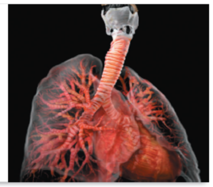
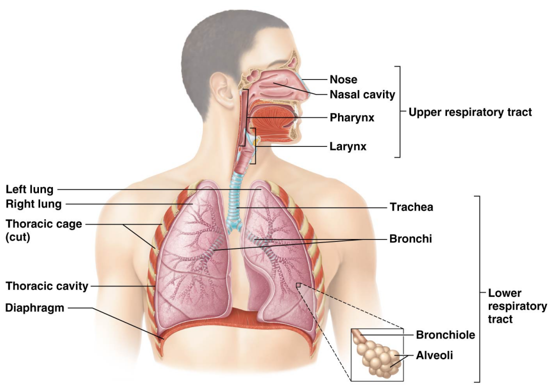
21
The Respiratory System



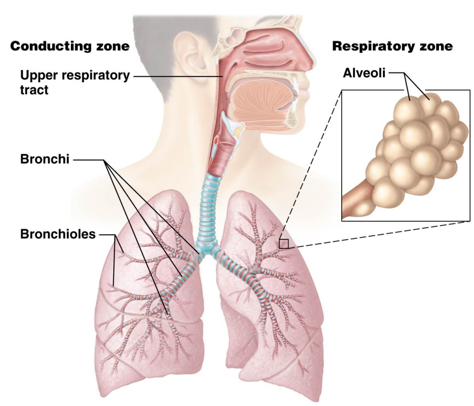
21.1 Overview of the Respiratory System



- Classified anatomically into upper and lower tracts:
  - _______– passageways from nasal cavity to larynx
  - **Lower** – passageways from trachea alveoli
    - **Alveoli** – tiny air sacs, site of gas exchange
    - _______–
      - » Each is a collection of millions of alveoli and their blood vessels embedded in elastic connective tissue

Basic Functions of the Respiratory System

- Classified functionally into **conducting** and **respiratory zones**:
  - __________________- pathway air travels
    - Air is filtered, warmed, and moistened
    - Includes structures from nose and nasal cavity to bronchioles
  - __________________– where gas exchange occurs; alveoli



- **Respiration** – process that provides body cells with oxygen and removes waste product carbon dioxide:
  1. **Pulmonary ventilation** – movement of air in and out of lungs
  2. **Pulmonary gas exchange** – movement of gases between lungs and blood
  3. _______________– movement of gases through blood
  4. **Tissue gas exchange** –

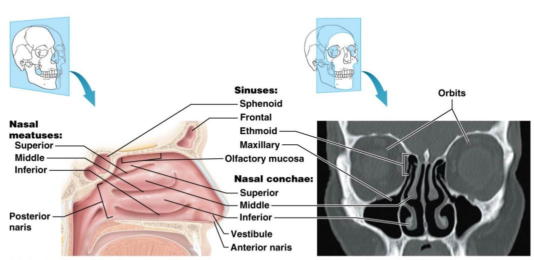
- Other functions – serve to maintain homeostasis:
  - Speech and sound production
  -
  - Assist with defecation, urination, and childbirth by increasing pressure in thoracic cavity
  - Assist with flow of venous blood and lymph
  - Maintaining acid-base balance
  -

21.2 Anatomy of the Respiratory System

The Nose and Nasal Cavity

- Nose and nasal cavity are entryway into respiratory system; serve following functions:
  -
  - Filter debris from inhaled air and secrete antibacterial substances
  -
  - Resonates of voice

- Anatomy of nasal cavity:
  - **Nasal cavity** – divided into left and right portions by nasal septum from nostrils (anterior nares) to posterior nares
  - _______________– contain bristle-like hairs
  - **Superior**, **inferior**, and **middle conchae** create turbulence
  - **Paranasal sinuses** – hollow cavities found within frontal, ethmoid, sphenoid, and maxillary bones
    - Warm and humidify air; also enhance voice resonance and reduce weight of skull

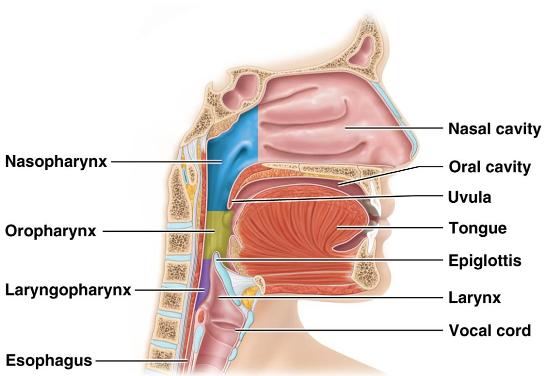


(a) Sagittal section of nasal cavity
(b) Frontal section of nasal cavity (CT scan)

