Respiration: The Exchange of Gases 22

Most of the time we don't give respiration much thought. It just happens without thinking—a process "as natural as breathing." But have you ever been short of breath on a mountain hike or had "the wind knocked out of you" on an athletic field? Have you ever choked on a piece of food or been knocked down by a wave at the beach and come up coughing and sputtering? When breathing is interrupted, even for a few seconds, we realize how important every breath is. Breathing is part of the process of gas exchange. Not all animals breathe as we do, but they do need to obtain oxygen from their environment and dispose of carbon dioxide. This chapter is about the vital subject of gas exchange.

Organizing Your Knowledge

Exercise 1 (Module 22.1)

In most animals, there are three phases of gas exchange: **breathing, transport** of gases by the circulatory system, and **exchange** of gases with tissues. State which phase is interfered with in each of the following situations.

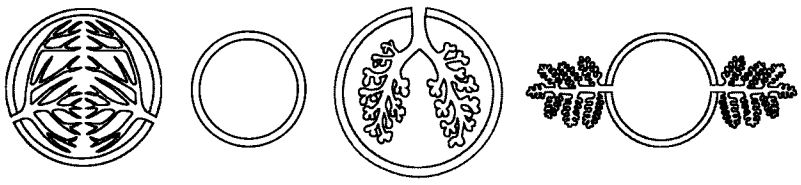
_____ 1. In the disease cystic fibrosis, thick mucus coats the inside of the lungs, blocking passage of gases.
_____ 2. A broken neck can paralyze the muscles of the chest.
_____ 3. Babies sometimes inhale small objects that can block the windpipe.
_____ 4. Anemia is a decrease in the oxygen-carrying protein hemoglobin.
_____ 5. During a heart attack, blockage of a blood vessel causes heart muscle cells to die from lack of oxygen.
_____ 6. An asthma attack narrows air passages into the lungs.
_____ 7. Bedridden patients sometimes get bedsores when blood vessels to the skin are pinched.
_____ 8. A mountain climber is breathing rapidly and his heart is beating strongly, but in the thin air there is not enough oxygen in his blood to diffuse into brain cells.

Exercise 2 (Module 22.2)

Match each of the following animals with a term (A–D) that describes it and a diagram (P–S) that shows its respiratory surface. Also color each respiratory surface yellow.

A. Lungs B. Gills C. Tracheae D. Body surface

Animal	*Term*	*Diagram*
1. Beetle	____	____
2. Cat	____	____
3. Earthworm	____	____
4. Trout	____	____
5. Human	____	____
6. Chicken	____	____
7. Crayfish	____	____



P. Q. R. S.

Exercise 3 (Modules 22.2 - 22.7)

Web/CD Activity 22A *The Human Respiratory System*

Review gas-exchange mechanisms of different animals by filling in the blanks below.

Although some small animals, such as earthworms, use their [1]_____ as a gas-exchange organ, most animals have specialized organs that enable them to obtain [2]_____ and expel waste [3]_____. The part of an animal where gas exchange occurs is called the [4]_____ surface. Individual molecules of O_2 and CO_2 diffuse through a membrane only if they are dissolved in [5]_____, so the respiratory surface must be [6]_____. The surface must also be [7]_____ enough to take in sufficient oxygen for the body's needs and [8]_____ enough for gases to diffuse through it rapidly.

Most aquatic animals obtain dissolved oxygen from the surrounding water by means of [9]_____—outfoldings of the body surface. An advantage of exchanging gases in water is that the animal does not have to expend effort to keep the respiratory surface [10]_____. A disadvantage is that the concentration of available oxygen is much [11]_____ in water than in the air. The gills of a fish are efficient gas-exchange organs. Gill arches on each side of the fish's body bear numerous elongated gill filaments, and each of these bears numerous platelike [12]_____. The gills are red because the lamellae are filled with tiny [13]_____ covered by a thin layer of cells. The fish opens and closes its mouth and gill coverings to [14]_____ its gills, increasing contact between the water and the respiratory surface. Water flows past the lamellae in a direction [15]_____ to the flow of [16]_____ inside the lamellae. This countercurrent increases the efficiency of the gills. [17]_____ is transfer of a substance from a fluid moving in one direction to a fluid moving in the opposite direction. As water and blood flow past each other, [18]_____ diffuses from water to blood. As the blood picks up more and more oxygen, it comes into contact with water containing [19]_____ and [20]_____ available oxygen. Thus the countercurrent flow of water and blood creates a [21]_____ gradient that favors the diffusion of oxygen along the entire length of the lamella, greatly enhancing the efficiency of the gill.

