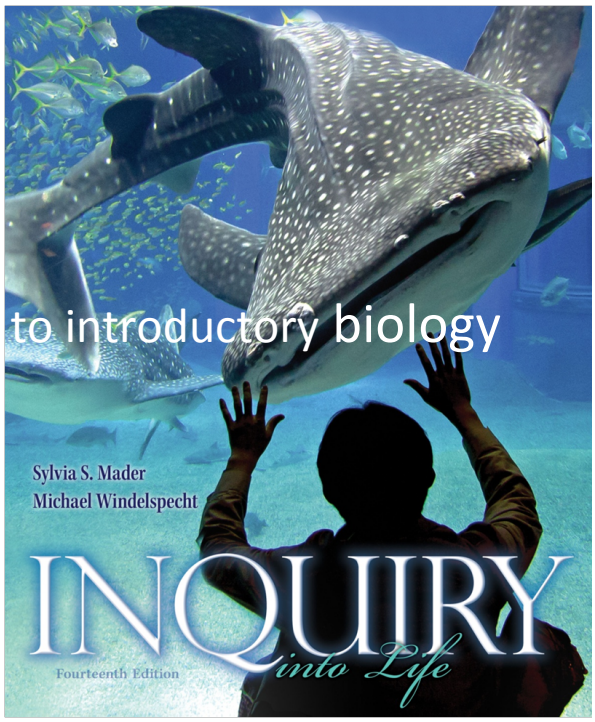
Fundamental Biology
BI 1101

an interdisciplinary approach to introductory biology



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Five Levels of Organization

Molecular

Cellular

Organismal

Population

Ecological System

Learning outcomes

After this lecture, you should be able to:

1. Describe the three main phases of gas exchange in a human.
2. Describe four types of respiratory surfaces and the kinds of animals that use them.
3. Explain how the amount of oxygen available in air compares to that available in cold and warm fresh water and cold and warm salt water.
4. Explain how the structure and movements of fish gills maximize oxygen exchange.
5. Explain why breathing air is easier than using water for gas exchange.
6. Describe the tracheal system of insects.
7. Explain how the metabolic rate of a vertebrate corresponds to the nature of its respiratory system.

8. Describe the structures and corresponding functions of a mammalian respiratory system.
9. Describe the impact of smoking on human health.
10. Compare the mechanisms and efficiencies of lung ventilation in humans and birds.
11. Explain how breathing is controlled in humans.
12. Explain how blood transports gases between the lungs and tissues of the body.
13. Describe the functions of hemoglobin.
14. Explain how a human fetus obtains oxygen prior to and immediately after birth.

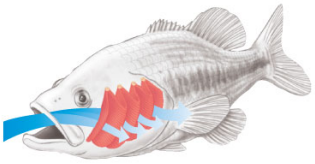
ANIMAL STRUCTURE & FUNCTION

GAS EXCHANGE

Introduction

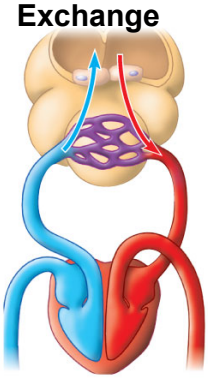
- People cannot survive for long in the air at the world's highest peaks in the Himalayan Mountains.
- Yet twice a year, flocks of geese migrate over the Himalayas.
- How can geese fly where people cannot breathe?
  - Geese have more efficient lungs than humans, and
  - their hemoglobin has a very high affinity for oxygen.

Big Ideas



Mechanisms of Gas Exchange

The Human Respiratory System



Transport of Gases in the Human Body

MECHANISMS OF GAS EXCHANGE

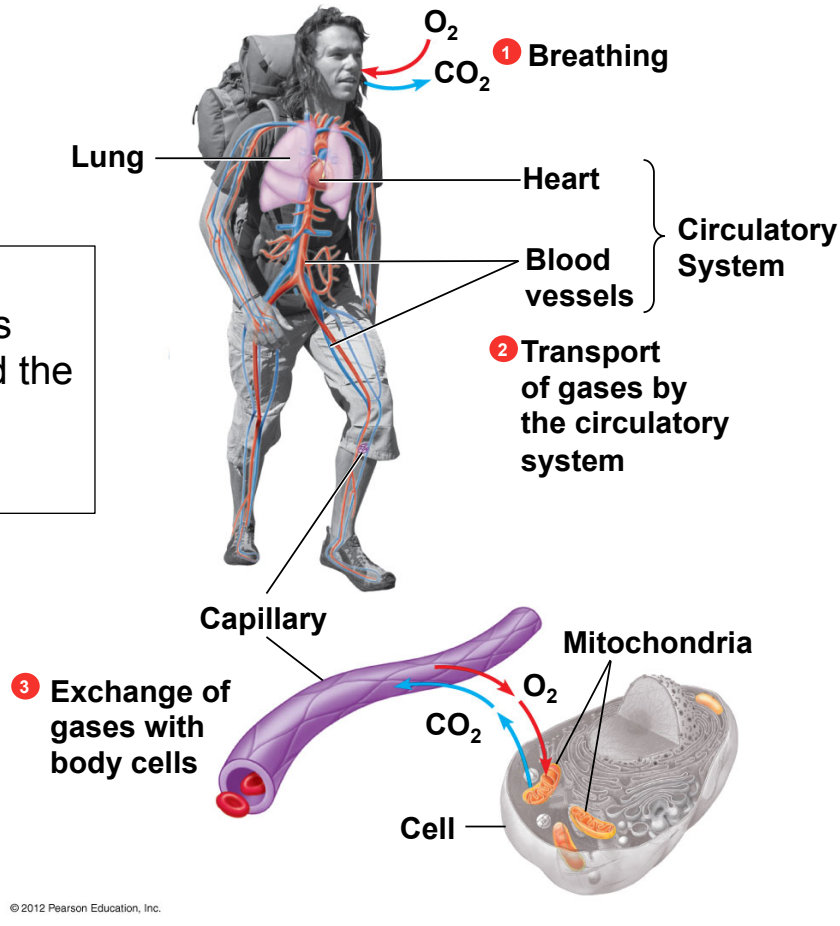
Overview: Gas exchange in humans involves breathing, transport of gases, and exchange with body cells

The process of **gas exchange** is sometimes called respiration, the interchange of

- O_2 and the waste product CO_2
- between an organism and its environment.

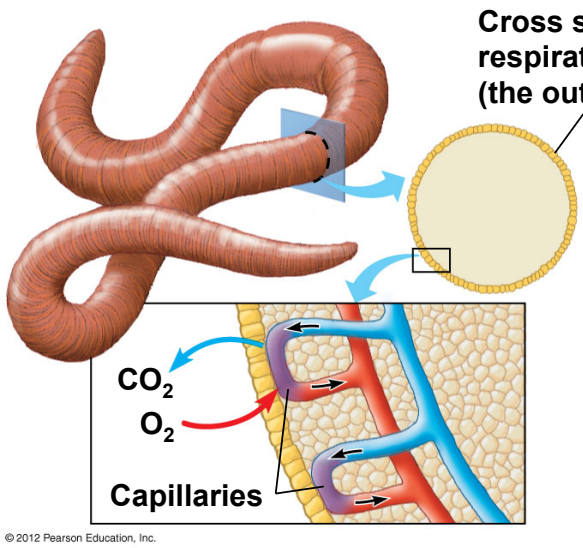
- Three phases of gas exchange occur in humans and other animals with lungs:
  1. breathing,
  2. transport of oxygen and carbon dioxide in blood, and
  3. exchange of gases with body cells.
     - Body tissues take up oxygen and
     - release carbon dioxide.

