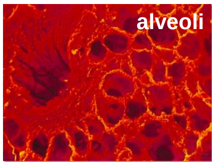
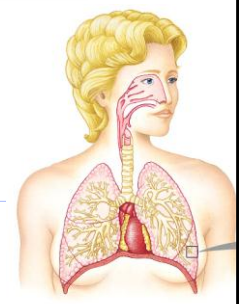
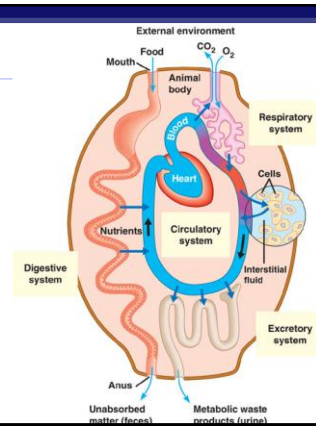
Gas Exchange
Respiratory Systems



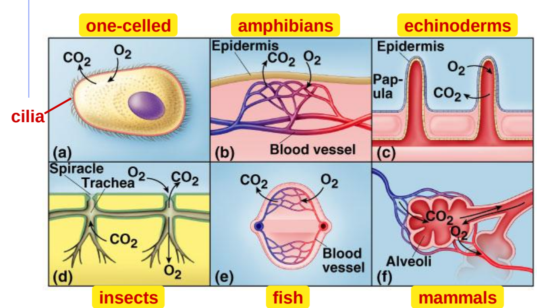




Optimizing gas exchange

- Why high surface area?
  - maximizing rate of gas exchange
  - CO_2 & O_2 move across cell membrane by diffusion
    - rate of diffusion proportional to surface area
- Why moist membranes?
  - moisture maintains cell membrane structure
  - gases diffuse only dissolved in water

Gas exchange in many forms…



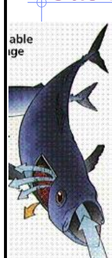
size • water vs. land • endotherm vs. ectotherm

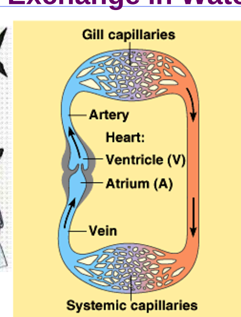
Evolution of gas exchange structures

Aquatic organisms
external systems with lots of surface area exposed to aquatic environment

Terrestrial
moist internal respiratory tissues with lots of surface area

Gas Exchange in Water: Gills



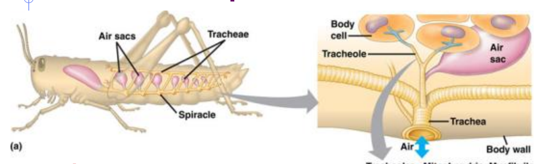


(a) Fish

Gas Exchange on Land

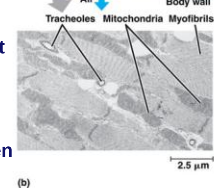
- **Advantages of terrestrial life**
  - air has many advantages over water
    - higher concentration of O_2
    - O_2 & CO_2 diffuse much faster through air
      - respiratory surfaces exposed to air do not have to be ventilated as thoroughly as gills
    - air is much lighter than water & therefore much easier to pump
      - expend less energy moving air in & out
- **Disadvantages**
  - keeping large respiratory surface moist causes high water loss
    - reduce water loss by keeping lungs internal

Terrestrial adaptations



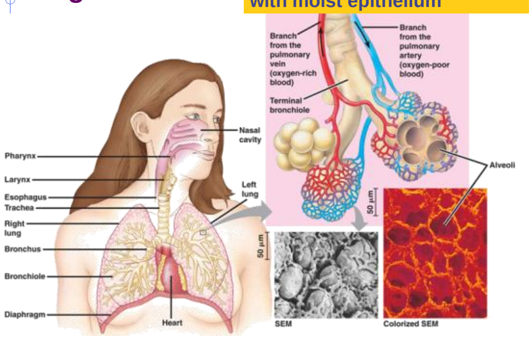
Tracheae

- air tubes branching throughout body
- gas exchanged by diffusion across moist cells lining terminal ends, not through open circulatory system