Land animals obtain oxygen from the [22]_____. There are advantages to breathing air: It contains a [23]_____ concentration of oxygen than water, and it is [24]_____ to move than water. The biggest disadvantage of breathing air is that it tends to [25]_____ the respiratory surface. The [26]_____ system of an insect is an effective mechanism for gas exchange. [27]_____ tubes that branch throughout the body deliver gases directly to body cells without the help of the [28]_____ system. The tracheae branch and rebranch and end in tiny fluid-filled tubes that touch the surface of individual body [29]_____. [30]_____ dissolves in the fluid and diffuses into the cells, while [31]_____ diffuses out of the cells and is expelled from the insect's body.

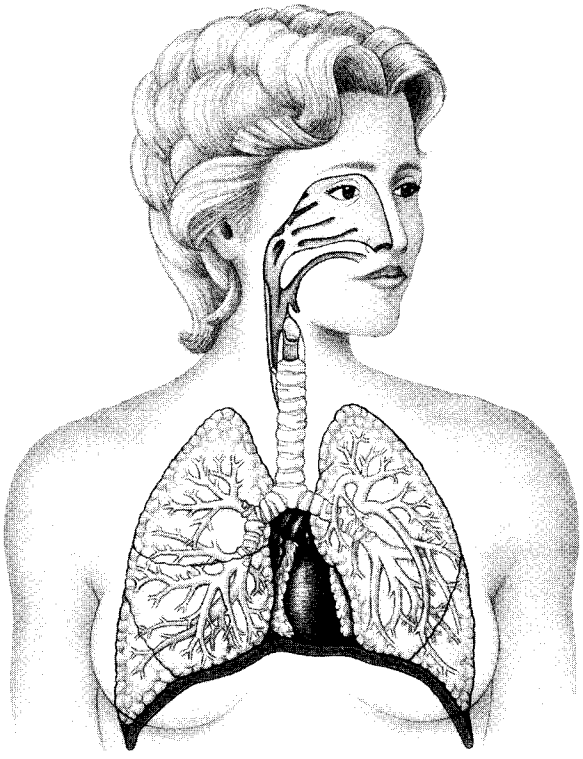
Most land vertebrates have [32]_____ that function in gas exchange. The human lungs are in the chest cavity, above a thin sheet of muscle called the [33]_____ that functions in breathing. When you inhale, air enters through the [34]_____ and is warmed, humidified, and [35]_____ in the

[36]_____ cavity. The air then passes into the [37]_____ (throat) and through the [38]_____, or voicebox. Here a pair of [39]_____ make the sounds that enable us to speak. When the vocal cords are [40]_____, high-pitched sounds are produced. When the cords are [41]_____, they make lower-pitched sounds. From the larynx, air passes through the [42]_____ into a pair of [43]_____, one leading to each lung. Inside the lungs, the bronchi branch into numerous narrow tubes called [44]_____. The surfaces of these respiratory passageways are covered by a film of [45]_____ that traps dust and other contaminants. The beating of numerous [46]_____ move the mucus and trapped particles out of the respiratory tract. The bronchioles end in clusters of tiny air sacs called [47]_____. There are [48]_____ of these tiny sacs in each lung, so their total surface area is enormous. The lining of each alveolus is a thin layer of epithelial cells that makes up the respiratory surface. Oxygen diffuses through a thin layer of moisture, through the epithelium, and into a network of [49]_____ that covers the surface of the alveolus. [50]_____ diffuses out of the blood and into the air within the alveolus. Thus the respiratory system works with the circulatory system in the process of gas exchange.

Exercise 4 (Module 22.6)