- Histology of nasal cavity:
  - **Vestibule** is lined with stratified squamous epithelium; resists mechanical stress
  - Most of nasal cavity is lined with mucosa composed of PSCCE and goblet cells
    - Traps foreign particles in mucus → ciliated cells move it toward posterior nasal cavity and pharynx

The Pharynx

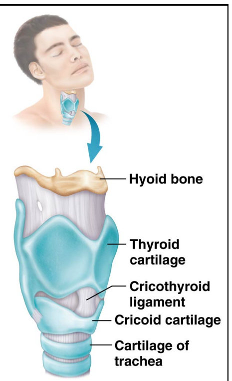
- **Pharynx** (throat) – three divisions:
  - _______________– posterior to nasal cavity; lined with PSCCE
    - Extends from posterior nares to soft palate
  - _______________– posterior to oral cavity
    - Extends from uvula to hyoid bone
    - stratified squamous epithelium
  - _______________– **hyoid bone** to **esophagus**
    - stratified squamous epithelium



The Larynx

- **Larynx** or **voice box** – houses **vocal cords**
  - Stratified squamous epithelium superior to vocal cords
  - PSCCE found inferior to vocal cords
- Composed of _________ pieces of **cartilage**

- **Thyroid cartilage** – largest of three unpaired sections ("**Adam's apple**")
- _________ **cartilage** –inferior to thyroid cartilage

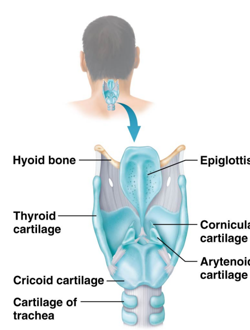


(a) Anterolateral view

- _________ –posterior to thyroid cartilage

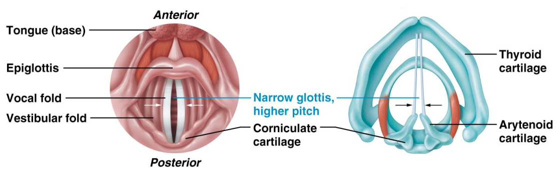
Remaining six found pairs:

- **Cuneiform cartilages** –help support epiglottis
- **Arytenoid cartilages** – involved in sound production
- **Corniculate cartilages** – involved in sound production



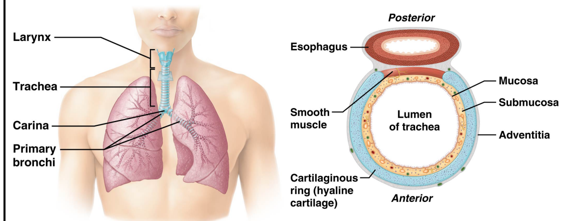
(b) Posterior view

- **Vestibular folds** (false vocal cords) close off glottis during swallowing; play no role in sound production
- **True vocal cords** and **Vocal ligaments** – elastic bands; vibrate to produce sound when air passes over them



The Trachea

- **Trachea** (**windpipe**) - C shape cartilage rings
  -



(a) Trachea and lungs

(b) Cross section through trachea and esophagus

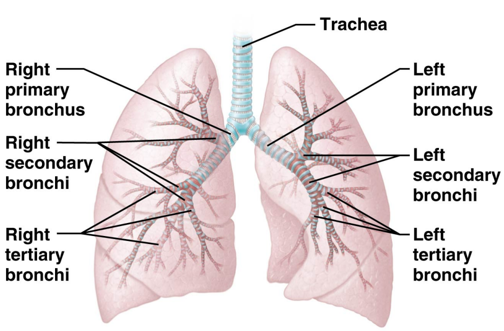
Smoker's Cough

A&P in the Real World

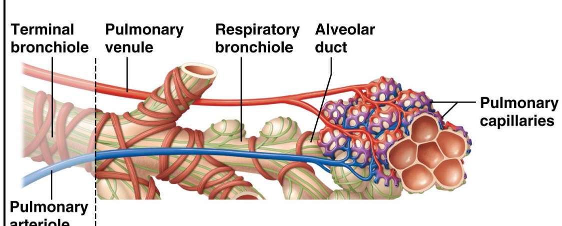
- Deep, rattling cough of a smoker is linked directly to numerous adverse effects of smoke on the respiratory system
- Chemicals in smoke
  - Act as irritants, increasing mucus secretion
  - Partially paralyze and eventually destroy cilia lining tract
- As result, more mucus is present, but cilia are less able to sweep it out of airways
- Cough develops as only way to prevent mucus buildup
- Cilia will reappear within a few months after smoking stops

The Bronchial Tree

- _________ **bronchi** (enters the left or right lung at hilum)
  - **Right primary bronchus** – wider, shorter, and straighter than left
- _________ **bronchi** once inside each lung; three on right and two on left
- _______ **bronchi** continue to branch smaller and smaller
- **Bronchioles** – smallest airways
  - **Terminal bronchioles → Respiratory bronchioles**



