

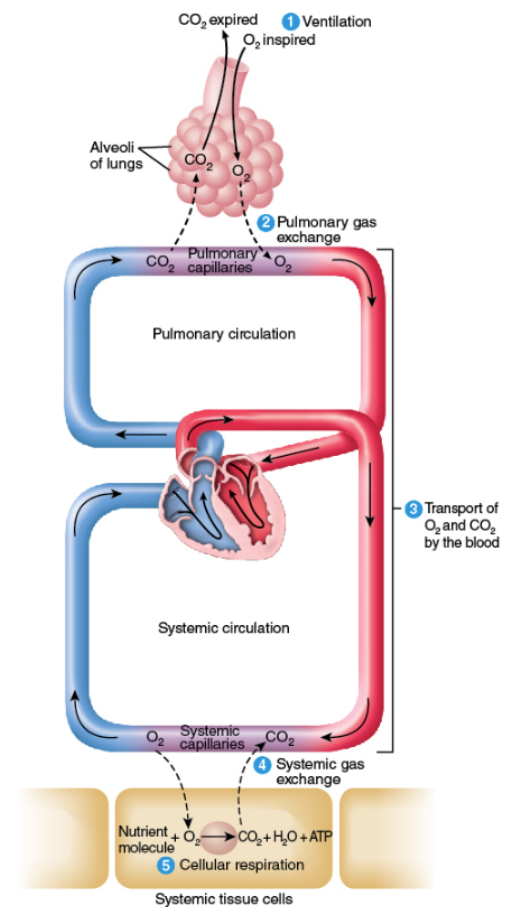
Respiratory and Hematology Lab Supplemental Resource

- I. Your body's cells continually use oxygen (O_2) for the metabolic reactions that generate ATP from the breakdown of nutrient molecules. At the same time, these reactions release carbon dioxide (CO_2) as a waste product. Because an excessive amount of CO_2 produces acidity that can be toxic to cells, excess CO_2 must be eliminated quickly and efficiently. You inhale needed O_2 and exhale the waste product CO_2 because of the respiratory system. In addition, the respiratory system helps regulate blood pH, contains receptors for the sense of smell, filters inspired air, produces sounds, and rids the body of some water and heat in exhaled air. In this chapter, you will learn about the various functions of the respiratory system.

II. Overview of the Respiratory System

A. The process of supplying the body with O_2 and removing CO_2 is known as respiration, which has five basic steps:

1. **Ventilation (breathing).** Air flows into and out of the lungs. Movement of air into the lungs is called inspiration (inhalation). Movement of air out of the lungs is referred to as expiration (exhalation). Inspiration allows O_2 to enter the lungs and expiration permits CO_2 to leave the lungs.
2. **Pulmonary gas exchange.** Gases are exchanged between the alveoli (air sacs) of lungs and blood in pulmonary capillaries. In this step, pulmonary capillary blood gains O_2 and loses CO_2 .
3. **Transport of O_2 and CO_2 by the blood.** The blood carries O_2 from the lungs to tissue cells and CO_2 from tissue cells to the lungs.
4. **Systemic gas exchange.** Gases are exchanged between blood in systemic capillaries and tissue cells of the body. In this step, systemic capillary blood loses O_2 and gains CO_2 .
5. **Cellular respiration.** Cells consume O_2 and give off CO_2 as metabolic reactions break down nutrient molecules to produce ATP.

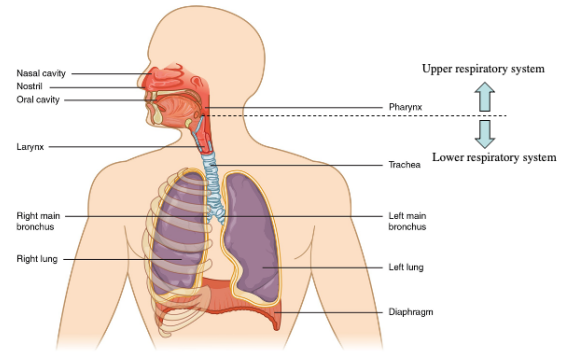


III. Components of the Respiratory System

A. Respiratory tract – consists of nose, pharynx, larynx, trachea, primary bronchi, and lungs

1. Can be divided into two: upper and lower respiratory systems

- Some consider the larynx part of the lower respiratory tract. Here we will consider the larynx part of the upper respiratory tract



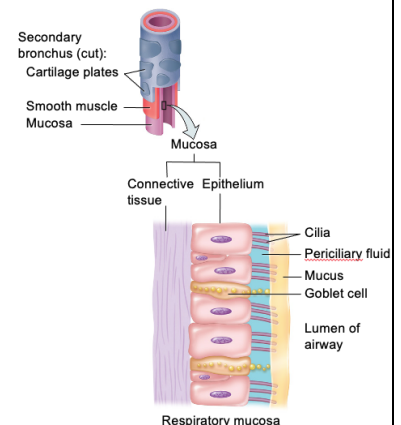
B. Respiration

1. External
2. Exchanging gases between environment and cells
3. Involves 4 major steps
 - Atmosphere to lungs = ventilation
 - Gas exchange from lungs to blood
 - Transport of gases through blood
 - Exchange of gases between blood and tissues

C. Respiratory epithelium

1. Designed to help remove dust and debris

- Epithelium
 - ◇ many parts of airways contains ciliated cells (cells with cilia attached to them) and scattered goblet cells that secrete mucus.
- Cilia
 - ◇ short, hairlike projections that extend from surface of a cell.
 - ◇ in the nose moves mucus and trapped particles down toward the pharynx
 - ◇ in the larynx, trachea, bronchi, and bronchioles moves these substances up toward the pharynx.
- Mucosa
 - ◇ or mucous membrane, consists of a layer of epithelial cells and an underlying layer of connective tissue
 - ◇ Mucus is a sticky secretion that traps inhaled particles and serves as a lubricant for the lining of the respiratory tract.



- Mucociliary escalator
 - ◇ refers to movement of mucus along respiratory tract toward the pharynx.
 - ◇ once mucus and trapped particles reach the pharynx, they can be swallowed or expectorated (spit out).
 - ◇ movement of cilia is paralyzed by nicotine. For this reason, smokers cough often to remove foreign particles from their airways.