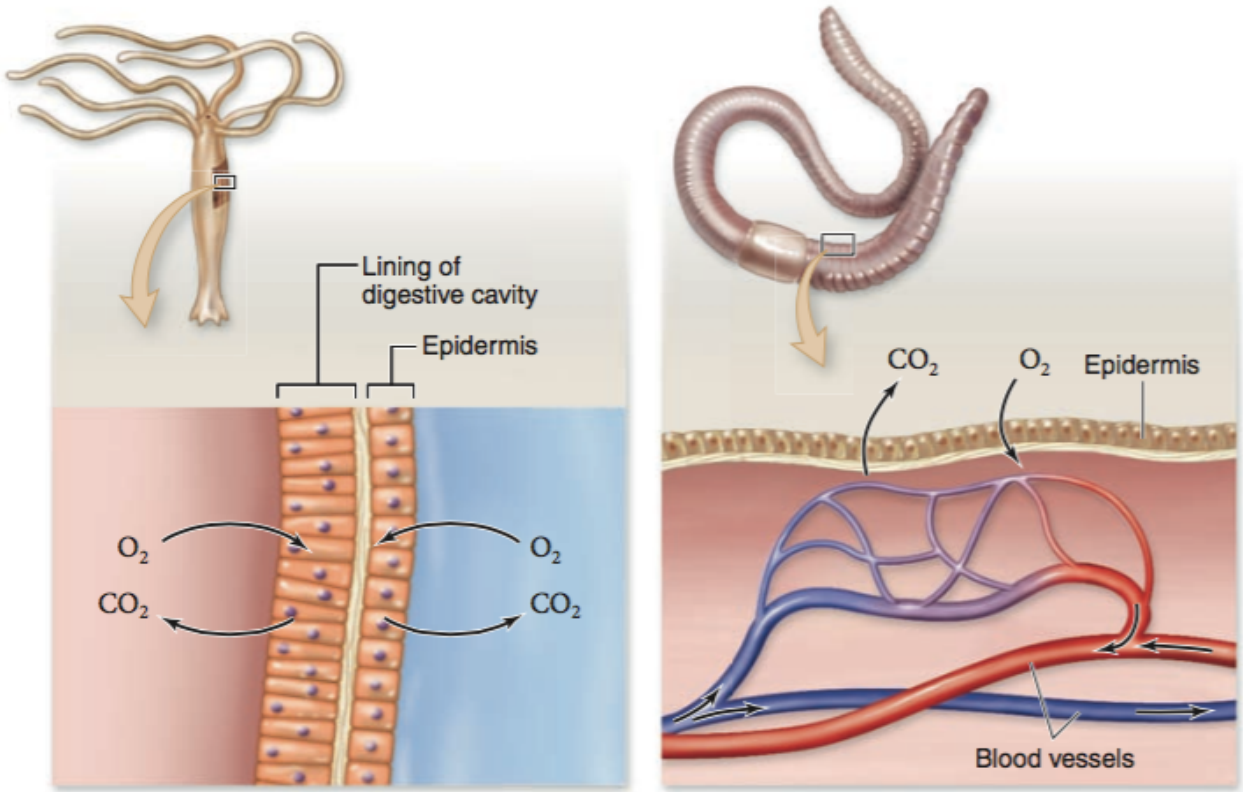
Cellular respiration requires a continuous supply of oxygen and the disposal of carbon dioxide.



Animals exchange O_2 and CO_2 across moist body surfaces

- Respiratory surfaces must be
  - moist for diffusion of O_2 and CO_2 and
  - thin, to best facilitate diffusion.
- The skin may be used for gas exchange in animals that are
  - wet and
  - small.
  - Earthworms are an example.

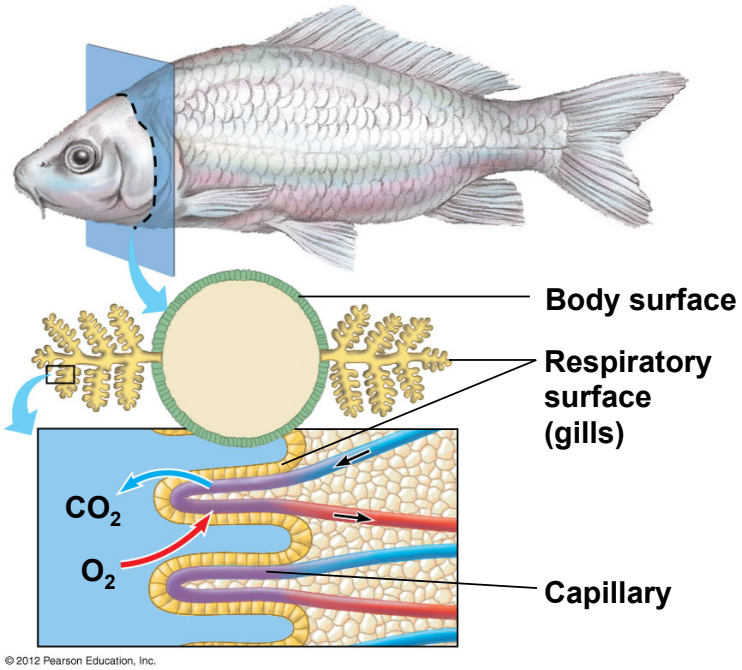


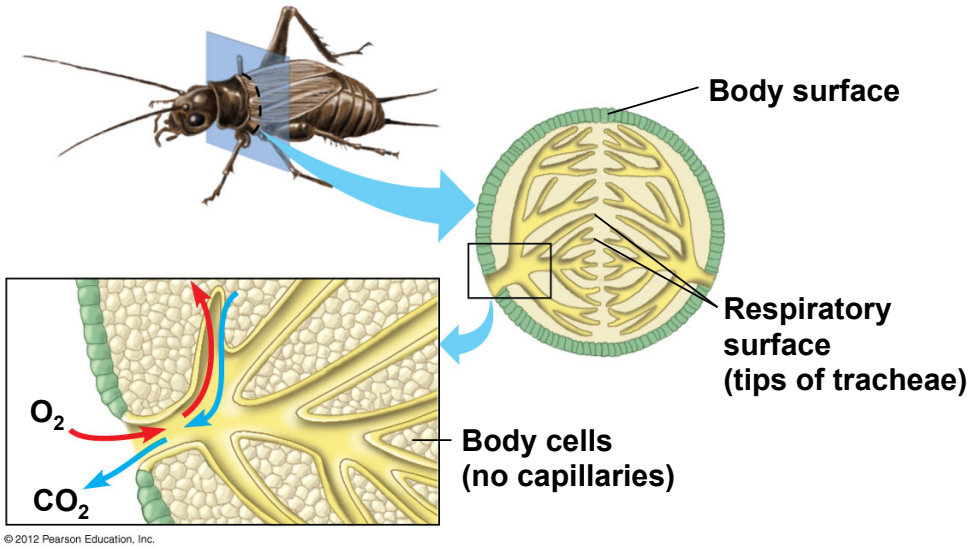


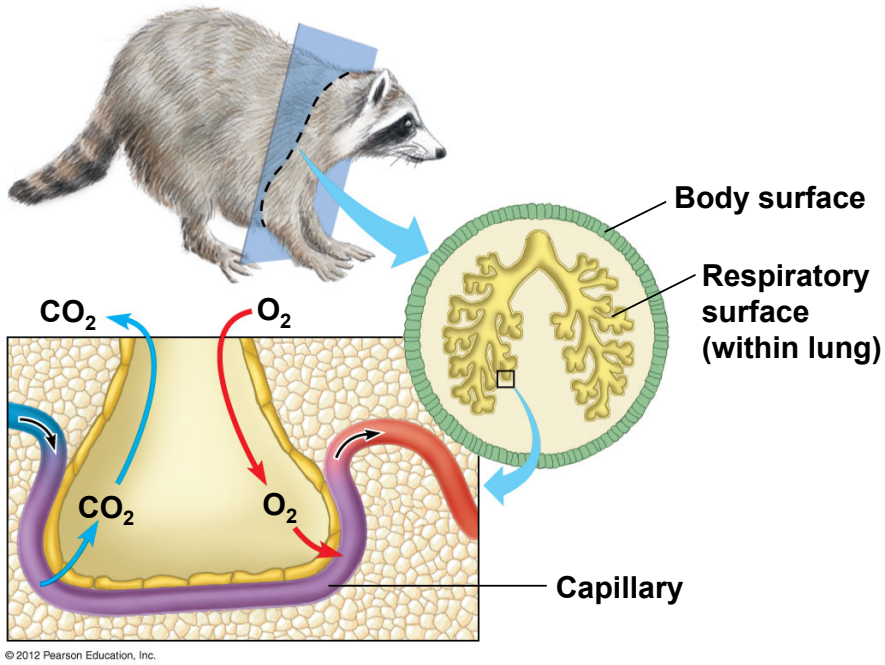
Body surface: Gases diffuse through the body's surface. Found in many invertebrates and amphibians.