(a) Conducting zone passages and bronchial tree

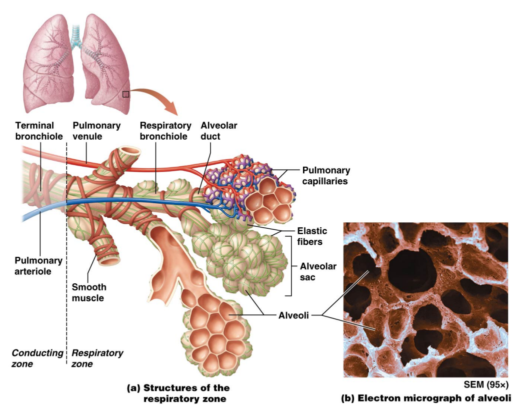


- As airways divide and get smaller:
  - Epithelium gradually changes from PSCCE to
  - Amount of smooth muscle increases
  - Hyaline cartilage decreases

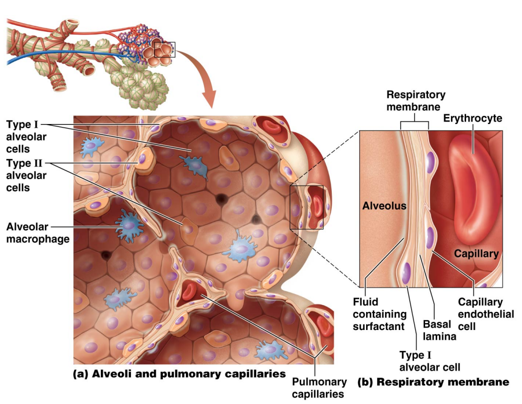
Nares → Nasal cavity → Nasopharynx → Oropharynx → Laryngopharynx → Larynx → Trachea → Primary bronchi → Secondary bronchi → Tertiary bronchi → Multiple branches of bronchi → Bronchioles → Terminal bronchioles → Respiratory bronchioles → Alveolar ducts → Alveolar sacs

ALVEOLI AND THE RESPIRATORY MEMBRANE

- **Alveolar ducts → Alveolar sacs** - grapelike clusters of alveoli (site of gas exchange)
  1. Type I alveolar cells (____________________)
  2. Type II alveolar cells (simple cuboidal cells) produce surfactant
  3. Alveolar macrophages are mobile __________



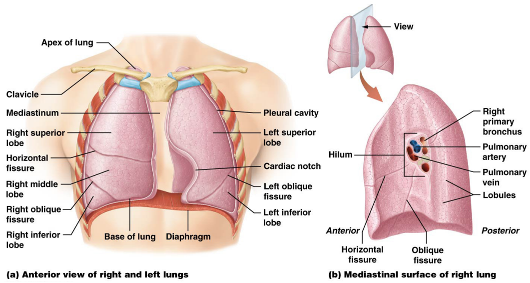
(a) Structures of the respiratory zone
(b) Electron micrograph of alveoli



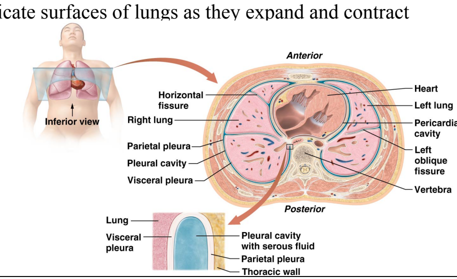
(a) Alveoli and pulmonary capillaries
(b) Respiratory membrane

THE LUNGS AND PLEURAE

- Right and left lungs are separated by heart and mediastinum
  -
  -
  - __________ – where primary bronchi, blood and lymphatic vessels, and nerves enter and exit lung
  - Cardiac notch
  - Right lung - three lobes; left lung - two lobes



- Each lung is found within a **pleural cavity**
  - __________ **pleura** – outer layer of serous membrane
  - __________ **pleura** continuous with surface of lungs
  - Pleural membranes secrete a thin layer of **serous fluid** to lubricate surfaces of lungs as they expand and contract



Pleuritis and Pleural Friction Rub

- Many conditions (heart failure to pneumonia) can cause inflammation of the visceral and parietal pleura (**pleuritis**)
- **Pleuritic pain** – one of most common symptoms; chest pain with inhalation; results from inflamed pleura rubbing together as lungs expand and contract
- Rubbing can sometimes be *heard with stethoscope*; termed **pleural friction rub**; resembles sandpaper rubbing against itself

21.3 Pulmonary Ventilation

The Pressure-Volume Relationship

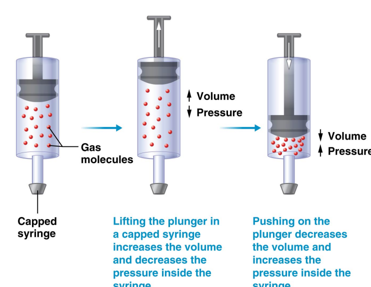
- First process of respiration is **pulmonary ventilation**
- The **pressure-volume relationship** provides driving force for pulmonary ventilation
  - Gas molecules move from areas of __________ pressure to areas of __________ pressure

