low levels of O_2 or high levels of CO_2? Explain why.

Concept 42.7 Adaptations for gas exchange include pigments that bind and transport gases

LO 42.7: Use examples to describe the adaptive properties of respiratory pigments in gas exchange between body cells and the environment.

55. Using Figure 42.29 in your text, trace oxygen and carbon dioxide from the point of inhalation to exhalation. Your answer will involve six reference points.

56. Which two of your six steps in the previous question have the highest oxygen partial pressures?

57. What is the *respiratory pigment* in vertebrates?

58. *Hemoglobin* is a protein with quaternary structure. How many subunits does it have? What is the role of iron?

59. Explain the role of cooperativity in both loading and unloading oxygen.

    a. Because of the effect of subunit cooperativity, a slight drop in P_{O_2} causes a(n) _____in the amount of O_2 the blood unloads.

    b. As pH of the blood decreases, the affinity of hemoglobin for oxygen decreases, and oxygen is released from hemoglobin. What is this called?

60. Study Figure 42.31 a in your text.

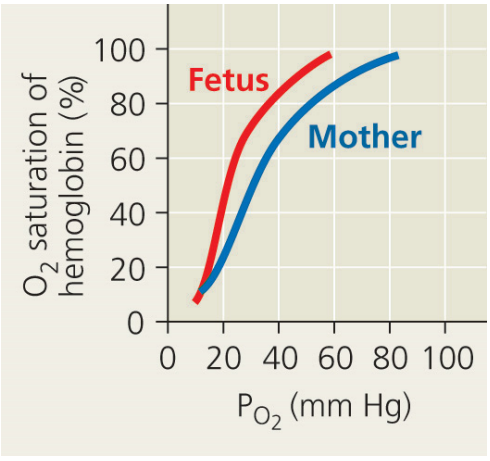
    a. What is the % O_2 saturation level of hemoglobin in the lungs?

    b. What is the % O_2 saturation level of hemoglobin in tissues at rest?

    c. When exercising?

61. The loading of oxygen is only one piece of the respiratory puzzle. The body must also remove carbon dioxide. Where does the constant production of carbon dioxide originate and how is it removed from the body?

62. Fetal hemoglobin and adult hemoglobin are different, as the dissociation curves indicate in the figure. Formulate a hypothesis to explain this difference.



63. We are not sure where the humans are that can swim to 20 meters and hold their breath for two to three minutes, but even these superhumans would pale in a contest with Weddell seals. What is the secret to the remarkable ability of these seals to dive so deep and stay below water for extended time periods?

Solution to Question 42: At 520 mm Hg the partial pressure of oxygen is 0.21 × 520 mm Hg = **109.2 mm Hg**.

Testing Your Understanding, p. 951.

1. _____ 2. _____ 3. _____ 4. _____ 5. _____ 6. _____

7. _____