Animals exchange O_2 and CO_2 across moist body surfaces

- Most animals have specialized body parts that promote gas exchange:
  - **gills** in fish and amphibians,
  - **tracheal systems** in arthropods, and
  - **lungs** in tetrapods that live on land, such as
    - amphibians,
    - reptiles including birds, and
    - mammals.







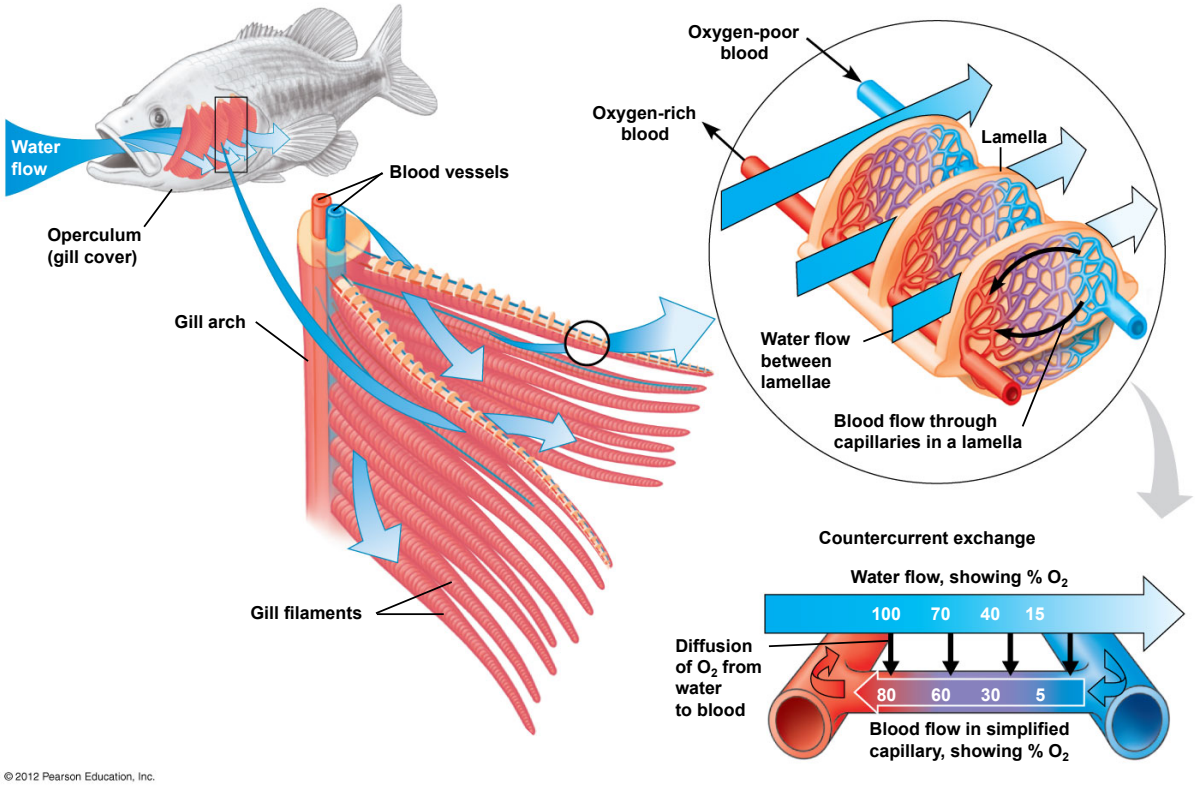
Gills are adapted for gas exchange in aquatic environments

- Gills
  - are extensions of the body,
  - increase the surface to volume ratio, and
  - increase the surface area for gas exchange.
    - Oxygen is absorbed.
    - Carbon dioxide is released.

- In a fish, gas exchange is enhanced by
  - **ventilation** of the gills (moving water past the gills) and
  - **countercurrent** flow of water and blood.

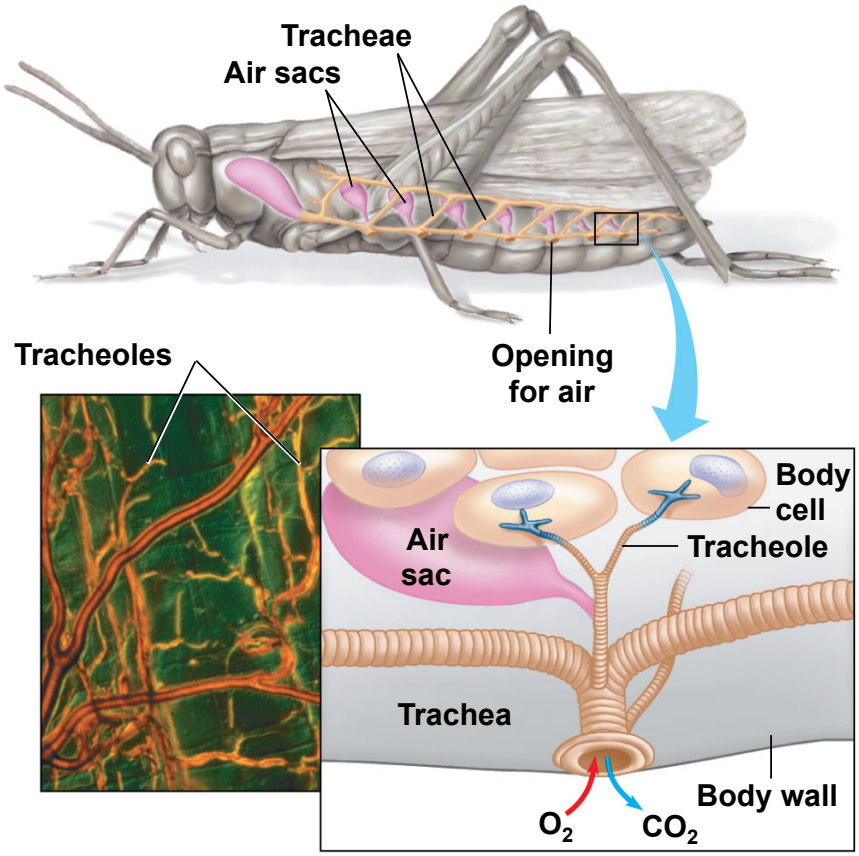
Gills are adapted for gas exchange in aquatic environments

- Gas exchange with water has its limits.
  - Water holds only about 3% of the oxygen in air.
  - Cold water holds more oxygen than warm water.
  - Fresh water holds more oxygen than salt water.
  - Turbulent water holds more oxygen than still water.



