Gas Exchange
Respiratory Systems

Optimizing gas exchange
- Why high surface area?
  - maximizing rate of gas exchange
  - CO₂ & O₂ 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...
- one-celled
- amphibians
- echinoderms

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
Gas Exchange on Land

- **Advantages of terrestrial life**
  - Air has many advantages over water
    - Higher concentration of O₂
    - O₂ & CO₂ 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

- Bronchi, Bronchial Tree, and Lungs

Alveoli

- Gas exchange across thin epithelium of millions of alveoli
  - Total surface area in humans ~100 m²
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 O₂ & CO₂ in blood

Medulla monitors blood

- Monitors CO₂ level of blood
  - measures pH of blood & cerebrospinal fluid bathing brain
    - CO₂ + H₂O → H₂CO₃ (carbonic acid)
  - if pH decreases then increase depth & rate of breathing & excess CO₂ is eliminated in exhaled air

Breathing and Homeostasis

- **Homeostasis**
  - keeping the internal environment of the body balanced
  - need to balance O₂ in and CO₂ out
  - need to balance energy (ATP) production
- **Exercise**
  - breathe faster
    - need more ATP
    - bring in more O₂ & remove more CO₂
- **Disease**
  - poor lung or heart function = breathe faster
    - need to work harder to bring in O₂ & remove CO₂

Diffusion of gases

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

![Diagram of diffusion of gases](image-url)
Hemoglobin

- Why use a carrier molecule?
  - O₂ not soluble enough in H₂O for animal needs
  - blood alone could not provide enough O₂ to animal cells
  - hemocyanin in insects = copper (bluish/greenish)
  - hemoglobin in vertebrates = iron (reddish)
- Reversibly binds O₂
  - loading O₂ at lungs or gills & unloading at cells

Cooperativity in Hemoglobin

- Binding O₂
  - binding of O₂ to 1st subunit causes shape change to other subunits
    - conformational change
    - increasing attraction to O₂

- Releasing O₂
  - when 1st subunit releases O₂, causes shape change to other subunits
    - conformational change
    - lowers attraction to O₂

Transporting CO₂ in blood

- Dissolved in blood plasma as bicarbonate ion

Releasing CO₂ from blood at lungs

- Lower CO₂ pressure at lungs allows CO₂ to diffuse out of blood into lungs

Measuring Lung Volumes

- Air is constantly exchanging at a rate of roughly 0.35dm³/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)