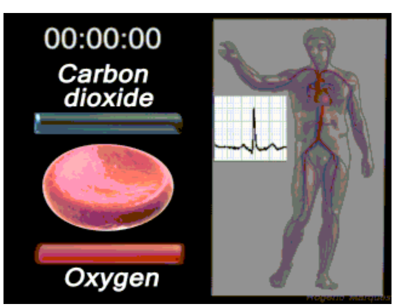
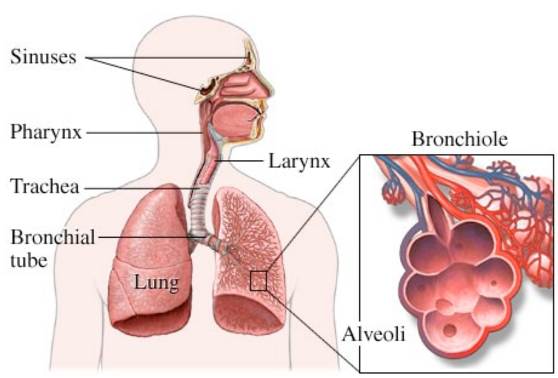
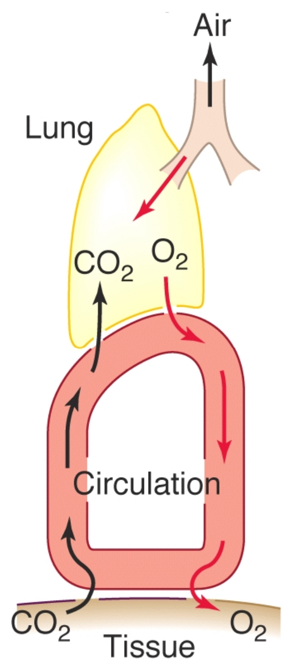
Gases and Respiration