D. Movement of air

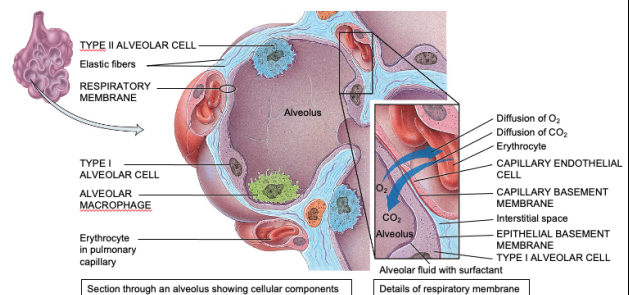
1. Brought in by nose
2. Enters pharynx
 - Common passageway for food, liquid, and air
3. Larynx routes air into proper channels
 - Also where vocalization takes place
4. Trachea carries air to bronchi
5. Primary bronchi transport air to lungs
6. Branching of the respiratory tract

E. Lungs

1. Paired, cone shaped
2. Located in thoracic cavity
3. Covered by pleura membrane
4. Contain most of the components of the respiratory tract
 - Terminate at the alveoli

F. Alveoli

1. Single layer of epithelium
 - Two types of cells
 - ◇ Type I alveolar cells
 - 95% of alveolar surface
 - ◇ Type II alveolar cells
 - Secrete surfactant



G. Capillaries

1. Fill about 80–90% of space between alveoli
2. Interstitial fluid
 - Very little
 - Maximizes gas exchange

H. Zones of the respiratory system

1. Conducting zone

- Prepares air

2. Respiratory zone

- Where gas exchange takes place

I. Blood flows to the lungs

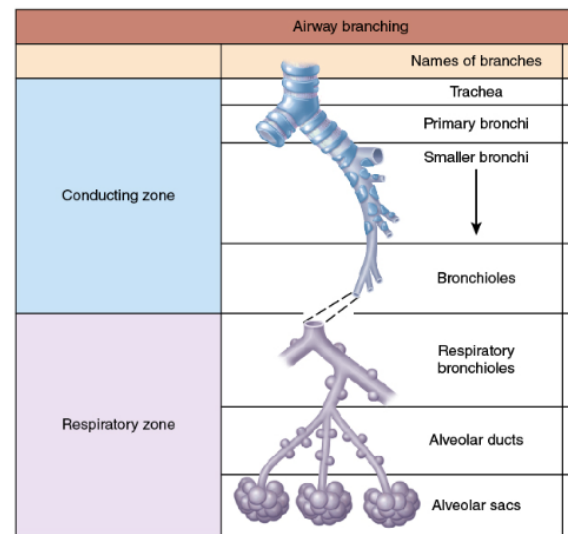
1. Network of capillaries

2. Blood flow is high

3. Entire Cardiac Output from Right Ventricle

4. Blood pressure is low

- 25/8 mmHg



IV. Ventilation

A. Defined as breathing

B. Mechanical flow of air into and out of the lungs

1. Dependent on

- **Atmospheric pressure** – pressure of the air in the atmosphere, which at sea level is about 760 millimeters of mercury (mmHg), or 1 atmosphere (atm).
- **Alveolar pressure** – pressure of air within the alveoli of the lungs. Depending on the stage of the breathing cycle, it may be equal to, lower than, or higher than atmospheric pressure. Air flows into or out of the lungs because a pressure gradient exists between the atmosphere and the alveoli. Air moves into the lungs when alveolar pressure is lower than atmospheric pressure. Air moves out of the lungs when alveolar pressure is higher than atmospheric pressure.
- **Intrapleural pressure** – pressure within the pleural cavity. Recall that the pleural cavity is the space between the parietal and visceral layers of the pleura. A small amount of intrapleural fluid is present in this space. Intrapleural pressure is always a negative pressure (lower than atmospheric pressure), ranging from 754–756 mmHg during normal quiet breathing. Because the pleural cavity has a negative pressure, it essentially functions as a vacuum. The suction of this vacuum couples the lungs to the chest wall via the pleura to form the lung–chest wall system. Thus, if the thoracic cavity increases in size, the lungs also expand; if the thoracic cavity decreases in

size, the lungs recoil (become smaller). The changes in lung volume caused by alterations in thoracic cavity size in turn cause a change in alveolar pressure.

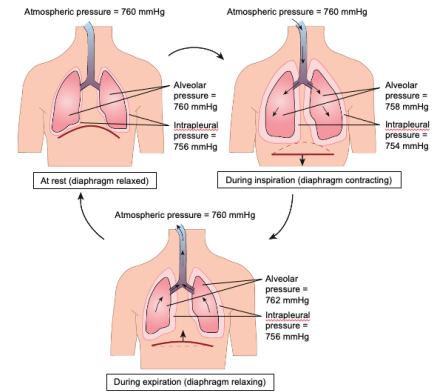
C. Air flow is dependent on pressure gradients

1. Boyle's Law and the lungs

D. Breathing cycle

1. Has three phases:

- Rest
 - ◇ No air movement into or out of lungs
- Inspiration
 - ◇ Bringing air into lungs from atmosphere
- Expiration
 - ◇ Expelling air into the environment from the lungs

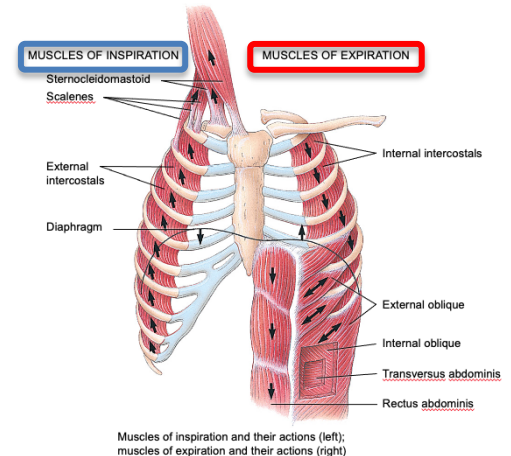


2. Inspiration

- Respiratory muscles contract to cause a change in thoracic volume
 - ◇ During a normal quiet inspiration, the diaphragm and external intercostals contract, the lungs expand, and air moves into the lungs
- Results in a drop in alveolar pressure
- Air moves into lung