The tracheal system of insects provides direct exchange between the air and body cells

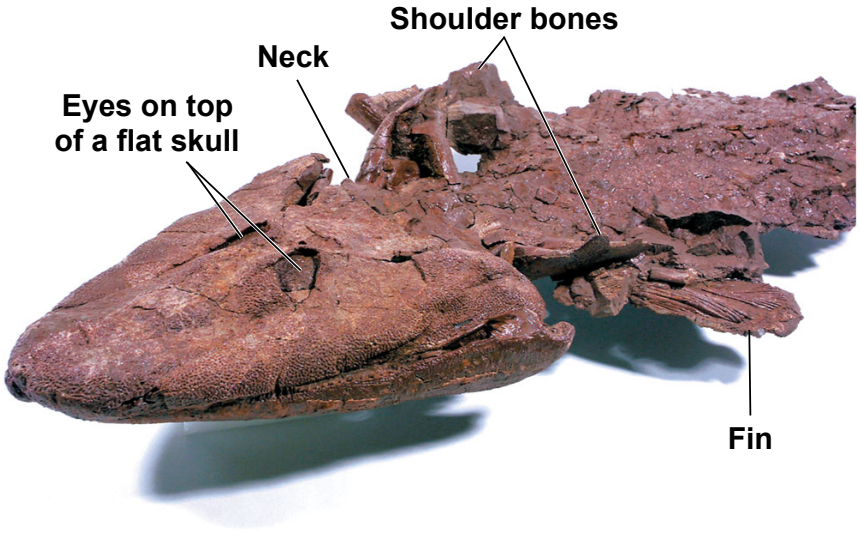
- Compared to water, using air to breathe has two big advantages.
  1. Air contains higher concentrations of O_2 than water.
  2. Air is lighter and easier to move than water.
- However, air-breathing animals lose water through their respiratory surfaces.
- Insect tracheal systems use tiny branching tubes that
  - reduce water loss and
  - pipe air directly to cells.



EVOLUTION CONNECTION:The evolution of lungs facilitated the movement of tetrapods onto land

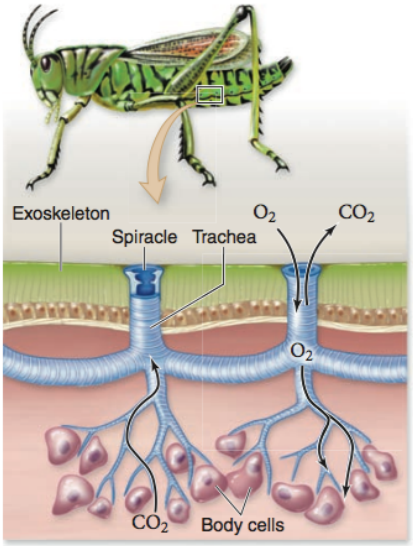
- Tetrapods seem to have evolved in shallow water.
  - Fossil fish with legs had lungs and gills.
  - Legs may have helped them lift up to gulp air.
  - The fossil fish *Tiktaalik*
    - lived about 375 million years ago and
    - illustrates these air-breathing adaptations.

Figure 22.5

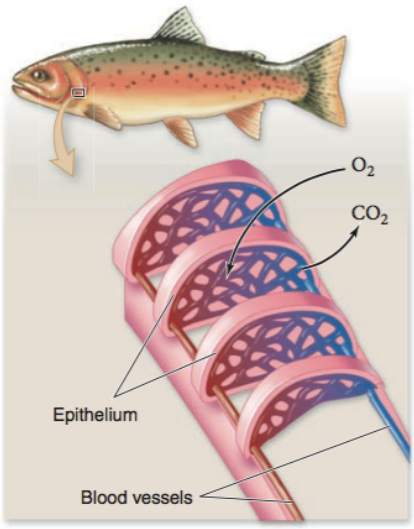


CONNECTION: The evolution of lungs facilitated the movement of tetrapods onto land

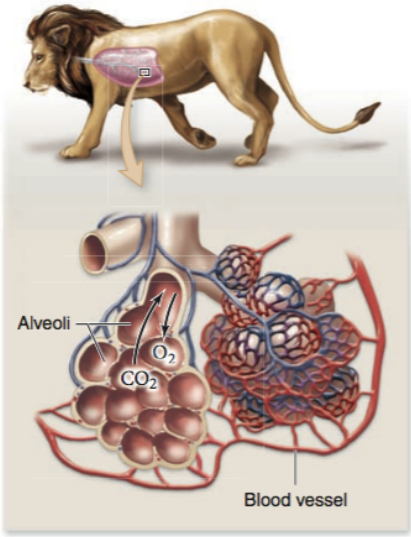
- The first tetrapods on land diverged into three major lineages.
  1. Amphibians use small lungs and their body surfaces.
  2. Nonbird reptiles have
     - lower metabolic rates and
     - simpler lungs.
  3. Birds and mammals have
     - higher metabolic rates and
     - more complex lungs.



Tracheae: Gases enter tracheae and diffuse directly into the cells; they do not enter capillaries first as in most other respiratory systems. Found in many arthropods, including insects.



Gills: Gases are exchanged at blood vessels covered by a thin layer of epithelium. Found in fishes, amphibian larvae, and many invertebrates.



Lungs: Two-way airflow. Found in terrestrial vertebrates.

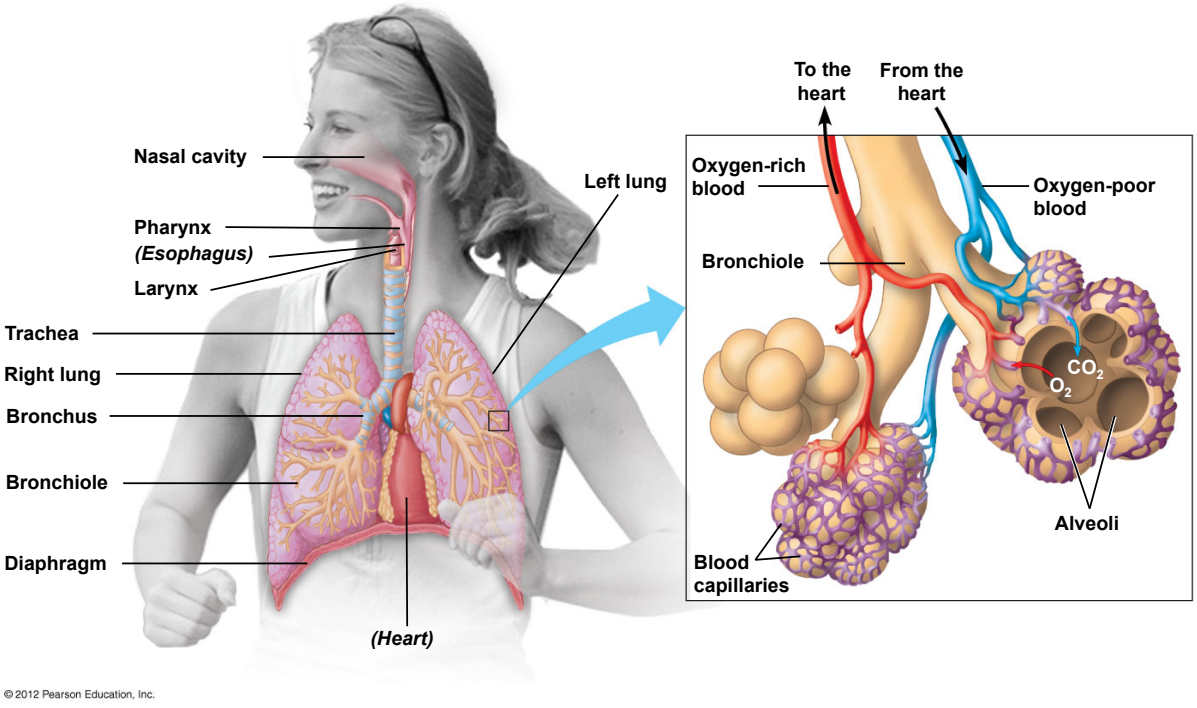
THE HUMAN RESPIRATORY SYSTEM

In mammals, branching tubes convey air to lungs located in the chest cavity

- The **diaphragm**
  - separates the abdominal cavity from the thoracic cavity and
  - helps ventilate the lungs.
- In mammals, air is inhaled through the nostrils into the nasal cavity. Air is
  - filtered by hairs and mucus surfaces,
  - warmed and humidified, and
  - sampled for odors.