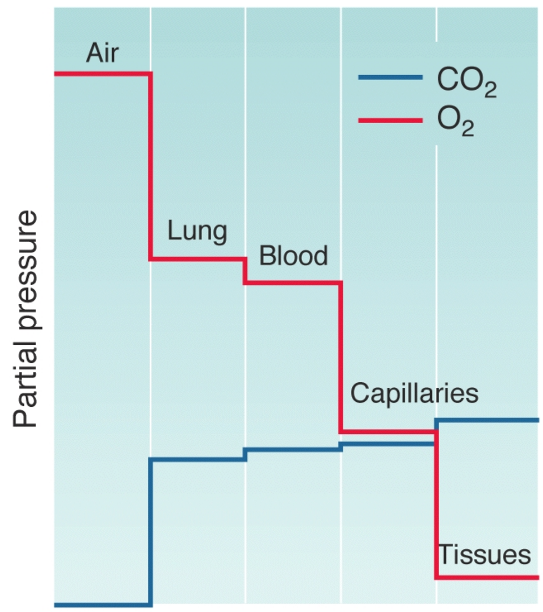
Respiration Overview I





Respiration Overview II

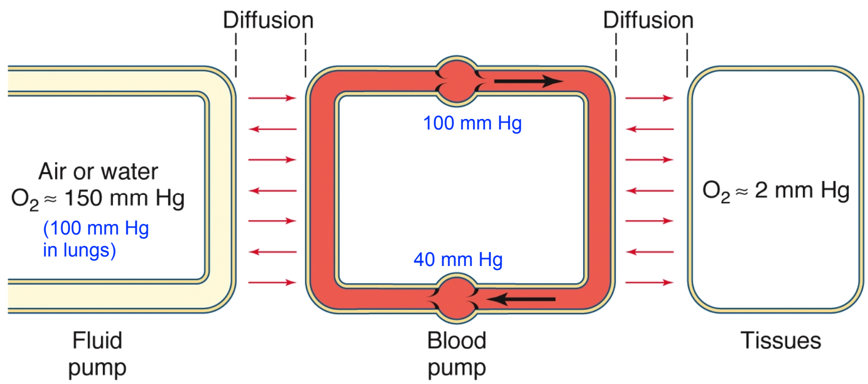




Gas Laws

- Equation of State:
  - PV = nRT
    - Same volumes of different gases have same # of molecules
  - BTPS: body temp, atmospheric pressure, saturated
  - ATPS: ambient temp,….
  - STPD; standard temp, atmospheric pressure, dry (0 C, 760 mm Hg)
  - Use this equation to convert across conditions
- Dalton's law:
  - Total pressure = sum of independent partial pressures (including water vapor pressure)
- Henry's law:
  - Gas concentration dissolved in a liquid, $c = \alpha P_{p}$,
    - $\alpha = f(T, \text{gas, liquid})$,
    - P_p = partial pressure of the gas at the interface
  - Lower temperature holds more gas
  - Example: 20% O_2 in air is 9 mM; associated concentration in water: 0.3 mM

Gas Transport Requirements



- Ventilation
- Diffusion from/to respiratory system
- Bulk transport
- Diffusion to/from tissue

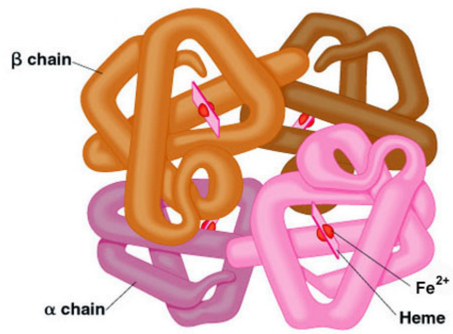
In maximal exercise, what is the rate limiting step?

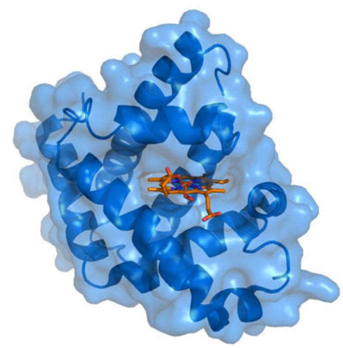
Gas Transport

- Rate of gas diffusion:
  - Depends on molecule size so O_2 and CO_2 have almost the same rate
  - Metabolic production of CO_2 and consumption of O_2 approximately equal
  - Large range of values: 0.08 ml/gh (worm) to 40 ml/gh (hummingbird); 500 fold difference!
- Surface to volume ratio of organism is critical
- Bulk transport system required in most animals
- Insects have tracheal system, others use blood

Respiratory pigments

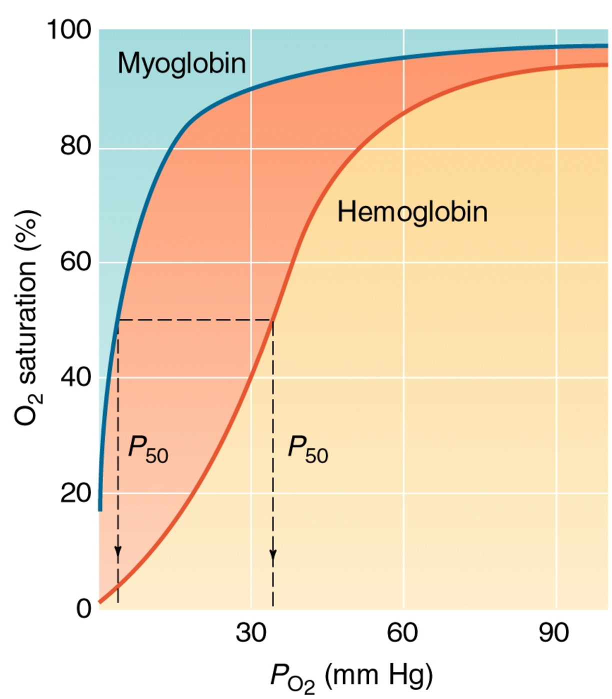
- Hemoglobin:
  - raises O_2 concentration from 0.3% (dissolved) to 20% (bound to Hg) by volume
  - 2 subunits and 4 heme units
  - Oxyhemoglobin and deoxyhemoglobin
  - CO has 200 times higher affinity than O_2
- Myoglobin:
  - Found in vertebrate muscle
  - Resembles a single hemoglobin subunit
- Others:
  - Hemerythrin
  - Chlorocruorin
  - Hemocyanin