3. Expiration

- Respiratory muscles relax
 - ◇ during a normal quiet expiration, the diaphragm and external intercostals relax, and lungs recoil inward, forcing air out of the lungs
- Rib cage decreases volume
- Alveolar pressure increases
- Air flows out



E. Factors affecting ventilation

1. Surface tension of alveolar fluid

- A thin layer of alveolar fluid coats the luminal surface of alveoli and exerts a force known as surface tension. Surface tension arises at all air–water interfaces because the polar water molecules are more strongly attracted to each other than they are to the nonpolar gas molecules in the air. When liquid

surrounds a sphere of air, as in an alveolus or a soap bubble, surface tension produces an inwardly directed force. Soap bubbles burst because they collapse inward due to surface tension. In the lungs, surface tension causes the alveoli to assume the smallest possible diameter. During breathing, surface tension must be overcome to expand the lungs during each inspiration. Surface tension also accounts for two-thirds of lung elastic recoil, which decreases the size of alveoli during expiration.

- The surfactant in alveolar fluid reduces surface tension. Surfactant, a surface active agent, is a complex mixture of lipids and proteins secreted by type II alveolar cells of the lungs. It intersperses between the water molecules at the air–water interface. This disrupts the cohesive forces between water molecules, causing a marked decrease in surface tension. The presence of surfactant in alveolar fluid reduces the work of breathing and increases lung compliance (described shortly).
- A deficiency of surfactant in premature infants causes respiratory distress syndrome (RDS), in which the surface tension of alveolar fluid is greatly increased so that many alveoli collapse at the end of each expiration. Treatment involves the administration of surfactant directly into the lungs.

2. Compliance of lungs

- refers to how much effort is required to stretch lungs and chest wall. High compliance means that lungs and chest wall expand easily; low compliance means that they resist expansion. By analogy, a thin balloon that is easy to inflate has high compliance, and a heavy and stiff balloon that takes a lot of effort to inflate has low compliance. In lungs, compliance is related to two principal factors: elasticity and surface tension. Lungs normally have high compliance and expand easily because elastic fibers that are present in lung tissue are easily stretched and surfactant in alveolar fluid reduces surface tension. Decreased compliance is a common feature in pulmonary conditions that (1) scar lung tissue, (2) cause lung tissue to become filled with fluid (pulmonary edema), (3) produce a deficiency in surfactant, or (4) impede lung expansion in any way (for example, paralysis of the intercostal muscles). By contrast, increased lung compliance occurs in emphysema because there is less elastic recoil of lungs due to destruction of elastic fibers in alveolar walls.

3. Airway resistance

- Like the flow of blood through blood vessels, the rate of airflow through the airways depends on both the pressure gradient and the resistance: Airflow equals the pressure gradient between the alveoli and the atmosphere divided by the resistance. The relationship among airflow, the pressure gradient, and resistance is given by the following equation:

$$F = \frac{\Delta P}{R}$$

where F = airflow,
ΔP = the pressure gradient, and
R = the resistance to airflow.

- The walls of the airways, especially the bronchioles, offer some resistance to the normal flow of air into and out of the lungs. (Larger-diameter airways have decreased resistance.) As the lungs expand during inspiration, the bronchioles enlarge because their walls are pulled outward in all directions. Airway resistance then increases during expiration as the diameter of bronchioles decreases. Airway diameter is also regulated by the degree of contraction or relaxation of smooth muscle in the walls of the airways. Signals from the sympathetic division of the autonomic nervous system (ANS) cause relaxation of bronchiolar smooth muscle, which results in bronchodilation and decreased resistance. Signals from the parasympathetic division of the ANS cause contraction of bronchiolar smooth muscle, resulting in bronchoconstriction and increased resistance.
- Any condition that narrows or obstructs the airways increases resistance so that more pressure is required to maintain the same airflow. The hallmark of asthma or chronic obstructive pulmonary disease (COPD)—emphysema or chronic bronchitis—is increased airway resistance due to obstruction or collapse of airways.

V. Lung Volumes and Capacities

A. Lung volumes – Measured to assess lung function

B. Lung capacities – Combinations of lung volumes

C. These can all be measured using a spirogram – Can also use these to measure minute ventilation

D. Lung volumes and lung capacities

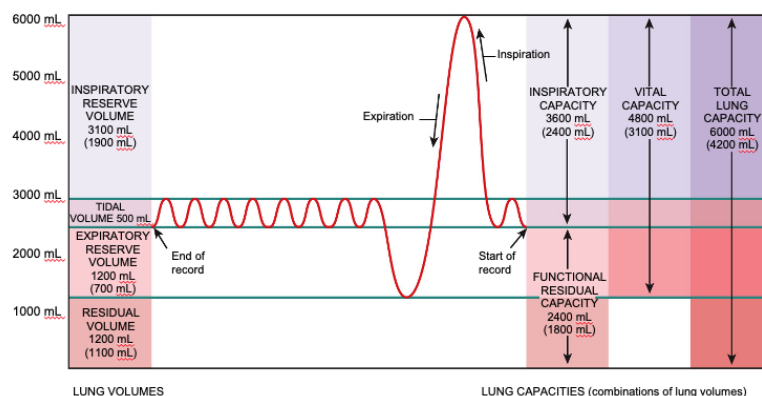
1. **Tidal volume (V_T)** – volume of air inspired or expired during a single breathing cycle under resting conditions. It equals 500 mL in an average adult male or female.

2. **Inspiratory reserve volume (IRV)** – maximum volume of air that can be inspired after a normal inspiration. It is about 3100 mL in an average adult male and 1900 mL in an average adult female.
3. **Expiratory reserve volume (ERV)** – maximum volume of air that can be expired after a normal expiration. It averages 1200 mL in males and 700 mL in females.
4. **Residual volume (RV)** – volume of air that remains in the lungs after a maximum expiration. It amounts to

about 1200 mL in males and 1100 mL in females.

This air remains in the lungs because the subatmospheric intrapleural pressure keeps the alveoli slightly

inflated, and some air also remains in the noncollapsible airways. Because it does not leave the lungs, RV and any lung capacity that includes the RV cannot be measured with a spirometer.