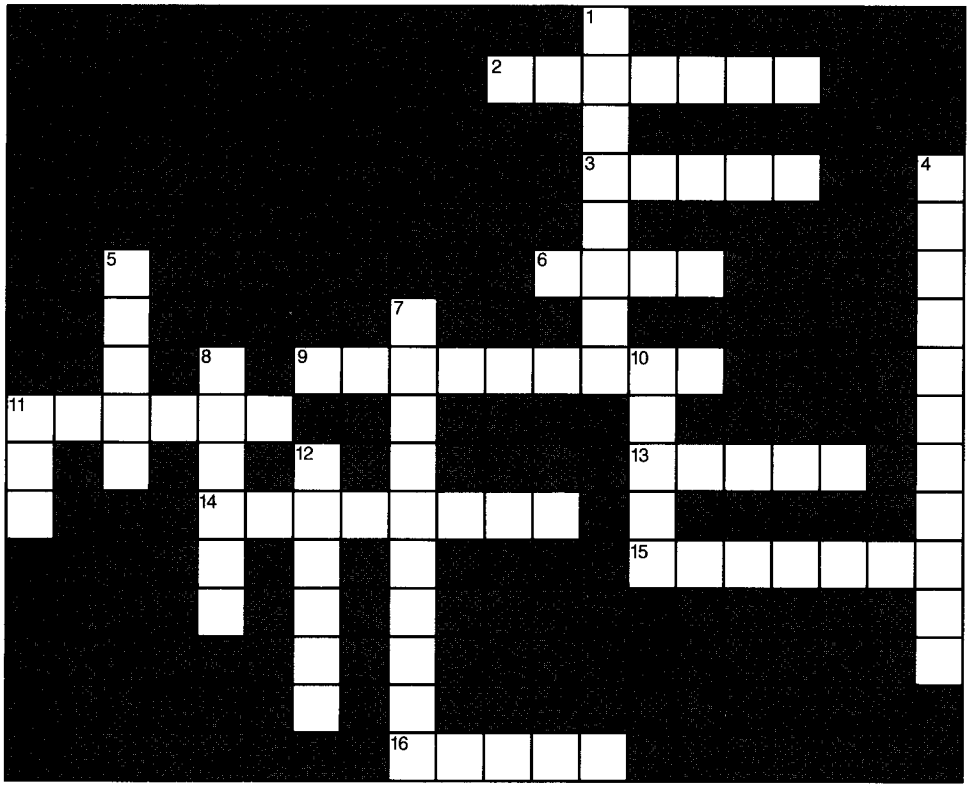
Web/CD Activity 22A *The Human Respiratory System*

Use this diagram to review the parts of the human respiratory system. Label and color the parts in **bold** type. Color the **nasal cavity** purple, the **pharynx** blue, the **larynx** green, the **trachea** yellow, the **bronchi** orange, and the **bronchioles** red. Also color the surrounding **lung tissue** healthy pink (this woman is definitely a nonsmoker!) and the **diaphragm** brown.



Exercise 5 (Module 22.7)

How do tobacco smoke and other air pollutants affect the respiratory system? Test your knowledge by completing this crossword puzzle.



Across

2. Cigarette smoke irritates the lining of the ____, destroying their cilia and microphages.
3. ____ is an air pollutant associated with respiratory disease.
6. Every cigarette probably cuts ____ minutes from the smoker's life.
9. In ____, the alveoli become brittle and the victim becomes short of breath.
11. Besides lung cancer, smoking also increases the risk of cancer of the pancreas, bladder, and ____.
13. Cigarette smoking destroys the ____ that normally sweep out pollutants.
14. When cilia are destroyed, only ____ can rid the lungs of pollutants.
15. Each year, ____ kills more than 350,000 Americans.
16. The ____ of a smoker are black, not pink.

Down

1. Carbon ____ is a harmful gas in polluted air.
4. ____ are defensive amoeboid cells that engulf microorganisms and particles.
5. Emphysema often leads to ____ disease.
7. The ____ tissue lining the respiratory system is very delicate.
8. Lung ____ is the deadliest disease caused by smoking.
10. ____ and cilia protect the respiratory passages.
11. ____ years after quitting smoking, the risk of lung cancer drops to one-half that of continuing smokers.
12. ____ dioxide is one of thousands of harmful pollutants in city air.

Exercise 6 (Module 22.8)

State whether each of the following pertains to inhalation (I) or exhalation (E).

_____ 1. The diaphragm contracts.
_____ 2. The rib cage expands.
_____ 3. The diaphragm expands and arches upward.
_____ 4. Air enters the lungs.
_____ 5. The diaphragm moves downward.
_____ 6. Muscles between the ribs contract.
_____ 7. Muscles between the ribs relax.
_____ 8. The volume of the rib cage decreases.
_____ 9. Air pressure in the alveoli is less than that of the atmosphere.
_____ 10. The diaphragm relaxes.
_____ 11. Air pressure in the alveoli is greater than that of the atmosphere.
_____ 12. Air is forced out of the lungs.