- ______________ – pressure and volume of a gas are <u>inversely</u> related

As volume

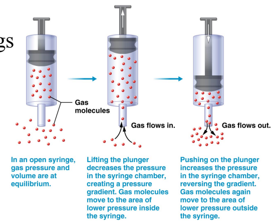
Pressure

(and vise versa)



The Process of Pulmonary Ventilation

- Process of pulmonary ventilation consists of **inspiration** and **expiration**
- Volume changes in thoracic cavity and lungs leads to pressure changes and air to move into or out of the lungs

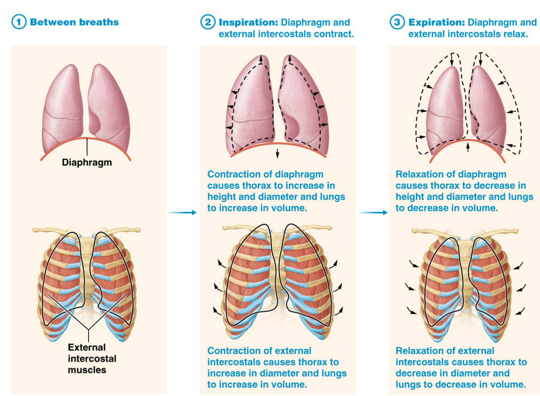


- Inspiration:
  - __________ – main inspiratory muscle
  - External __________ – muscles found between ribs

  These muscles increase thoracic cavity volume along with lung volume

- Maximal inspiration aided by contraction of sternocleidomastoid , pectoralis minor, and scalenes muscles

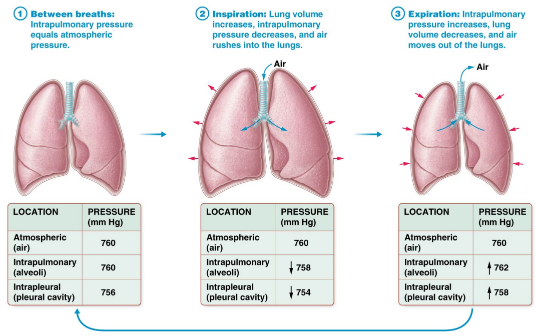
- Expiration is a mostly passive process that does not utilize muscle contraction
  - Diaphragm returns to its original dome shape that pushes up on lungs
  - __________ decrease lung volume and raise intrapulmonary pressure above atmospheric pressure so air flows out of lungs



- Maximum expiration muscles include **internal intercostals** and **abdominal muscles**
  - Forcefully decrease size of thoracic cavity; why your abdominal and back muscles are often sore after having a cough
  - **Heimlich maneuver** – delivering abdominal thrusts that push up on diaphragm

- **Nonrespiratory movements**, not intended for ventilation, include yawns, coughs, sighs, sneeze, laughing, hiccups, crying, etc.

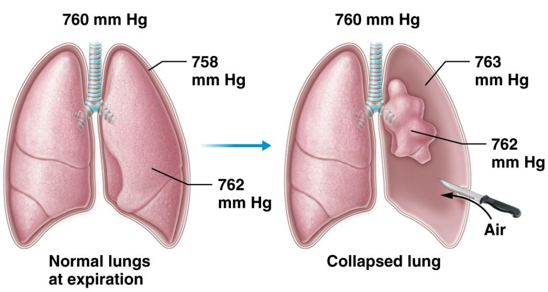
- Pressures at work during ventilation :
  - **Atmospheric pressure** – at sea level atmospheric pressure is about 760 mm Hg
  - ______________ **pressure** – rises and falls with inspiration and expiration
  - **Intrapleural pressure** – rises and falls with inspiration and expiration; always below intrapulmonary pressure

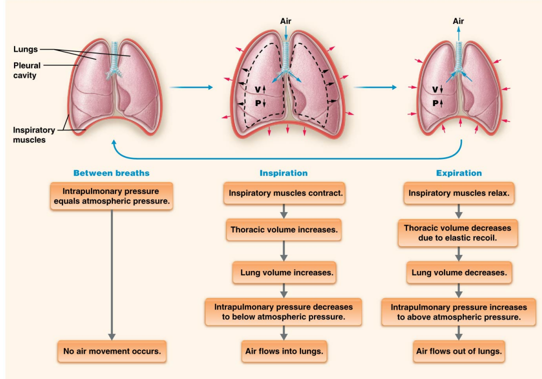


LOCATION	PRESSURE (mm Hg)
Atmospheric (air)	760
Intrapulmonary (alveoli)	760
Intrapleural (pleural cavity)	756