5. **Functional residual capacity (FRC)** – volume of air in the lungs at the end of a normal expiration. It is the sum of residual volume and expiratory reserve volume (1200 mL + 1200 mL = 2400 mL in males and 1100 mL + 700 mL = 1800 mL in females).
6. **Inspiratory capacity (IC)** – maximum volume of air that can be inspired after a normal expiration. It is the sum of tidal volume and inspiratory reserve volume (500 mL + 3100 mL = 3600 mL in males and 500 mL + 1900 mL = 2400 mL in females).
7. **Vital capacity (VC)** – maximum volume of air that can be expired after a maximum inspiration. It is equal to the sum of inspiratory reserve volume, tidal volume, and expiratory reserve volume (4800 mL in males and 3100 mL in females). A term related to the VC is the forced expiratory volume in 1 second (FEV1), the volume of air that can be exhaled from the lungs in 1 second with maximal effort following a maximal inspiration. Under normal conditions, the FEV1 is about 80% of the VC. Typically, chronic obstructive pulmonary disease (COPD) greatly reduces FEV1 because COPD increases airway resistance.
8. **Total lung capacity (TLC)** – total volume of air in the lungs after a maximum inspiration. It is the sum of vital capacity and residual volume (4800 mL + 1200 mL = 6000 mL in males and 3100 mL + 1100 mL = 4200 mL in females).

VI. Exchange of Oxygen and Carbon Dioxide

A. Occurs via passive diffusion

B. Governed by the behavior of gasses

1. Explained by two laws

- Dalton's law
 - ◇ Each gas in a mixture of gases exerts its own pressure as if there were no other gases present
 - ◇ The pressure that a specific gas exerts is called the partial pressure (P_x)
- Henry's Law
 - ◇ Quantity of a gas that will dissolve in a liquid is proportional to the partial pressure of the gas and its solubility
 - ◇ Oxygen has a lower solubility than carbon dioxide

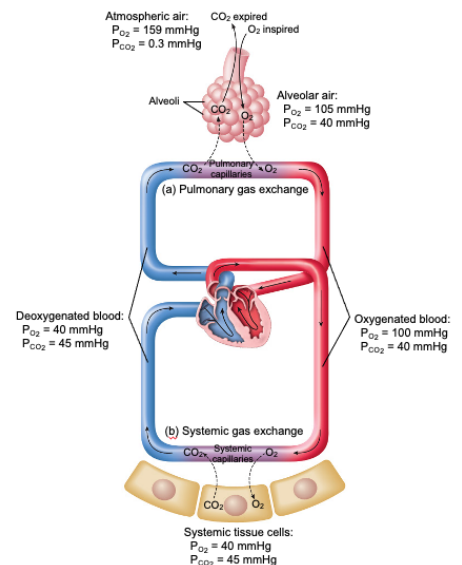
C. Two types

1. Pulmonary gas exchange

- Converts deoxygenated blood into oxygenated blood

2. Systemic gas exchange

- Allows peripheral tissues to use the oxygen that is in the blood



VII. Transport of Oxygen and Carbon Dioxide

A. Oxygen transport

1. Oxygen has poor solubility
2. 98.5% is bound to hemoglobin and transported in red blood cells
3. Referred to differently when there is O_2 attached
 - Deoxyhemoglobin
 - ◇ Without O_2
 - Oxyhemoglobin
 - ◇ With O_2
4. Partial pressure of oxygen determines how much binds to hemoglobin

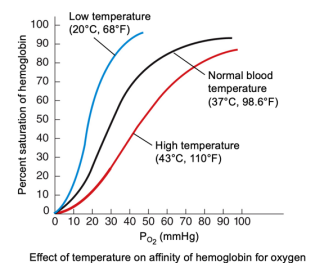
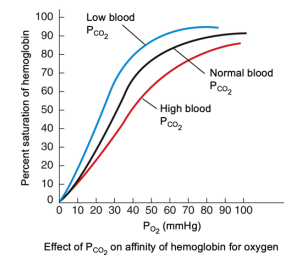
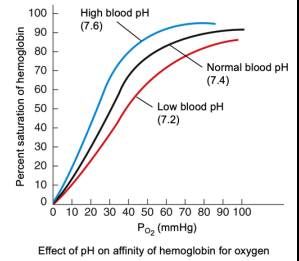
5. Factors affecting oxygen affinity to hemoglobin

- **Acidity (pH)** – As acidity increases (pH decreases), the affinity of hemoglobin for O₂ decreases, and O₂ dissociates more readily from hemoglobin. In other words, increasing acidity enhances the unloading of oxygen from hemoglobin. The main acids produced by metabolically active tissues are lactic acid and carbonic acid. When pH decreases, the entire oxygen–hemoglobin dissociation curve shifts to the right; at any given P_{O2}, hemoglobin is less saturated with O₂, a change termed the Bohr effect.
- **Partial pressure of carbon dioxide** – CO₂ can also bind to hemoglobin, and the effect is similar to that of H⁺ (shifting the curve to the right). As P_{CO2} rises, hemoglobin releases O₂ more readily. P_{CO2} and pH are related factors because low blood pH (acidity) results from high P_{CO2}. As CO₂ enters the blood, much of it is temporarily converted to carbonic acid (H₂CO₃), a reaction catalyzed by an enzyme in erythrocytes called carbonic anhydrase (CA):

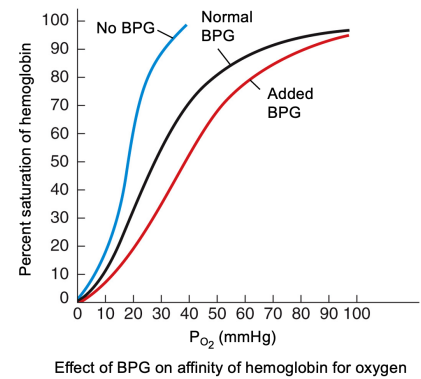


The carbonic acid thus formed in erythrocytes dissociates into hydrogen ions and bicarbonate ions. As the H⁺ concentration increases, pH decreases. Thus, an increased P_{CO2} produces a more acidic environment, which helps release O₂ from hemoglobin. During exercise, lactic acid—a by-product of anaerobic metabolism within muscles—also decreases blood pH. Decreased P_{CO2} (and elevated pH) shifts the saturation curve to the left.