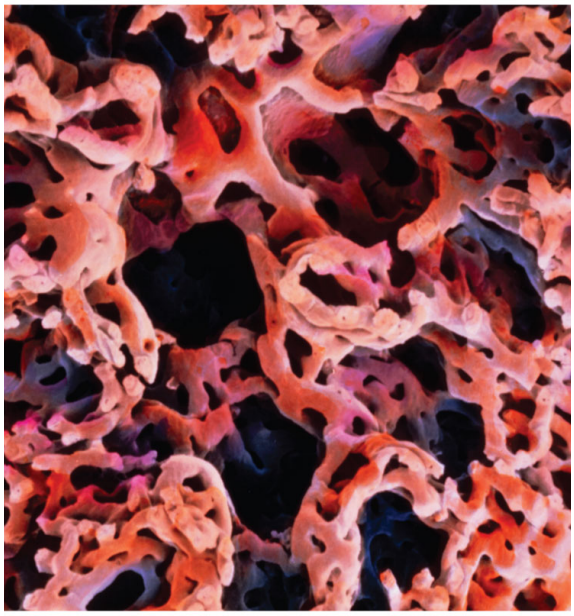
In mammals, branching tubes convey air to lungs located in the chest cavity

- From the nasal cavity, air next passes
  - to the **pharynx**,
  - then **larynx**, past the **vocal cords**,
  - into the **trachea**, held open by cartilage rings,
  - into the paired **bronchi**,
  - into **bronchioles**, and finally
  - to the **alveoli**, grapelike clusters of air sacs, where gas exchange occurs.



In mammals, branching tubes convey air to lungs located in the chest cavity

- Alveoli are well adapted for gas exchange with high surface areas of capillaries.
- In alveoli,
  - O_2 diffuses into the blood and
  - CO_2 diffuses out of the blood.



In mammals, branching tubes convey air to lungs located in the chest cavity

- **Surfactants** are specialized secretions required to keep the walls of the small alveoli from sticking shut.
  - Babies born 6 weeks or more before their due date often struggle with respiratory distress syndrome due to an inadequate amount of lung surfactant.
  - Artificial surfactants are now administered to preterm infants.

In mammals, branching tubes convey air to lungs located in the chest cavity

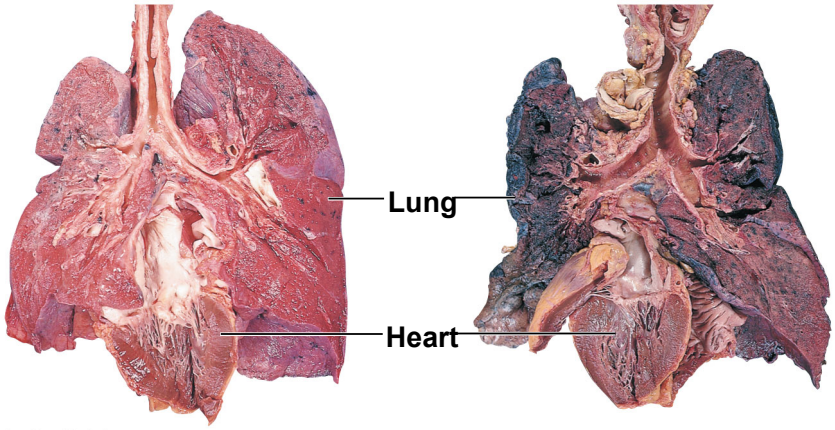
- Exposure to pollutants can cause continual irritation and inflammation of the lungs.
  - Examples of common lung pollutants include
    - air pollution and
    - tobacco smoke.
  - Chronic obstructive pulmonary disease (COPD) can result, limiting
    - lung ventilation and
    - gas exchange.

CONNECTION: Smoking is a serious assault on the respiratory system

- Mucus and cilia in the respiratory passages
  - sweep contaminant-laden mucus up and out of the airways and
  - can be damaged by smoking.
- One of the worst sources of lung-damaging air pollutants is tobacco smoke, containing more than 4,000 chemicals.
- Without healthy cilia, smokers must cough to clear dirty mucus from the trachea.

CONNECTION: Smoking is a serious assault on the respiratory system

- Smoking can cause
  - lung cancer,
  - cardiovascular disease, and
  - emphysema.
- Smoking accounts for 90% of all lung cancer cases.
- Smoking increases the risk of other types of cancer.

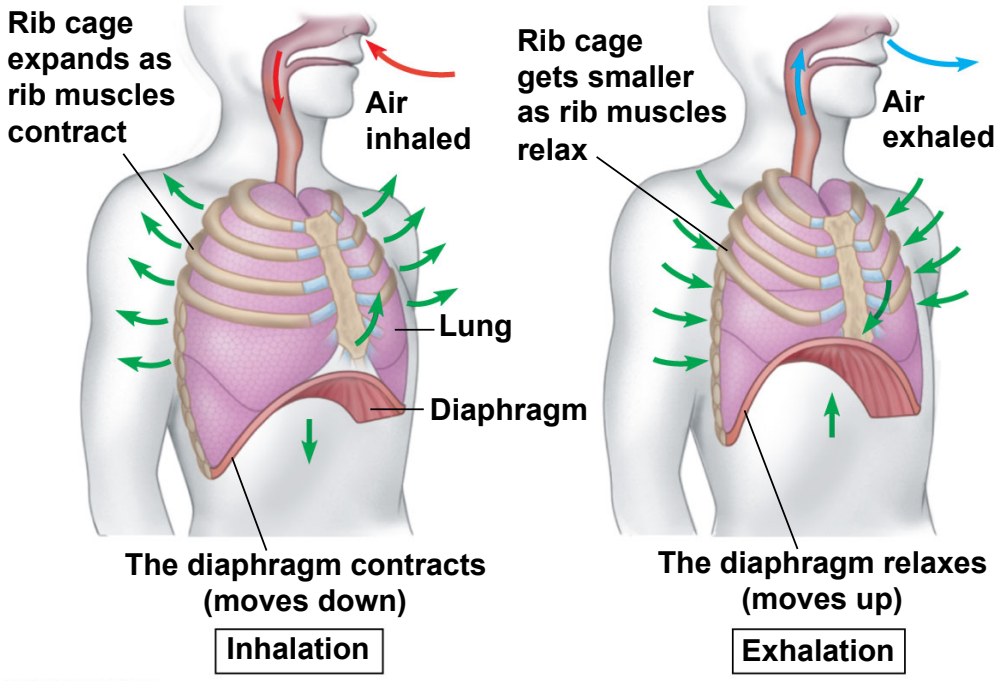


CONNECTION: Smoking is a serious assault on the respiratory system

- Smoking also
  - increases the risk of heart attacks and strokes,
  - raises blood pressure, and
  - increases harmful types of cholesterol.
- Every year in the United States, smoking
  - kills about 440,000 people,
  - more than all the deaths from accidents, alcohol, drug abuse, HIV, and murders combined.
- Adults who smoke die 13–14 years earlier than nonsmokers.

Negative pressure breathing ventilates your lungs

- **Breathing** is the alternate inhalation and exhalation of air (ventilation).
- In mammals, inhalation occurs when
  - the rib cage expands,
  - the diaphragm moves downward,
  - the pressure around the lungs decreases, and
  - air is drawn into the respiratory tract.
- This type of ventilation is called **negative pressure breathing.**



Negative pressure breathing ventilates your lungs

- Exhalation occurs when
  - the rib cage contracts,
  - the diaphragm moves upward,
  - the pressure around the lungs increases, and
  - air is forced out of the respiratory tract.