LOCATION	PRESSURE (mm Hg)
Atmospheric (air)	760
Intrapulmonary (alveoli)	↓ 758
Intrapleural (pleural cavity)	↓ 754

LOCATION	PRESSURE (mm Hg)
Atmospheric (air)	760
Intrapulmonary (alveoli)	↑ 762
Intrapleural (pleural cavity)	↑ 758



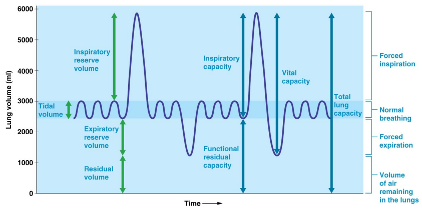


Infant Respiratory Distress Syndrome

- Inadequate surfactant makes alveolar inflation between breaths very difficult
- Surfactant is not produced significantly until last 10–12 weeks of gestation; premature newborns may therefore suffer from infant respiratory distress syndrome (RDS)
- Treatment – delivery of surfactant by inhalation; also positive airway pressure (CPAP); slightly pressurized air prevents alveoli from collapsing during expiration

Pulmonary Volumes and Capacities

- __________ – amount of air inspired or expired during normal quiet ventilation
- __________ – volume of air that can be forcibly inspired after a normal TV inspiration
- __________ – amount of air that can be forcibly expired after a normal tidal expiration (700–1200 ml)
- __________ – air remaining in lungs after forceful expiration



21.4 Gas Exchange

Gas Exchange

- Pulmonary ventilation only brings new air into and removes oxygen-poor air from alveoli
- Two processes are involved in **gas exchange**:
  - ____________ **gas exchange** involves exchange of gases between alveoli and blood
  - __________ **gas exchange** involves exchange of gases between blood in systemic capillaries and body's cells

The Behavior of Gases

- **Gas behavior** – important factor that affects gas exchange

1.
2. Surface area of respiratory membrane
3.
4. Ventilation-perfusion matching

- _________ **law of partial pressures** – each gas in a mixture exerts its own pressure, called its **partial pressure** (**P_{gas}**); total pressure of a gas mixture is sum of partial pressures of all its component gases

$PN_2 + PO_2 + PO_2 + \text{Pothers} = \text{Atmospheric pressure (760 mm Hg)}$

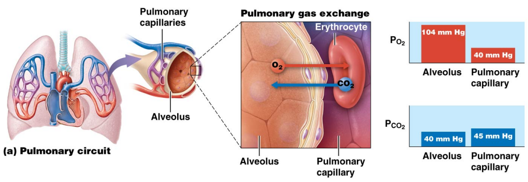
$PN_2 = 0.78 \times 760 = 593$ mm Hg

$PO_2 = 0.21 \times 760 = 160$ mm Hg

Partial pressure of a gas in a mixture determines <u>where</u> gas diffuses

Pulmonary Gas Exchange

- Pulmonary gas exchange (**external respiration**) is diffusion of gases between alveoli and blood;
  - Oxygen diffuses from _________ into _________
  - Carbon dioxide simultaneously diffuses in opposite direction
    - Blood has a low PO_2 (40 mm Hg) while PO_2 in air is 104 mm Hg
    - Blood has a high CO_2 (45 mm Hg) compared to alveoli air (40 mm Hg)



Review

Oxygen diffusion during gas exchange is

a. from the pulmonary blood into the alveolar air
b. so slow that equilibrium is never reached
c. driven by the gradient between inspired air and alveolar blood
d. less efficient than diffusion of carbon dioxide

Review

The efficiency of pulmonary gas exchange is impacted by all of the following EXCEPT

a. Degree of match between air and blood flow
b. Surface area of respiratory membrane
c. Thickness of the respiratory membrane
d. Blood pressure in the pulmonary capillaries

Review

The efficiency of pulmonary gas exchange is <u>increased</u> by

a. A mismatch between air and blood flow
b. An increase in respiratory membrane surface area
c. Thickening of the respiratory membrane
d. A decrease in respiratory membrane surface area

Hyperbaric Oxygen Therapy

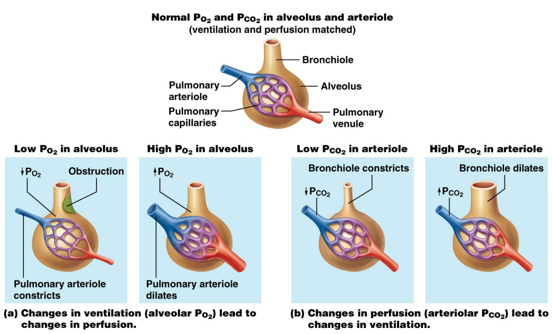
- Person placed in chamber and exposed to *higher than normal partial pressures of oxygen*; increases oxygen levels dissolved in plasma; in turn increases *delivery to tissues*
- Used to treat conditions benefiting from increased oxygen delivery: severe blood loss, crush injuries, anemia (decreased O_2 carrying capacity of blood), chronic wounds, certain infections, burns
- Also used for **decompression sickness** (“**bends**”); seen in divers who *ascended too rapidly*; caused by dissolved gases in blood coming out of solution and *forming bubbles* in bloodstream; therapy forces gases <u>back</u> into solution, eliminating bubbles