Oxygen Binding

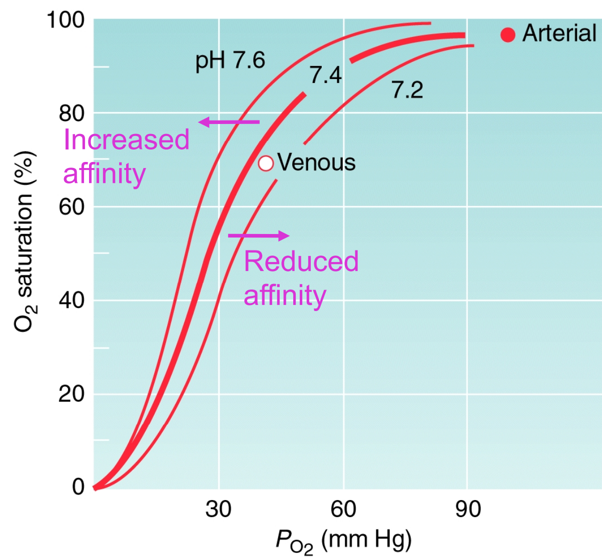
- Oxygen saturation:
  - 1 hemoglobin = 4 heme = 4 O_2 molecules
  - Blood has 0.9 mmole/100 ml of heme = 20.2 ml O_2 (20.2 % by volume) = 100% saturation
  - Dissolved O_2 is minimal
  - Binding of O_2 with Hg is fast, rate does not limit O_2 transport
- Oxygen dissociation curves
  - Saturation is a function of partial pressure
  - Binding of O_2 is easily reversible
  - Binding is facilitated by one subunit binding O_2
- Myoglobin in poorly suited for transport but good for storage because of its high affinity for O_2



Oxygen Dissociation

- Binding depends on PO_2 and pigment
  - 100% saturation in lungs
  - 70% saturation of venous blood at rest
  - 30% saturation of venous blood in exercise
- Affinity can be different in different parts of the body
- Variations come from changes in hemoglobin; affinity reduced by:
  - Rise in temperature
  - Binding of phosphate ligands (2,3-DPG, ATP, GTP)
  - Drop in pH (Bohr shift)
  - Increase in CO_2

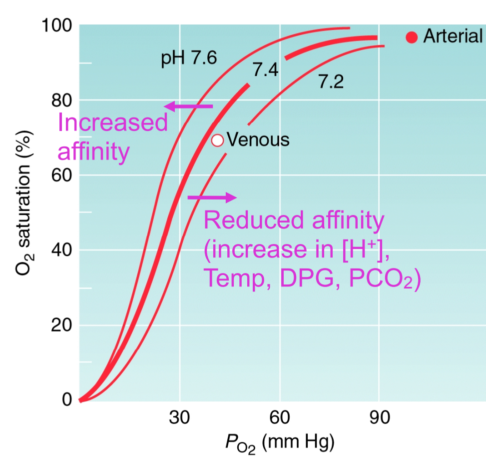
Bohr Shift



Oxygen Binding Shifts

- CO_2:
  - Combines with water to form carbonic acid and causes drop in pH (causes right shift)
  - Binds to hemoglobin competitively with O_2 (causes right shift)
  - Well matched to respiration
- 2,3-DPG (diphosphoglycerate)
  - Present in Hb as byproduct of anaerobic metabolism
  - Compete with O_2 for space on hemoglobin and so decrease affinity (right shift)
  - DPG levels rises in conditions of low O_2 and increased pH
- At altitude,
  - Lung CO_2 drops, pH rises: left shift in lungs
  - Tissue 2,3-DPG rises: right shift in tissue
- Temperature:
  - Rising temperature reduces affinity (right shift)
  - Also reduces amount of dissolved O_2 in water for fish