Exercise 7 (Module 22.9)

Review control of breathing by the respiratory control centers: State whether each of the following changes would speed up (↑) or slow down (↓) your rate of breathing.

_____ 1. A rise in blood CO_2 concentration
_____ 2. Hyperventilating
_____ 3. A severe drop in blood oxygen concentration
_____ 4. An increase in pH of the cerebrospinal fluid
_____ 5. An increase in carbonic acid in the blood
_____ 6. A drop in blood pH
_____ 7. A decrease in blood CO_2 concentration
_____ 8. Holding your breath as long as you can, then releasing it

Exercise 8 (Modules 22.9 – 22.12)

Web/CD Activity 22B *Transport of Respiratory Gases*

The following story summarizes the cooperation of the respiratory and circulatory systems in gas exchange and transport. Fill in the blanks to complete the story.

Your respiratory system works together with your [1]_____ system in exchange and transport of gases. Imagine that you are riding a bicycle. Your leg muscles are working hard, consuming [2]_____ and producing [3]_____ as a waste product. Blood returning from the muscles therefore has a relatively [4]_____ concentration of oxygen and a [5]_____ concentration of carbon dioxide. One side of the heart pumps this oxygen-poor blood through the capillaries covering the [6]_____ in your lungs. You are breathing hard. A breathing control center in your [7]_____ responds to the [8]_____ in the pH of your blood caused by the increase in [9]_____. It speeds up the pace of nerve impulses sent to the [10]_____ and muscles between your [11]_____, and you breathe more rapidly. This helps expel the [12]_____ and meet the muscles' needs for more [13]_____.

The air in the lungs has a high partial pressure of [14]_____ and a low partial pressure of [15]_____ relative to the blood. [16]_____ diffuses out of the blood into the air inside the alveolus, moving from a region of [17]_____ partial pressure to a region of [18]_____ partial

pressure. [19]_____ similarly diffuses down its pressure gradient from the air in the alveolus into the blood.

The oxygen that enters the blood is not very [20]_____ in water, so little oxygen is transported in dissolved form. Most oxygen is carried by a protein called [21]_____, contained within [22]_____ blood cells. A hemoglobin molecule consists of four polypeptide chains, each of which contains a heme group with an [23]_____ atom at its center. Each of these atoms can carry one [24]_____ molecule, so each of the millions of hemoglobin molecules in a red blood cell can carry millions of O_2 molecules.

The oxygen-rich blood that leaves the lungs returns to the heart, which pumps it out to the exercising [25]_____ of your legs. The blood passing through the capillaries in a muscle contains a [26]_____ partial pressure of O_2 than the muscle cells where it is being used up, so O_2 diffuses out of the blood and into the cells. The cells are making CO_2 at a fast pace, so the partial pressure of CO_2 is [27]_____ in the cells than in the blood. CO_2 diffuses [28]_____ the cells and [29]_____ the blood.

Some CO_2 is carried dissolved in blood plasma. Most of it enters [30]_____ blood cells, but most does not combine with [31]_____. Instead, enzymes in the blood cells cause most of it to react with [32]_____ molecules, forming carbonic acid (H_2CO_3). Each carbonic acid molecule then breaks apart, forming a hydrogen ion (H^+) and a [33]_____ ion (HCO_3^-). Hemoglobin picks up most of the H^+ ions, so it does not acidify the blood much. The bicarbonate ions diffuse out into the blood [34]_____, where they are part of the blood- [35]_____ system that stabilizes the pH of the blood. If blood pH drops, the bicarbonate ions combine with H^+ ions and remove them from the plasma. If pH [36]_____, the bicarbonate releases these H^+ ions back into solution.

When the blood from the muscles returns (via the heart) to the lungs, the events that formed bicarbonate ions are reversed. Bicarbonate and H^+ form carbonic acid, which breaks up to form water and [37]_____, which in turn diffuses out of the blood into the air of the alveoli. Thus the respiratory and circulatory systems continue to work in close cooperation as you continue your bicycle ride.

Exercise 9 (Modules 22.10 - 22.12)

Web/CD Activity 22B *Transport of Respiratory Gases*

Number the following in order from first to last to show the path an O_2 molecule must follow through a mother to a cell in her fetus.