Factors Affecting Efficiency of Pulmonary Gas Exchange

- **Surface area of respiratory membrane** of both lungs is extremely large (approximately 1000 square feet)
  - Any factor that reduces surface area decreases efficiency of pulmonary gas exchange
  - __________ – low blood oxygen level; sign of severely impaired pulmonary gas exchange
  - __________ – high blood carbon dioxide level; sign of severely impaired pulmonary gas exchange

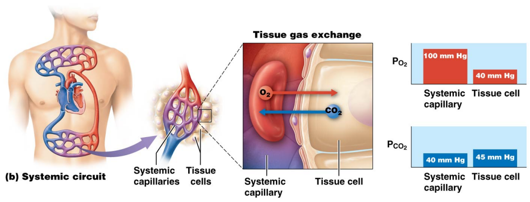
- **Thickness of respiratory membrane** – distance that a gas must diffuse
  -
  - Thickening of the membrane reduces exhange efficiency (**inflammation)**

- **Ventilation-perfusion matching** – degree of match between amount of air reaching alveoli (__________) and amount of blood flow (__________) in pulmonary capillaries
  - **Ventilation/perfusion ratio** (**V/Q**) – measurement that describes this match; when affected by disease, called a **mismatch**



Tissue Gas Exchange

- Tissue gas exchange (**internal respiration**) is oxygen and carbon dioxide between blood and tissues
  - Cells use oxygen constantly for cellular respiration so _________ in tissue is low
  - Tissues produce large quantities of _________ so partial pressure is high



- Factors affecting efficiency of tissue gas exchange include:
  - **Surface area available for gas exchange** (of branched systemic capillaries); large enough to allow for gas exchange efficiency
  - **Distance over which diffusion must occur**; less distance to diffuse results in more efficient gas exchange
  - **Perfusion of tissue** –

21.5 Gas Transport through the Blood

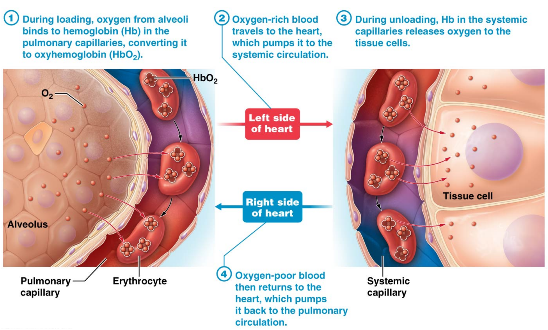
Gas Transport

- Only 1.5% of inspired oxygen is *dissolved* in blood plasma due to its *poor solubility*; majority of oxygen is transported in blood plasma by __________
- There are three ways that carbon dioxide is transported

Oxygen Transport

- Oxygen transport is facilitated by **hemoglobin (Hb)**
  - _________ carried by Hb
  - Hemoglobin is a protein found in __________
  - Consists of four subunits, each including a **heme group**; each heme contains one iron atom that can bind to one molecule of oxygen
  -

- Hemoglobin binds and releases oxygen
  - Oxygen from alveoli binds to hemoglobin in pulmonary capillaries; **oxyhemoglobin (HbO_2)**
  - Hb in systemic capillaries releases oxygen to cells of tissues



- Effect of affinity on hemoglobin saturation is determined by four factors:

1.

   Lower blood PO_2; unloading reaction is favored as fewer O_2 molecules are available to bind to Hb

2.

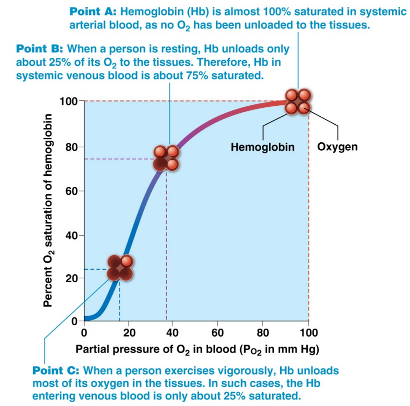
   PCO_2 increase, Hb binds oxygen less strongly so more oxygen is unloaded

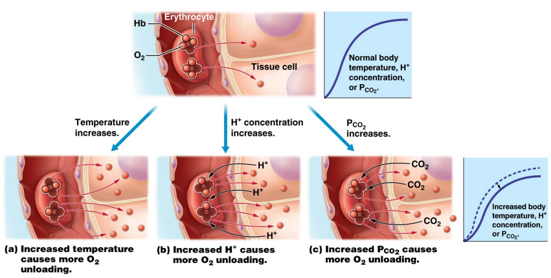
3.