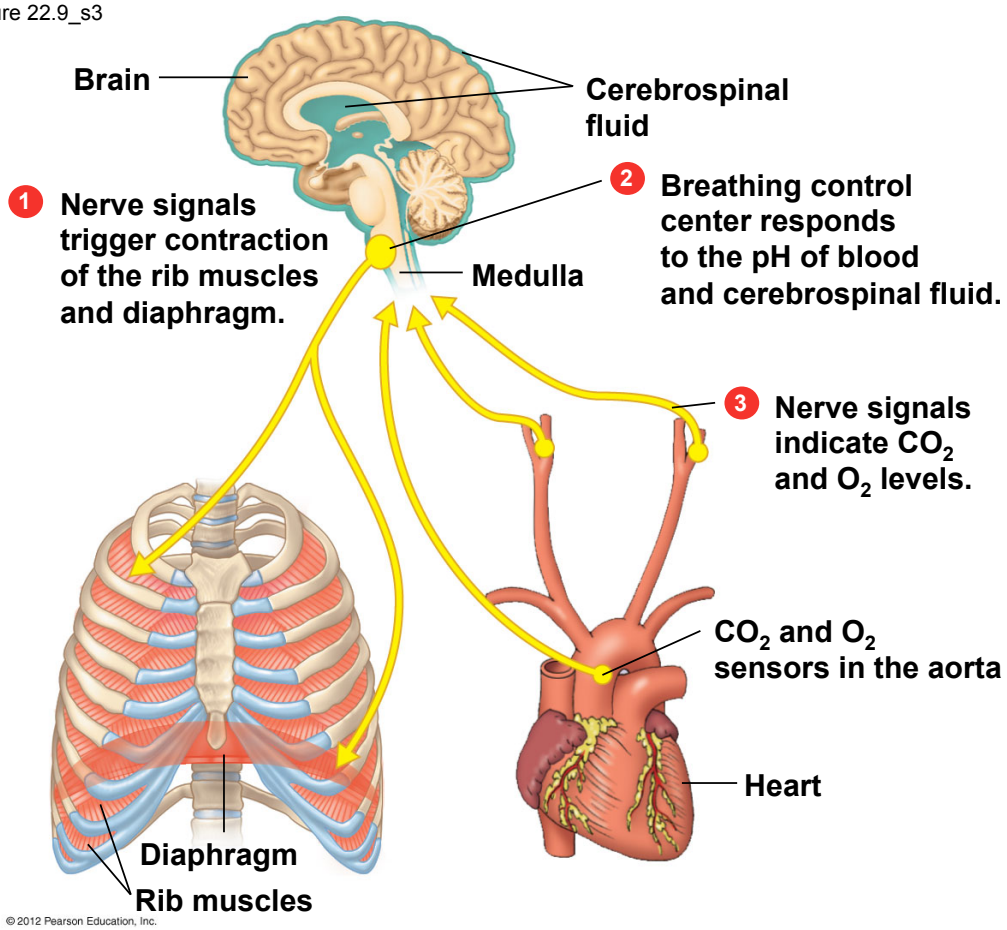
Negative pressure breathing ventilates your lungs

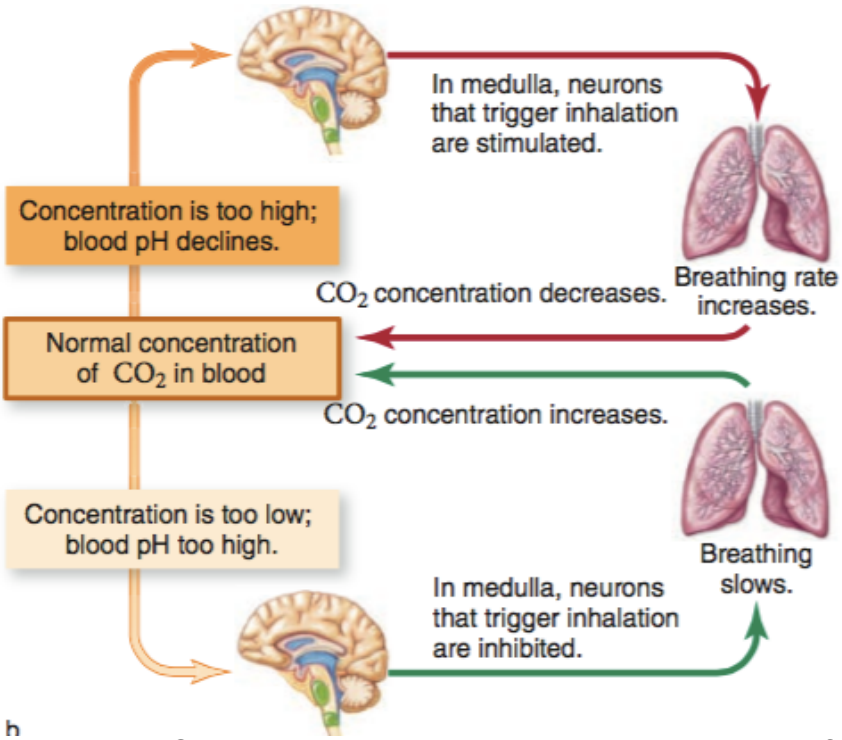
- Not all air is expelled during exhalation.
  - Some air still remains in the trachea, bronchi, bronchioles, and alveoli.
  - This remaining air is “dead air.”
  - Thus, inhalation mixes fresh air with dead air.
- One-way flow of air in birds
  - reduces dead air and
  - increases their ability to obtain oxygen.

Breathing is automatically controlled

- Breathing is usually under automatic control.
- **Breathing control centers** in the brain sense and respond to CO_2 levels in the blood.
- A drop in blood pH increases the rate and depth of breathing.

Figure 22.9_s3





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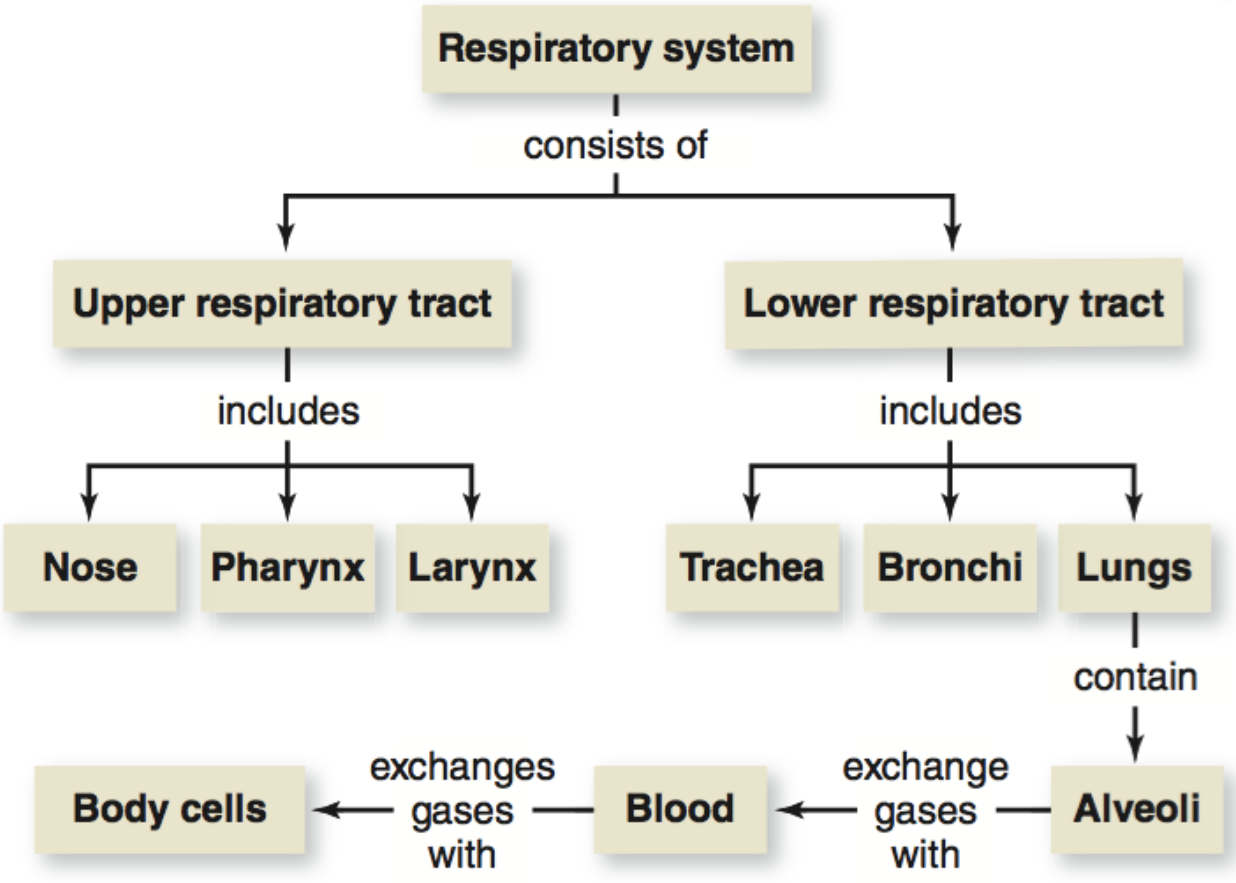
Breathing Control. (a) Multiple chemoreceptors send information about blood pH and CO concentrations to the brain. Neurons in the medulla integrate this information and regulate the contraction of rib and diaphragm muscles. (b) The control of breathing is an example of a negative feedback loop.