_____ A. The mother's heart pumps the oxygen-rich blood to her uterus.
_____ B. Oxygen diffuses out through the walls of capillaries in the uterus.
_____ C. The mother takes a deep breath of fresh air.
_____ D. Oxygen leaves the blood of the fetus and diffuses into a growing cell in the fetus's brain.
_____ E. Oxygen diffuses across the thin wall of an alveolus in the mother's lung and into a capillary.
_____ F. The mother's blood, now loaded with oxygen, returns from her lungs to the heart.
_____ G. Oxygen-rich fetal blood flows into the fetus through a vein in the umbilical cord.
_____ H. Oxygen diffuses through the wall of a capillary in the placenta and into the blood of the fetus.
_____ I. Oxygen attaches to hemoglobin in the mother's blood.
_____ J. Oxygen attaches to hemoglobin in fetal blood.
_____ K. The fetus's heart pumps the oxygen-rich blood out to its tissues.

Testing Your Knowledge

Multiple Choice

1. Which of the following has no specialized respiratory structures?
   a. crab
   b. earthworm
   c. salmon
   d. ant
   e. snake

2. The respiratory control centers are located in the
   a. heart.
   b. lungs.
   c. diaphragm and rib muscles.
   d. brain.
   e. large arteries.

3. When you exhale, the diaphragm
   a. relaxes and arches.
   b. relaxes and flattens.
   c. contracts and arches.
   d. contracts and flattens.
   e. contracts and arches, but only when you are exercising vigorously.

4. Why are bird lungs more efficient than human lungs?
   a. They use countercurrent exchange.
   b. They have more surface area than human lungs.
   c. They are able to concentrate the oxygen to much higher levels.
   d. Their alveoli are much larger.
   e. They use a one-way rather than an in-out air flow system.

5. Inhaled air passes through which of the following last?
   a. bronchiole
   b. larynx
   c. pharynx
   d. trachea
   e. bronchus

6. An advantage of gas exchange in water, compared with gas exchange in air, is that
   a. water usually contains a higher concentration of O_2 than air.
   b. water is easier to move over the respiratory surface.
   c. the respiratory surface does not dry out in water.
   d. ventilation requires less energy in water.
   e. the respiratory surface does not have to be as extensive in water.

7. In the blood, bicarbonate ions
   a. help transport oxygen.
   b. act as buffers to guard against pH changes.
   c. are transported by hemoglobin.
   d. attach to numerous CO_2 molecules, keeping them from solution.
   e. are poisonous and must constantly be removed.

8. Smoking destroys the cilia in the respiratory passageways. This
   a. makes it harder to move air in and out of the lungs.
   b. decreases the surface area for respiration.
   c. slows blood flow through lung blood vessels.
   d. makes it harder to keep the lungs clean.
   e. interferes with diffusion across the respiratory surface.

9. Most oxygen is carried by the blood ____. Most carbon dioxide is carried by the blood ____.
   a. attached to hemoglobin . . . in the form of bicarbonate ions
   b. dissolved in the plasma . . . dissolved in the plasma
   c. in the form of H^+ ions . . . in the form of bicarbonate ions
   d. attached to hemoglobin . . . attached to hemoglobin
   e. attached to hemoglobin . . . dissolved in the plasma

10. A disease called emphysema decreases the springiness of the lungs. This decreases ____ and makes it harder to breathe.
    a. the volume of each breath
    b. respiratory rate
    c. residual air
    d. countercurrent exchange
    e. vital capacity

11. The ____ is a structure specialized for diffusion of gases and nutrients between the blood of the mother and the fetus.
    a. uterus
    b. placenta
    c. lamella
    d. alveolus
    e. umbilicus

Essay

1. Compare the advantages and disadvantages of obtaining oxygen from water and obtaining it from the air.
2. How are gills and lungs similar? How are they different?
3. Describe how the structure, number, and arrangement of alveoli are well suited to their function in gas exchange.
4. Where are your vocal cords? How do they work? How do they produce high-pitched and low-pitched sounds?
5. When you inhale, does air flow into the lungs, causing them to expand? Or do the lungs expand, causing air to flow in? Explain.
6. Explain how countercurrent exchange in a fish gill enhances absorption of oxygen from water.