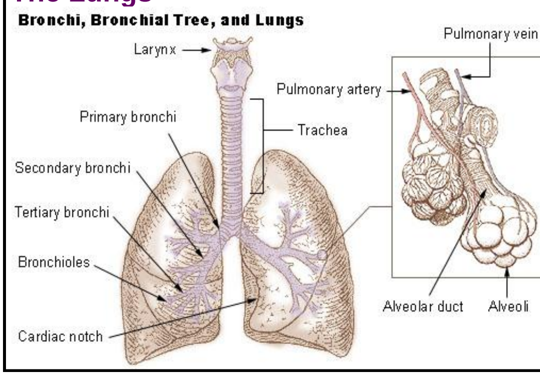


Lungs

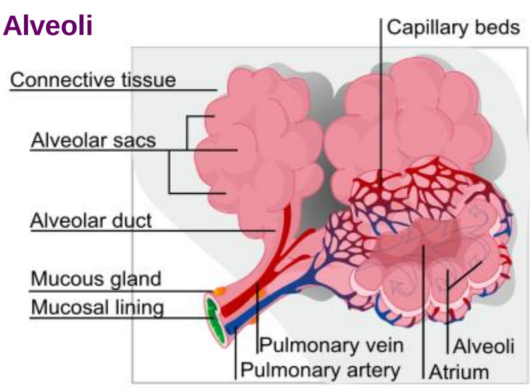
Exchange tissue:
spongy texture, honeycombed with moist epithelium



The Lungs

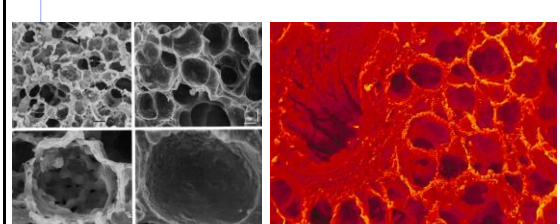


Alveoli



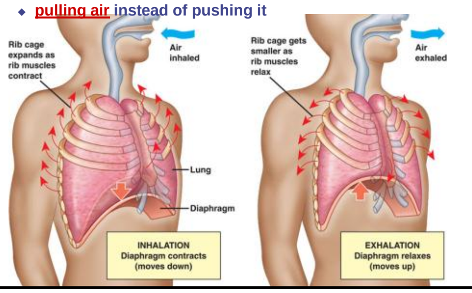
Alveoli

- Gas exchange across thin epithelium of millions of alveoli
  - total surface area in humans ~100 m^2



Negative pressure breathing

- Breathing due to changing pressures in lungs
  - air flows from higher pressure to lower pressure
  - pulling air instead of pushing it

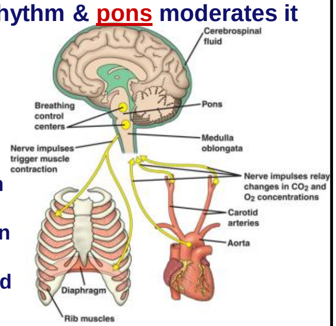


Mechanics of breathing

- Air enters nostrils
  - filtered by hairs, warmed & humidified
  - sampled for odors
- Pharynx → glottis → larynx (vocal cords) → trachea (windpipe) → bronchi → bronchioles → air sacs (alveoli)
- Epithelial lining covered by cilia & thin film of mucus
  - mucus traps dust, pollen, particulates
  - beating cilia move mucus upward to pharynx, where it is swallowed

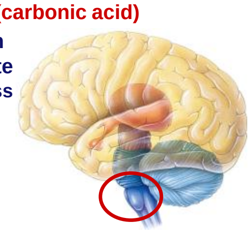
Autonomic breathing control

- Medulla sets rhythm & pons moderates it
  - coordinate respiratory, cardiovascular systems & metabolic demands
- Nerve sensors in walls of aorta & carotid arteries in neck detect O_2 & CO_2 in blood