TRANSPORT OF GASES IN THE HUMAN BODY

Blood transports respiratory gases

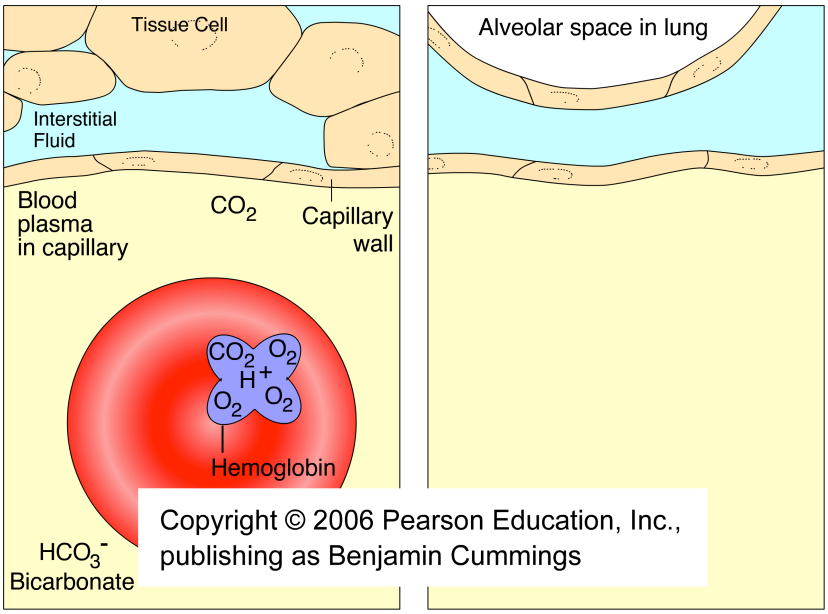
- The heart pumps blood to two regions.
  1. The right side pumps oxygen-poor blood to the lungs.
  2. The left side pumps oxygen-rich blood to the body.
- In the lungs, blood picks up O_2 and drops off CO_2.
- In the body tissues, blood drops off O_2 and picks up CO_2.

Blood transports respiratory gases

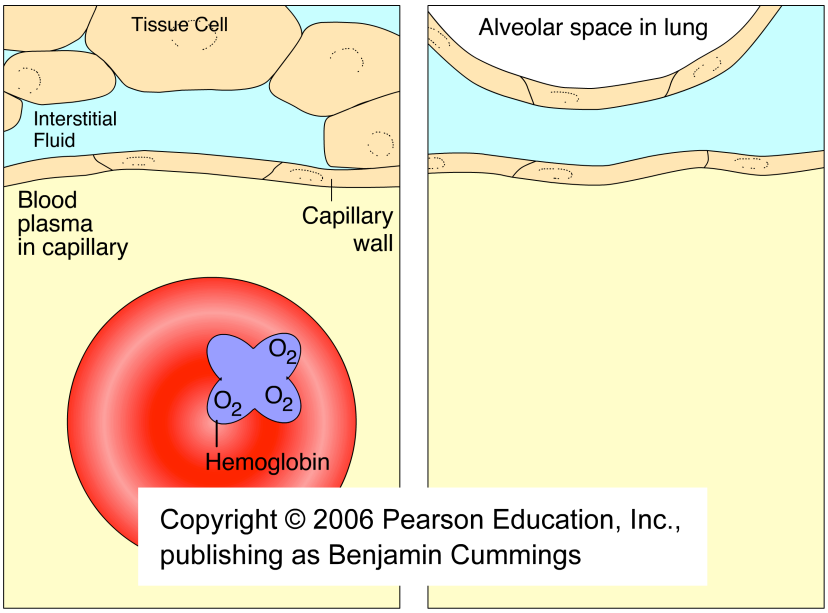
- A mixture of gases, such as air, exerts pressure.
  - Each kind of gas in a mixture accounts for a portion of the total pressure of the mixture.
  - Thus, each gas has a **partial pressure**.
  - The exchange of gases between capillaries and the surrounding cells is based on partial pressures.
  - Molecules of each kind of gas diffuse down a gradient of its own partial pressure, moving from regions of
    - higher partial pressure to
    - lower partial pressure.

Blood transports respiratory gases

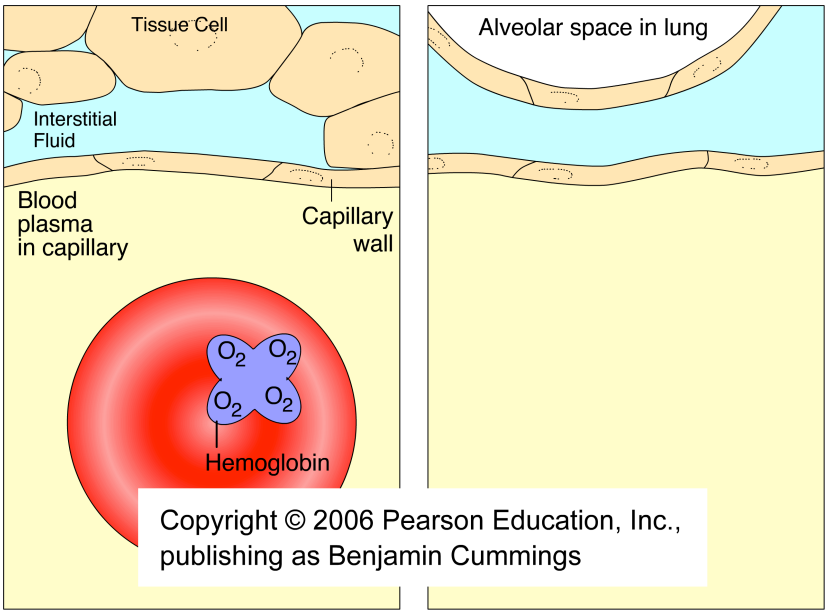
- Gases move from areas of higher concentration to areas of lower concentration.
  - Gases in the alveoli of the lungs have more O_2 and less CO_2 than gases in the blood.
    - O_2 moves from the alveoli of the lungs into the blood.
    - CO_2 moves from the blood into the alveoli of the lungs.
  - The tissues have more CO_2 and less O_2 than gases in the blood.
    - CO_2 moves from the tissues into the blood.
    - O_2 moves from the blood into the tissues.