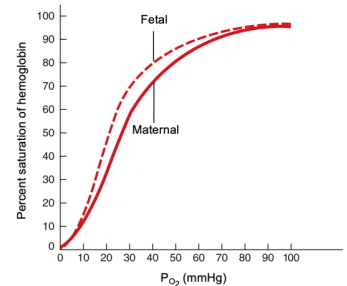
- **Temperature** – Within limits, as temperature increases, so does the amount of O₂ released from hemoglobin. Heat is a by-product of the metabolic reactions of all cells, and the heat released by contracting muscle fibers tends to raise body temperature. Metabolically active cells require more O₂ and liberate more acids and heat. The acids and heat in turn promote release of O₂ from oxyhemoglobin. Fever produces a similar result. By contrast, during hypothermia (lowered body temperature) cellular metabolism slows, the need for O₂ is reduced, and more O₂ remains bound to hemoglobin (a shift to the left in the saturation curve).



- **Biphosphoglycerate (BPG)** – A substance found in erythrocytes called 2,3-bisphosphoglycerate (BPG), previously called diphosphoglycerate (DPG), decreases the affinity of hemoglobin for O_2 and thus helps unload O_2 from hemoglobin. BPG is formed in erythrocytes when they break down glucose to produce ATP during glycolysis. When BPG combines with hemoglobin by binding to the terminal amino groups of the two beta globin chains, the hemoglobin binds O_2 less tightly at the heme group sites. The greater the level of BPG, the more O_2 is unloaded from hemoglobin. Certain hormones, such as thyroxine, growth hormone, epinephrine, norepinephrine, and testosterone, increase the formation of BPG. The level of BPG is also higher in people living at higher altitudes.



- **Fetal hemoglobin** – differs from adult hemoglobin (Hb-A) in structure and in its affinity for O_2 . Hb-F has a higher affinity for O_2 because it binds BPG less strongly. Thus, when P_{O_2} is low, Hb-F can carry up to 30% more O_2 than maternal Hb-A. As the maternal blood enters the placenta, O_2 is readily transferred to fetal blood. This is very important because the O_2 saturation in maternal blood in the placenta is quite low, and the fetus might suffer hypoxia were it not for the greater affinity of fetal hemoglobin for O_2 .



B. Carbon dioxide transport

1. Is transported through the blood in three ways:

1. **Dissolved in the plasma**

- 7% – Upon reaching the lungs, it diffuses into alveolar air and is exhaled.

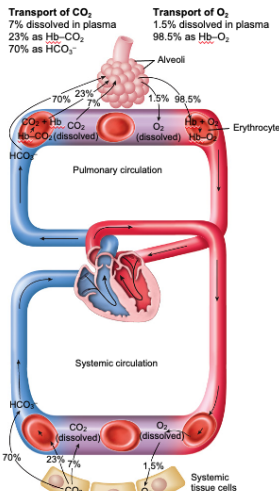
2. **Carbamino compounds**

- 23% – combines with the amino groups of amino acids and proteins in blood to form carbamino compounds. Because the most prevalent protein in blood is hemoglobin (inside erythrocytes), most of the CO_2 transported in this manner is bound to hemoglobin. The main CO_2 binding sites are the terminal amino acids in the two alpha and two beta globin chains.

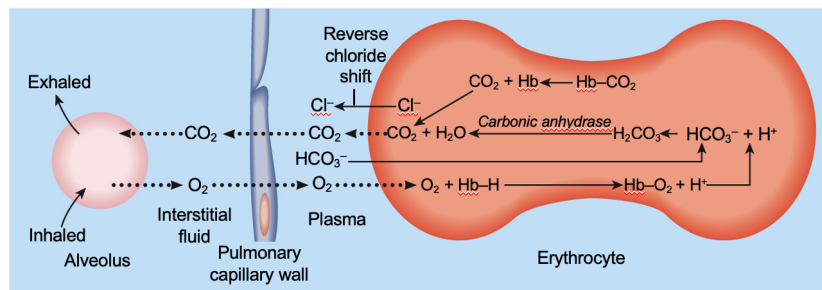
3. Bicarbonate ions

- 70% – As CO_2 diffuses into systemic capillaries and enters erythrocytes, it reacts with water in the presence of the enzyme carbonic anhydrase (CA) to form carbonic acid, which dissociates into H^+ and HCO_3^-

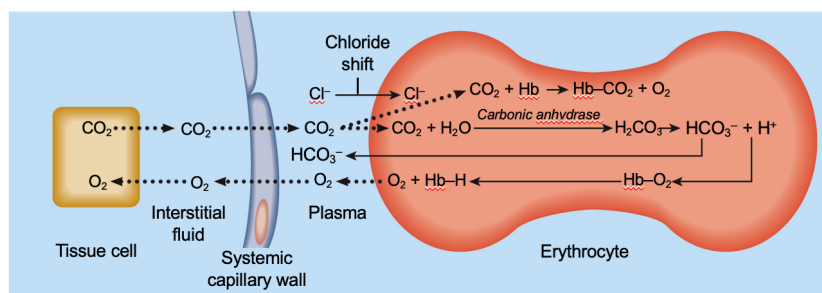
Gas Exchange and Transport Can Be Summarized: Deoxygenated blood returning to the pulmonary



capillaries in the lungs contains CO_2 dissolved in blood plasma, CO_2 combined with globin as carbaminohemoglobin (Hb-CO_2), and CO_2 incorporated into HCO_3^- within erythrocytes. The erythrocytes have also picked up H^+ , some of which binds to and therefore is buffered by hemoglobin (Hb-H). As blood passes through the pulmonary capillaries, molecules of CO_2 dissolved in blood plasma and CO_2 that dissociates from the globin portion of hemoglobin diffuse into alveolar air and are exhaled. At the same time, inhaled O_2 diffuses from alveolar air into erythrocytes and is binding to hemoglobin to form oxyhemoglobin (Hb-O_2). Carbon dioxide is also released from HCO_3^- when H^+ combines with HCO_3^- inside erythrocytes. The H_2CO_3 formed from this reaction then splits into CO_2 , which is exhaled, and H_2O . As the concentration of HCO_3^- declines inside erythrocytes in pulmonary capillaries, HCO_3^- diffuses in from the blood plasma, in exchange for Cl^- . In sum, oxygenated blood leaving the lungs has increased O_2 content and decreased amounts of CO_2 and H^+ . In systemic capillaries, as cells use O_2 and produce CO_2 , the chemical reactions reverse.