When pH decreases, Hb binds oxygen less strongly so more oxygen is unloaded

4.

Increasing temperature decreases Hb's affinity for oxygen; facilitates unloading reaction of oxygen into tissues; reverse also true





Carbon Dioxide Transport

- Carbon dioxide is transported from tissues to lungs in blood three ways:

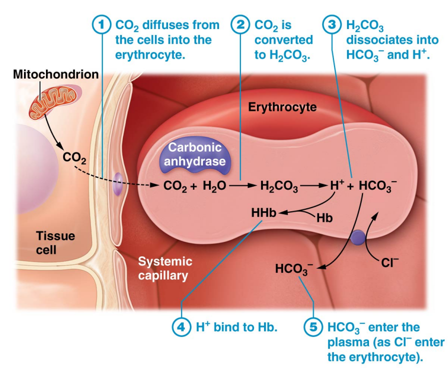
1. Dissolved in plasma (_____)

2. __________ (23%) - CO_2 binds to Hb's protein component (not heme group that oxygen binds) - **carbaminohemoglobin**

3. Bicarbonate ions (70%)

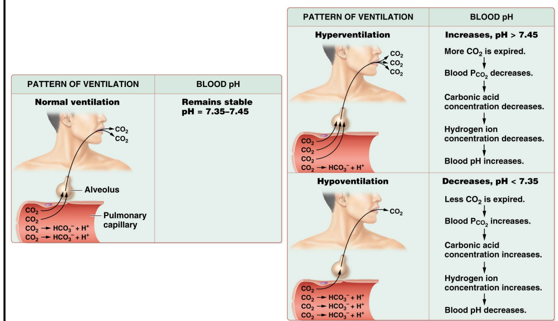
- CO_2 quickly diffuses into erythrocytes
- **Carbonic anhydrase** (**CA**) catalyzes:

- Most HCO_3^- diffuses into blood plasma and H^+ binds to Hb
- HCO_3^- carries a negative charge; counteracted by __________ __________ ; chloride ions move into erythrocytes as bicarbonate ions move out to balance charges



(a) Bicarbonate formation in an erythrocyte in a systemic capillary

- The PCO_2 level in blood is determined by the following two factors:
  - **1.** ________________ – rate and/or depth of breathing increase; increases amount of CO_2 expired from lungs
    - pH of blood rises; more oxygen may be dissolved in blood as well
  - **2.** ________________ – rate and/or depth of breathing decrease; causes retention of CO_2 (increases PCO_2)
    - Blood becomes more acidic; oxygen levels (PO_2) in blood may drop (**hypoxemia**)

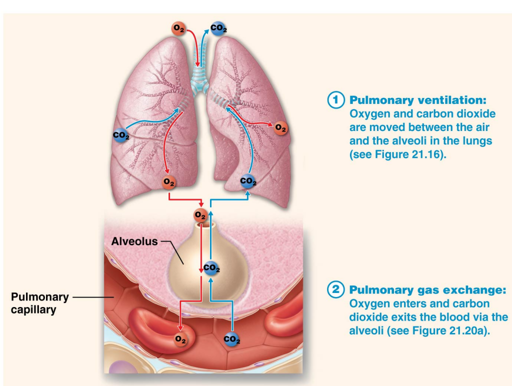


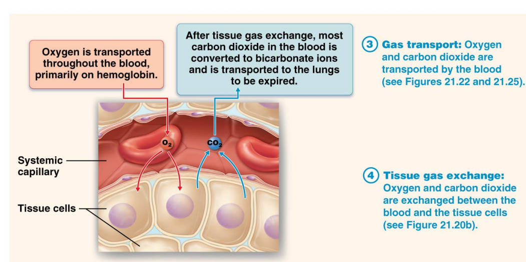
Carbon Monoxide Poisoning

- **Carbon monoxide** (**CO**) is produced from *burning organic compounds*; colorless, odorless, tasteless found in smoke from fires, cigarettes, exhaust fumes (from engines, heaters, stoves)
- Binds reversibly with Hb, producing **carboxyhemoglobin**; occupies oxygen binding sites with *affinity 200–230 times that of oxygen*; small concentrations of CO can therefore cause serious problems

Carbon Monoxide Poisoning

- CO binding changes *Hb's shape*, increasing *affinity for oxygen*; decreases amount of oxygen *released to tissues*
- **Symptoms** – confusion, dizziness, nausea; severe cases include seizures, coma, and death
- **Treatment** – 100% oxygen at atmospheric or hyperbaric pressure





21.7 Neural Control of Ventilation

Neural Control of Ventilation

- **Breathing** usually occurs without conscious thought or control
  - __________ – normal breathing; one of most vital functions body carries out as absence of breathing leads to death