Applying Your Knowledge

Multiple Choice

1. Which of the following normally contains the highest concentration of oxygen?
   a. body cells
   b. inhaled air
   c. air in the alveoli
   d. blood entering the lungs
   e. blood leaving the lungs
2. Which of the following in a human is most similar in function to the gill lamellae of a fish?
   a. vocal cords
   b. bronchioles
   c. alveoli
   d. tracheae
   e. diaphragm
3. In which of the following does oxygen pass directly from the air, through a moist surface, to individual cells, without being carried by the blood?
   a. mouse
   b. ant
   c. shark
   d. earthworm
   e. frog
4. A fish opens and closes its mouth and gill covers. A dog pants. A marine worm waves long, filmy gills in the water. All of these movements
   a. are examples of ventilation.
   b. show how circulation aids respiration.
   c. are examples of breathing.
   d. slow diffusion of CO_2.
   e. enhance countercurrent exchange.
5. ____ in CO_2 in your blood, which causes ____ in pH, would cause your breathing to speed up.
   a. An increase . . . a rise
   b. An increase . . . a drop
   c. A decrease . . . a rise
   d. A decrease . . . a drop
   e. Actually, it is rise and fall of O_2, not CO_2, that controls breathing.
6. Which of the following would have the same O_2 content?
   a. blood entering the lungs—blood leaving the lungs
   b. blood entering the right side of the heart—blood entering the left side of the heart
   c. blood entering the tissue capillaries—blood leaving the tissue capillaries
   d. blood entering the right side of the heart—blood leaving the right side of the heart
   e. blood leaving the tissue capillaries—blood leaving the lungs
7. Patients with chronic lung disease and difficulty breathing often adapt to the high concentration of CO_2 in their blood. The breathing centers stop responding to CO_2 level. If such a patient has difficulty breathing, medical personnel are reluctant to give the patient pure oxygen. Based on what you know about control of breathing, why do you think this is the case?
   a. The patient's body would use the oxygen to make even more CO_2.
   b. The oxygen would increase concentration of bicarbonate, altering pH.
   c. Increased oxygen in the blood might slow or stop breathing.
   d. The body is not used to the oxygen, and the patient would overdose.
   e. The patient would breathe too fast and become tired out.

8. In an old science fiction movie, the hero tried to drown a giant ant by holding its head under water. Would this work? Why?
   a. Yes. Ants use lungs to breathe much as we do.
   b. Yes. The skin surface, covered with water, could not get O_2 from the air.
   c. No. Ants use gills for respiration, like crabs do.
   d. No. Ants breathe through holes in the sides of their bodies.
   e. No. The ant could get oxygen by diffusion from the water.
9. A zoologist compared the respiratory efficiency and swimming speed of different fish. He found that less efficient fish tended to have
   a. greater ventilation.
   b. a thicker respiratory surface.
   c. more hemoglobin.
   d. a faster heart rate.
   e. a more extensive respiratory surface.
10. A biochemist mixed 10 drops of acid with 100 mL of water, and the pH dropped from 7.4 to 5.0. She then mixed 10 drops of acid with 100 mL of blood. The pH dropped from 7.4 to 7.2. What is the reason for this difference?
    a. Blood is thicker than water.
    b. Blood is already very acidic, so the acid has less effect.
    c. Blood is saturated with oxygen; there is little room for acid.
    d. Blood contains buffers that reduce pH change.
    e. Water is already more acidic than blood; there is little room for more.

Essay

1. Trace the path of an oxygen molecule from the air to one of your brain cells, naming all the places and structures it passes through on its way.
2. You are on the team to design a robot that will patrol the devastated terrain around the Chernobyl nuclear power plant. The robot will function like a living organism, gathering organic debris for "food" and obtaining oxygen from the surrounding air. What features would you want to include in your design of its respiratory surface?
3. Carbon monoxide molecules in cigarette smoke and automobile exhaust attach to hemoglobin molecules where oxygen normally attaches, and they hold on more strongly than oxygen. What effect would this have on the body?
4. A man smokes a pack of cigarettes (20) a day for 40 years. If each cigarette shortens his life, on average, by 5 minutes, how much "before his time" will he die?
5. In a submarine, the oxygen supply was accidentally interrupted, causing the oxygen content of the air to drop. A machine that removes carbon dioxide continued to function, so there was no corresponding buildup of CO_2. None of the sailors felt short of breath or noticed anything wrong until several individuals fainted. Why do you think they did not feel short of breath?

Extending Your Knowledge

1. Do you smoke, or are you close to a person who smokes? Quitting the smoking habit is one of the most important and effective changes you can make to improve your health and your quality of life. Quitting is not easy; the nicotine in tobacco is highly addictive. But there is help available. College health centers and wellness programs, lung and heart associations, and state and county health departments usually have information, classes, and programs to help people stop smoking. Thousands have kicked the habit—and you can too. Good luck!