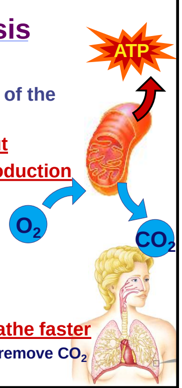
Medulla monitors blood

- Monitors CO_2 level of blood
  - measures pH of blood & cerebrospinal fluid bathing brain
    - $CO_2 + H_2O \rightarrow H_2CO_3$ (carbonic acid)
    - if pH decreases then increase depth & rate of breathing & excess CO_2 is eliminated in exhaled air



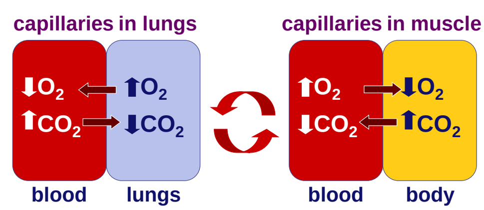
Breathing and Homeostasis

- Homeostasis
  - keeping the internal environment of the body balanced
  - need to balance O_2 in and CO_2 out
  - need to balance energy (ATP) production
- Exercise
  - breathe faster
    - need more ATP
    - bring in more O_2 & remove more CO_2
- Disease
  - poor lung or heart function = breathe faster
    - need to work harder to bring in O_2 & remove CO_2



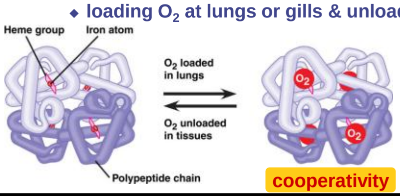
Diffusion of gases

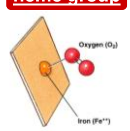
- Concentration gradient & pressure drives movement of gases into & out of blood at both lungs & body tissue



Hemoglobin

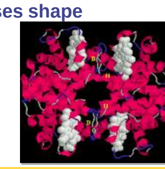
- Why use a carrier molecule?
  - O_2 not soluble enough in H_2O for animal needs
    - blood alone could not provide enough O_2 to animal cells
    - hemocyanin in insects = copper (bluish/greenish)
    - hemoglobin in vertebrates = iron (reddish)
- Reversibly binds O_2
  - loading O_2 at lungs or gills & unloading at cells

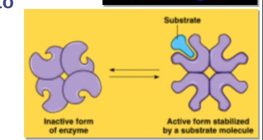




Cooperativity in Hemoglobin

- Binding O_2
  - binding of O_2 to 1st subunit causes shape change to other subunits
    - conformational change
  - increasing attraction to O_2
- Releasing O_2
  - when 1st subunit releases O_2, causes shape change to other subunits
    - conformational change
  - lowers attraction to O_2





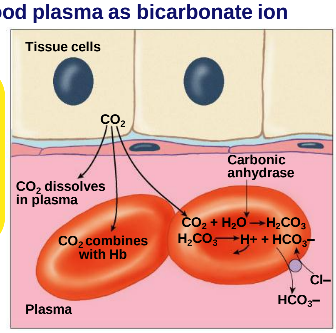
Transporting CO_2 in blood

- Dissolved in blood plasma as bicarbonate ion

carbonic acid
$CO_2 + H_2O \rightarrow H_2CO_3$

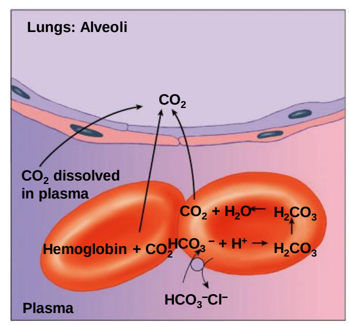
carbonic anhydrase

bicarbonate
$H_2CO_3 \rightarrow H^+ + HCO_3^-$



Releasing CO_2 from blood at lungs

- Lower CO_2 pressure at lungs allows CO_2 to diffuse out of blood into lungs



Measuring Lung Volumes

- Air is constantly exchanging at a rate of roughly $0.35 dm^3$/breath
- Breath that is not completely exhaled is the *residual volume*
- Total volume that comes in one breath is tidal volume
- Ventilation rate is tidal volume times breathing rate (total volume of air exchanged in a minute)