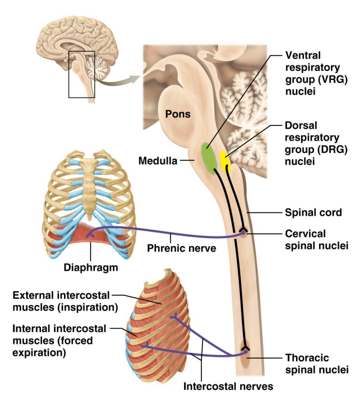
- Control of breathing is by neurons found in brainstem; specialized cells detect and monitor CO_2 levels, H^+ levels, and O_2 levels in body
- Negative feedback loops and stretch receptors in lungs also ensure oxygen intake and carbon dioxide elimination match metabolic requirements

Control of the Basic Pattern of Ventilation

- _____________ controls ventilation; neurons in __________ influence respiratory rhythm
  - **Respiratory rhythm generator** (**RRG**) – group of neurons that creates basic rhythm for breathing; found within a structure called the **ventral respiratory column**
  - Neurons found in **medullary reticular formation** assist RRG; known as **ventral** and **dorsal respiratory groups**

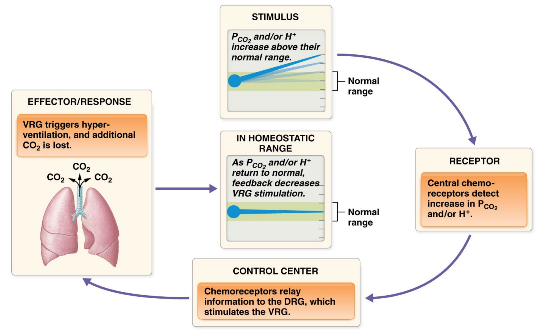
- **Ventral respiratory group** (**VRG**) found in anterior and lateral portion of medulla, contains both inspiratory and expiratory neurons

  Both nerves also supply certain accessory muscles of inspiration and expiration
- **Dorsal respiratory group** (**DRG**) found in posterior medulla; primarily involved in inspiration

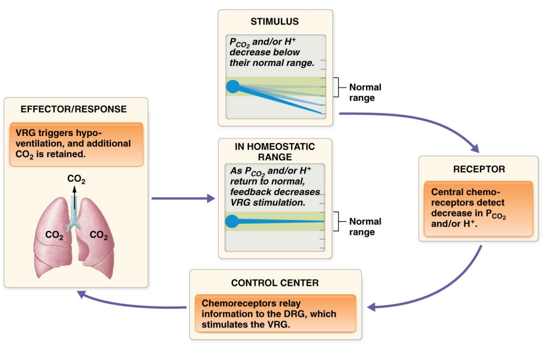


Control of the Rate and Depth of Ventilation

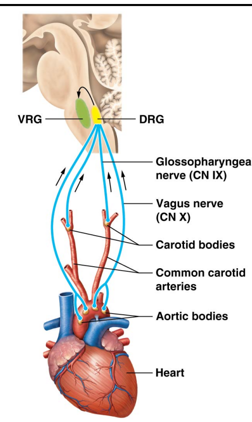
- ________________are specialized cells that respond to changes in the concentration of a specific chemical
  - ____PCO_2 or H^+ concentration triggers hyperventilation
  - ____PCO_2 or H^+ concentration triggers hypoventilation
  - Most sensitive to PO_2 in arterial blood
- **Central chemoreceptors** – neurons in medullary reticular formation
  - Detects changes in both CO_2 and H^+ concentrations CSF



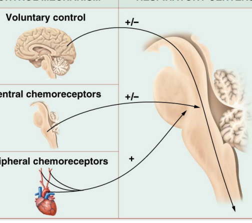
(a) Response to increased arterial P_{CO_2} and/or H^+ concentration by a negative feedback loop



(b) Response to decreased arterial P_{CO_2} and/or H^+ concentration by a negative feedback loop



STIMULI	CONTROL MECHANISM	EFFECT ON RESPIRATORY CENTERS	EFFECT ON VENTILATION
Cerebral cortex inputs (e.g., emotion)	Voluntary control	+/–	Varied
Changes in arterial P_{CO_2}, H^+ concentrations	Central chemoreceptors	+/–	Hyperventilation when P_{CO_2} and/or H^+ concentrations increase; hypoventilation when P_{CO_2} and/or H^+ decrease
Changes in arterial P_{O_2}	Peripheral chemoreceptors	+	Hyperventilation when arterial P_{O_2} decreases



High-Altitude Acclimatization

- **High-altitude acclimatization** allows peripheral chemoreceptors to stimulate an increase *in ventilation*, permitting body to maintain *acceptable blood* PO_2 *levels*, if elevation is gradually increased over period of days (rather than hours)
- Requires days because sensitivity of chemoreceptors for low PO_2 increases with prolonged exposure; the longer they are exposed to a low PO_2, the more they stimulate an increase in ventilation
- Allows experienced climbers to reach *great elevations* without *supplemental oxygen*