Exchange of O_2 and CO_2 in pulmonary capillaries (pulmonary gas exchange)



Exchange of O_2 and CO_2 in systemic capillaries (systemic gas exchange)

VIII. Control of Ventilation

A. Respiratory centers control breathing

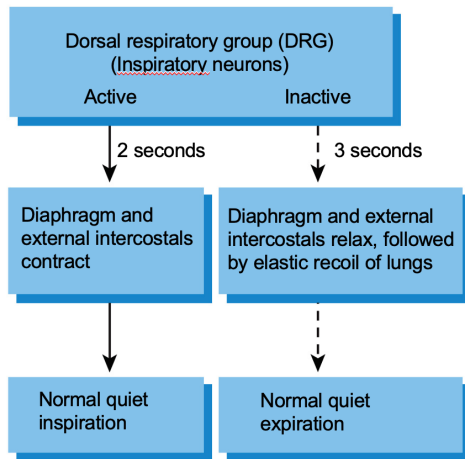
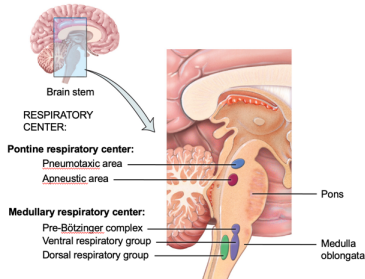
1. Cluster of neurons in the brainstem collectively known as the respiratory center

- Divided

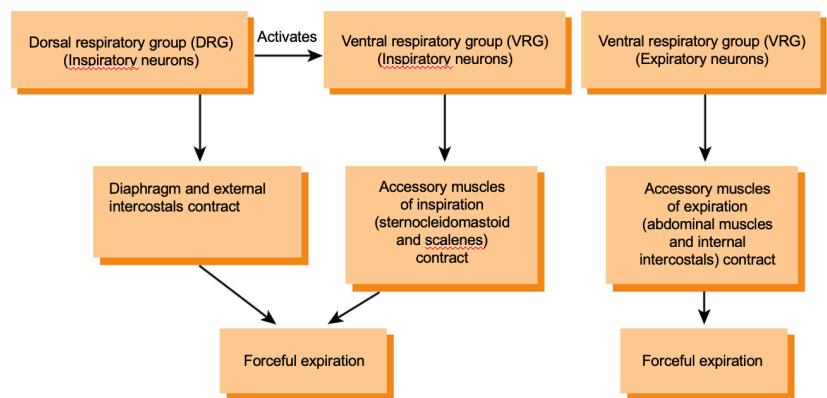
- ◇ Medullary respiratory center – dorsal respiratory group (DRG) and ventral respiratory group (VRG)

- Located in the VRG is a cluster of neurons called the pre-Bötzinger complex that is believed to be important in the generation of the rhythm of respiration

- ◇ Pontine respiratory center – pneumotaxic area (also known as pontine respiratory group) and apneustic area



During normal quiet breathing



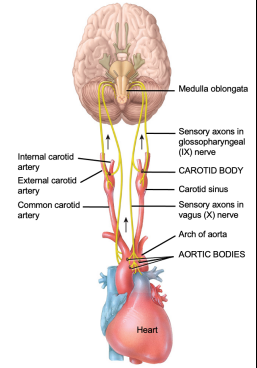
During forceful breathing

B. Respiratory centers are subject to regulation

1. **Cortical influences** – Because the cerebral cortex has connections with the respiratory center, we can voluntarily alter our pattern of breathing. We can even refuse to breathe at all for a short time. Voluntary control is protective because it enables us to prevent water or irritating gases from entering the lungs. The ability not to breathe, however, is limited by the buildup of CO_2 and H^+ in the body. When P_{CO_2} and H^+ concentrations increase to a certain level, the DRG neurons of the medullary respiratory center are strongly stimulated, action potentials are sent along the phrenic and intercostal nerves to inspiratory muscles, and breathing resumes, whether the person wants it to or not. It is impossible for small children to kill themselves by voluntarily holding their breath, even though many have tried in order to get their way. If breath is held long enough to cause fainting, breathing resumes when consciousness is lost. Action potentials from the hypothalamus and

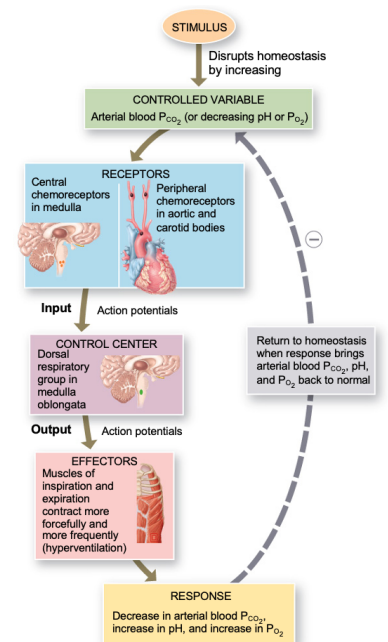
limbic system also stimulate the respiratory center, allowing emotional stimuli to alter respirations as in, for example, laughing and crying.

2. **Chemoreceptor regulation** – Certain chemical stimuli modulate how quickly and how deeply we breathe. The respiratory system functions to maintain proper levels of CO_2 and O_2 and is very responsive to changes in the levels of these gases in body fluids. Chemoreceptors are sensory receptors that are responsive to chemicals. Chemoreceptors in two locations monitor levels of CO_2 , H^+ , and O_2 and provide input to the respiratory center.



The central and peripheral chemoreceptors participate in a negative feedback system that regulates the levels of CO_2 , O_2 , and H^+ in the blood. As a result of increased P_{CO_2} , decreased pH (increased H^+), or decreased P_{O_2} , input from the central and peripheral chemoreceptors causes the DRG to become highly active, and the rate and depth of breathing increase. Rapid and deep breathing, called hyperventilation, allows the inhalation of more O_2 and expiration of more CO_2 until P_{CO_2} and H^+ are lowered to normal.