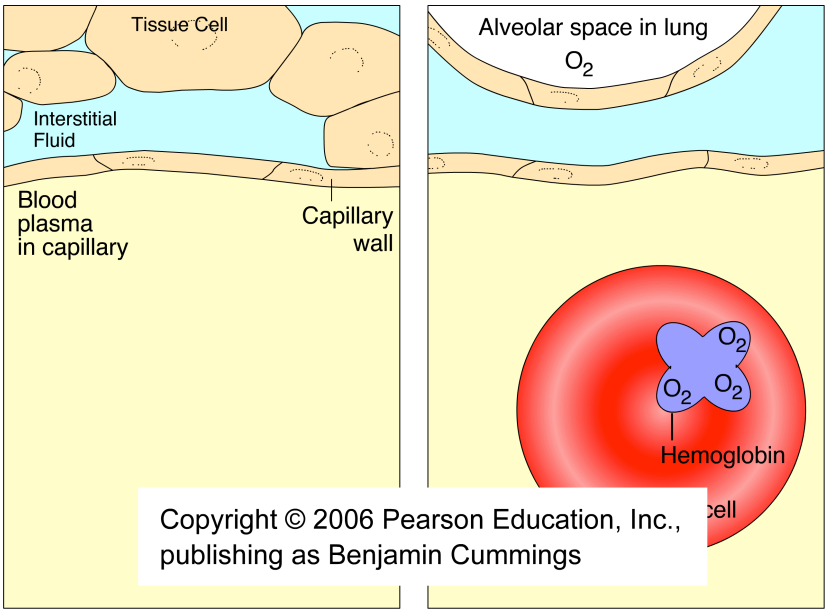
Animation: CO_2 from Blood to Lungs
Right click on animation / Click play



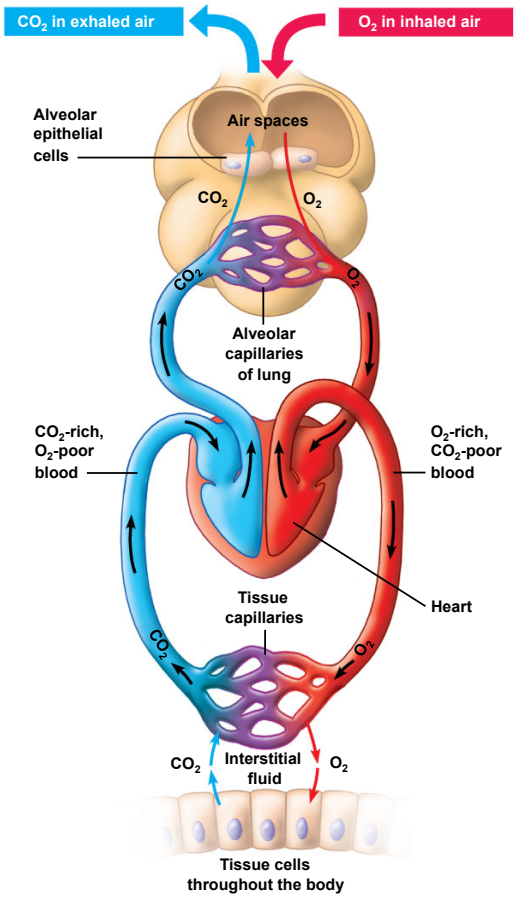
Animation: CO_2 from Tissues to Blood
Right click on animation / Click play



Animation: O_2 from Blood to Tissues
Right click on animation / Click play



Animation: O_2 from Lungs to Blood
Right click on animation / Click play



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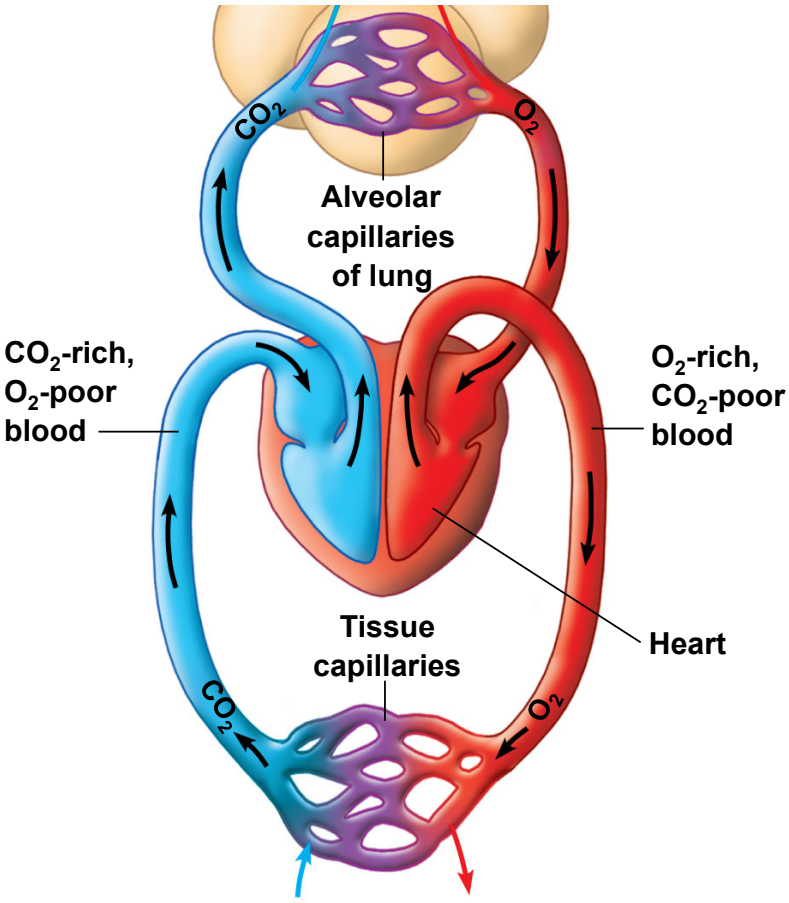

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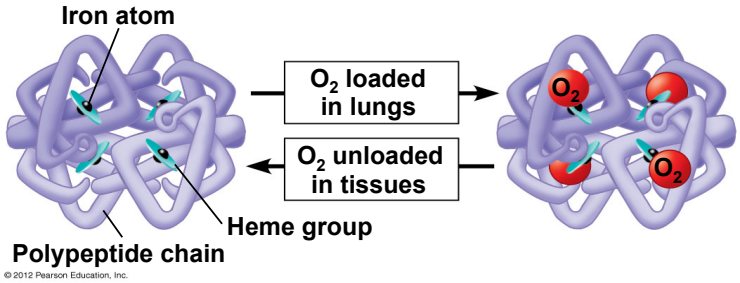
Hemoglobin carries O_2, helps transport CO_2, and buffers the blood

Most animals transport O_2 bound to proteins called respiratory pigments.

- Blue, copper-containing pigment is used by
  - molluscs and
  - arthropods.
- Red, iron-containing **hemoglobin**
  - is used by almost all vertebrates and many invertebrates and
  - transports oxygen, buffers blood, and transports CO_2.



Hemoglobin carries O_2, helps transport CO_2, and buffers the blood

- Most CO_2 in the blood enters red blood cells.
- Some CO_2 combines with hemoglobin.
- Other CO_2 reacts with water, forming carbonic acid, which then breaks apart into
  - hydrogen ions and
  - bicarbonate ions in a reversible reaction.
  - Hemoglobin binds most of the H^+ produced by this reaction, minimizing the change in blood pH.

$$\underset{\text{Carbon Dioxide}}{CO_2} + \underset{\text{Water}}{H_2O} \rightleftarrows \underset{\text{Carbonic Acid}}{H_2CO_3} \rightleftarrows \underset{\text{Hydrogen Ions}}{H^+} + \underset{\text{Bicarbonate}}{HCO_3^-}$$

CONNECTION: The human fetus exchanges gases with the mother's blood

- A human fetus does not breathe with its lungs. Instead, it exchanges gases with maternal blood in the placenta.
- In the placenta, capillaries of maternal blood and fetal blood run next to each other. The fetus and mother do not share the same blood.

CONNECTION: The human fetus exchanges gases with the mother's blood

- Fetal hemoglobin
  - attracts O_2 more strongly than adult hemoglobin and
  - takes oxygen from maternal blood.
- At birth
  - CO_2 in fetal blood increases and
  - breathing control centers initiate breathing.
- Smoking during pregnancy reduces the supply of oxygen to the fetus by up to 25%.