3. **Proprioceptor stimulation of breathing** – As soon as you start exercising, your rate and depth of breathing increase, even before changes in P_{O_2} , P_{CO_2} , or H^+ level occur. The main stimulus for these quick changes in respiratory effort is input from proprioceptors, which monitor movement of joints and muscles. Action potentials from the proprioceptors stimulate the DRG of the medulla oblongata. At the same time, axon collaterals (branches) of upper motor neurons that originate in the primary motor cortex also feed excitatory signals into the DRG.
4. **The inflation reflex** – Similar to those in the blood vessels, stretch-sensitive receptors are located in the walls of bronchi and bronchioles. When these receptors become stretched during overinflation of the lungs, action potentials are sent along the vagus (X) nerves to the dorsal respiratory group (DRG) in the medullary respiratory center. In response, the DRG is inhibited and the diaphragm and external intercostals relax. As a result, further inspiration is stopped and expiration begins. As air leaves the lungs during expiration, the lungs deflate and the stretch receptors are no longer stimulated. Thus, the DRG is no longer inhibited, and a new inspiration



begins. This reflex is referred to as the inflation (Hering–Breuer) reflex. In infants, the reflex appears to function in normal breathing. In adults, however, the reflex is not activated until tidal volume (normally 500 mL) reaches more than 1500 mL. Therefore, the reflex in adults is a protective mechanism that prevents excessive inflation of the lungs, for example, during severe exercise, rather than a key component in the normal control of respiration.

5. **Limbic system** – Anticipation of activity or emotional anxiety may stimulate the limbic system, which then sends excitatory input to the DRG, increasing the rate and depth of ventilation.
6. **Temperature** – An increase in body temperature, as occurs during a fever or vigorous muscular exercise, increases the rate of ventilation. A decrease in body temperature decreases respiratory rate. A sudden cold stimulus (such as plunging into cold water) causes temporary apnea, an absence of breathing.
7. **Pain** – A sudden, severe pain brings about brief apnea, but a prolonged somatic pain increases respiratory rate. Visceral pain may slow the rate of ventilation.
8. **Stretching the anal sphincter muscle** – This action increases the respiratory rate and is sometimes used to stimulate ventilation in a newborn baby or a person who has stopped breathing.
9. **Irritation of airways** – Physical or chemical irritation of the pharynx or larynx brings about an immediate cessation of breathing followed by coughing or sneezing.
10. **Blood pressure** – The carotid and aortic baroreceptors that detect changes in blood pressure have a small effect on breathing. A sudden rise in blood pressure decreases the rate of respiration, and a drop in blood pressure increases the respiratory rate.

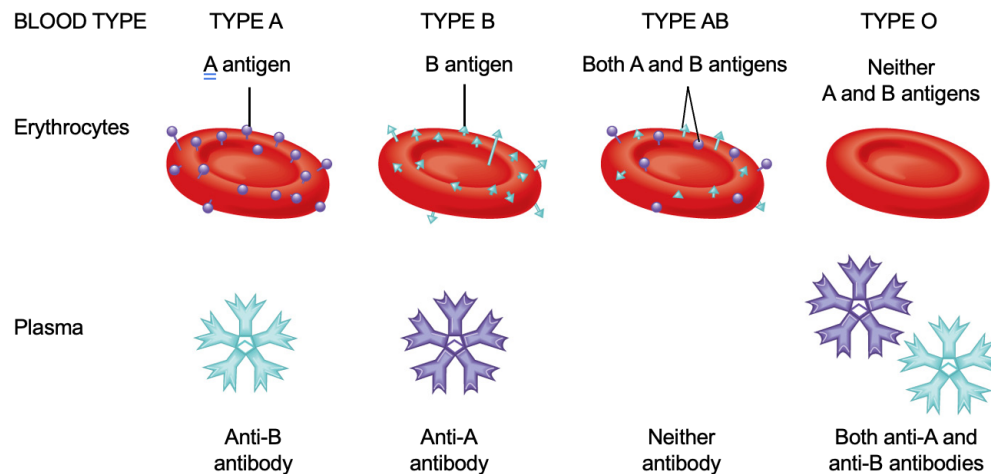
VI. Blood Groups and Blood Types

- A. The surfaces of erythrocytes contain a genetically determined assortment of antigens that includes carbohydrates and proteins. These antigens, called agglutinogens occur in characteristic combinations. Based on the presence or absence of various antigens, blood is categorized into different blood groups. Within a given blood group, there may be two or more different blood types. There are at least 24 blood groups and more than 100 antigens that can be detected on the surface of erythrocytes. Here, two major blood groups—ABO and Rh—are discussed.
- B. The incidence of ABO and Rh blood types varies among different population groups, as indicated in the table below.

Population Group	Blood Type (percentage)				
	O	A	B	AB	Rh ⁺
European American	45	40	11	4	85
African American	49	27	20	4	95
Korean American	32	28	30	10	100
Japanese American	31	38	21	10	100
Chinese American	42	27	25	6	100
Native American	79	16	4	1	100

C. ABO Blood Group Is Determined by the Presence or Absence of A and B Antigens

- ◇ The ABO blood group is based on two glycolipid antigens called A and B. People whose erythrocytes display only antigen A have type A blood. Those who have only antigen B are type B. Individuals who have both A and B antigens are type AB; those who have neither antigen A nor B are type O.

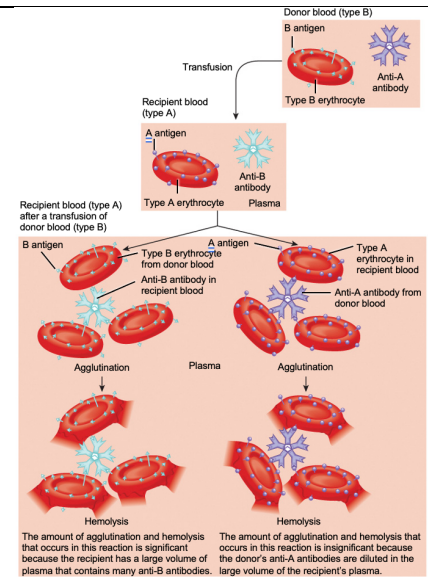


Plasma usually contains antibodies called agglutinins that react with the A or B antigens if the two are mixed. These are the anti-A antibody, which reacts with antigen A, and the anti-B antibody, which reacts with antigen B. The antibodies present in each of the four blood types are shown above. You do not have antibodies that react with the antigens of your own erythrocytes, but you do have antibodies for any antigens that your erythrocytes lack. For example, if your blood type is B, you have B antigens on your erythrocytes, and you have anti-A antibodies in your plasma. Although agglutinins start to appear in the blood within a few months after birth, the reason for their presence is not clear. Perhaps they are formed in response to bacteria that normally inhabit the gastrointestinal tract. Because the antibodies are large IgM-type antibodies that do not cross the placenta, ABO incompatibility between a mother and her fetus rarely causes problems.

D. An Incompatible Transfusion Causes Agglutination

- ◇ Despite the differences in erythrocyte antigens reflected in the blood group systems, blood is the most easily shared of human tissues, saving many thousands of lives every year through transfusions. A transfusion is the transfer of whole blood or blood components (erythrocytes only or plasma only) into the bloodstream or directly into the red bone marrow. A transfusion is most often given to alleviate anemia, to increase blood volume (for example, after a severe hemorrhage), or to improve immunity. However, the normal components of one person's erythrocyte plasma membrane can trigger damaging antigen-antibody responses in a

transfusion recipient. In an incompatible blood transfusion, antibodies in the recipient's plasma bind to the antigens on the donated erythrocytes, which causes agglutination, or clumping, of the erythrocytes. Agglutination is an antigen–antibody response in which erythrocytes become cross-linked to one another. (Note that agglutination is not the same as blood clotting.) When these antigen–antibody complexes form, they activate plasma proteins of the complement family. In essence, complement molecules make the plasma membrane of the donated erythrocytes leaky, causing hemolysis (rupture) of the erythrocytes and the release of hemoglobin into the plasma. The liberated hemoglobin may cause kidney damage by clogging the filtration membranes.



- ◇ Consider what happens if a person with type A blood receives a transfusion of type B blood. The recipient's blood (type A) contains A antigens on the erythrocytes and anti-B antibodies in the plasma. The donor's blood (type B) contains B antigens and anti-A antibodies. In this situation, two things can happen. First, the anti-B antibodies in the recipient's plasma can bind to the B antigens on the donor's erythrocytes, causing agglutination and hemolysis of the erythrocytes. Second, the anti-A antibodies in the donor's plasma can bind to the A antigens on the recipient's erythrocytes, a less serious reaction because the donor's anti-A antibodies become so diluted in the recipient's plasma that they do not cause significant agglutination and hemolysis of the recipient's erythrocytes.

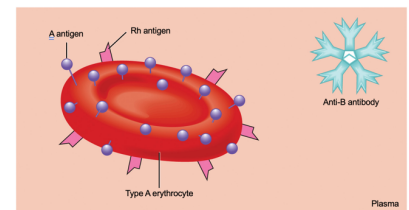
People with type AB blood do not have anti-A or anti-B antibodies in their blood plasma. They are sometimes called universal recipients because theoretically they can receive blood from donors of all four blood types. They have no antibodies to attack antigens on donated erythrocytes. People with type O blood have neither A nor B antigens on their erythrocytes and are sometimes called universal donors because theoretically they can donate blood to all four ABO blood types. Type O persons requiring blood may receive only type O blood. In practice, use of the terms universal recipient and universal donor is misleading and dangerous. Blood contains antigens and antibodies other than those associated with the ABO system that can cause transfusion problems. Thus, blood should be carefully cross-matched or screened

before transfusion. In about 80% of the population, soluble antigens of the ABO type appear in saliva and other body fluids, in which case blood type can be identified from a saliva sample.

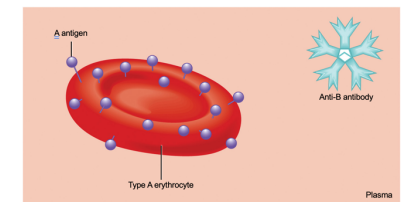
Characteristic	Blood Type			
	A	B	AB	O
Agglutinin (antigen) on erythrocytes	A	B	Both A and B	Neither A nor B
Agglutinin (antibody) in plasma	Anti-B	Anti-A	Neither anti-A nor anti-B	Both anti-A and anti-B
Compatible donor blood types (no hemolysis)	A, O	B, O	A, B, AB, O	O
Incompatible donor blood types (hemolysis)	B, AB	A, AB	—	A, B, AB

E. Rh Blood Group Is Based on the Presence or Absence of Rh Antigens

- ◇ The Rh blood group is so named because the antigen was discovered in the blood of the Rhesus monkey. The alleles of three genes may code for the Rh antigen, which is a protein. People whose erythrocytes have Rh antigens are designated Rh⁺ (Rh positive); those who lack Rh antigens are designated Rh⁻ (Rh negative). Normally, plasma does not contain anti-Rh antibodies. If an Rh⁻ person receives an Rh⁺ blood transfusion, however, the immune system starts to make anti-Rh antibodies that remain in the blood. If a second transfusion of Rh⁺ blood is given later, the previously formed anti-Rh antibodies would cause agglutination and hemolysis of the erythrocytes in the donated blood, and a severe reaction may occur.



Type A⁺ blood, an example of Rh⁺ blood



Type A⁻ blood, an example of Rh⁻ blood

F. Hemolytic disease of the newborn (HDN)

- ◇ Most common problem with Rh incompatibility
- ◇ May arise during pregnancy
- ◇ Normally, no direct contact occurs between maternal and fetal blood while a woman is pregnant. However, if a small amount of Rh⁺ blood leaks from the fetus through the placenta into the bloodstream of an Rh⁻ mother, the mother starts to make anti-Rh antibodies.
- ◇ Because the greatest possibility of fetal blood leakage into the maternal circulation occurs at delivery, the firstborn baby usually is not affected. If the mother becomes pregnant again, however, her anti-Rh antibodies can cross the placenta and enter the bloodstream of the fetus. If the fetus is Rh⁻, there is no problem because Rh⁻ blood does not have the Rh antigen. If the fetus is Rh⁺, however, agglutination and hemolysis brought on by fetal–maternal incompatibility may occur in the fetal blood.