Bohr Shift



Note: saturation is not the same as O_2 concentration, i.e., anemia

Oxygen Toxicity

- Symptoms
  - Exposure to high O_2 concentrations, elevated PO_2, for hours/ days
  - Nausea, dizziness, muscle twitches, blurred vision, seizures, pulmonary edema
  - Rare in diving, more frequent in critical care patients, never happens in space
- Mechanisms
  - Chemical reactions, oxidation, (O_2 is a free radical)
  - Superoxides attack bonds, e.g., in lipids in cell membranes, cell damage

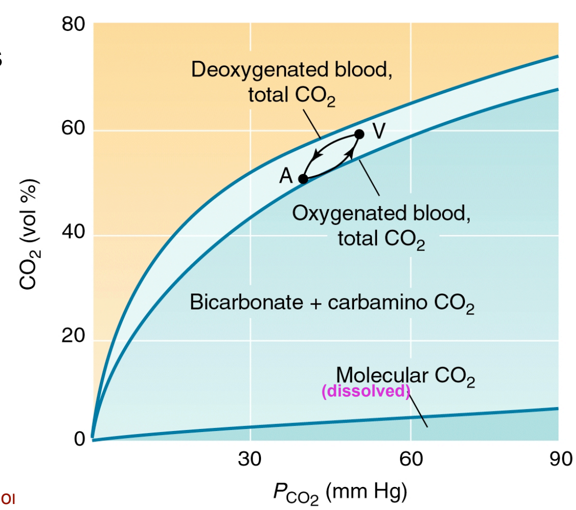
CO_2 Transport

$CO_2 + H_2O \rightleftarrows H_2CO_3 \rightleftarrows H^+ + HCO_3^-$ — carbonic acid

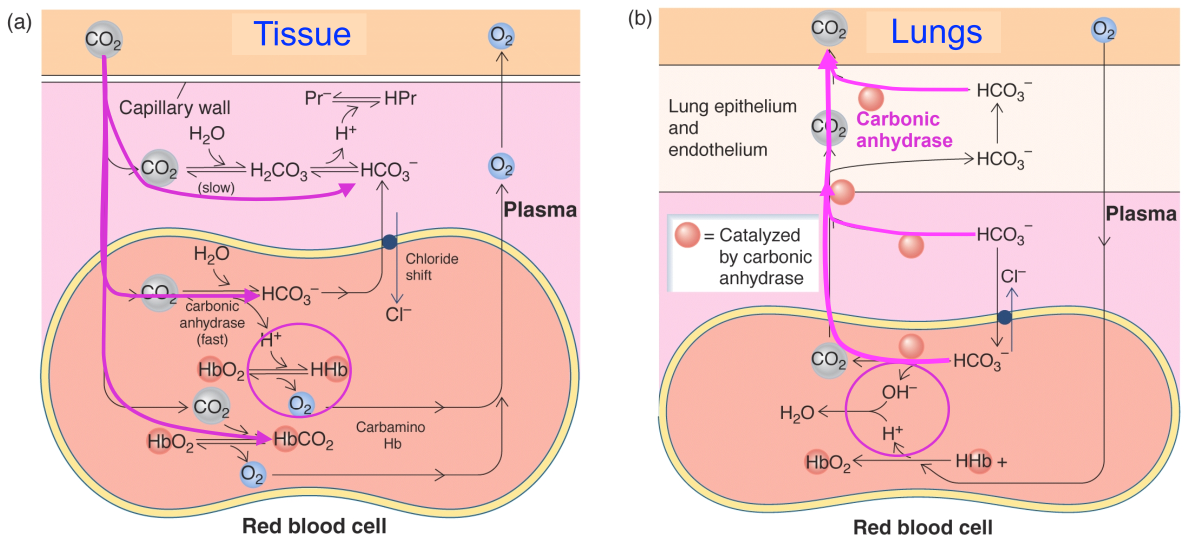
$CO_2 + H_2O \rightleftarrows H^+ + HCO_3^-$ — bicarbonate

$CO_2 + Hb \rightleftarrows HbCO_2$ — carbamino

- CO_2 handling has two roles:
  - CO_2 transport from tissues, increases 6-fold in exercise
  - pH balance (see next lecture)
- Bulk of CO_2 (>95%) in bicarb (at normal pH)
- Enters and leaves as CO_2
- Transported mostly in bicarb
- Daily transport of CO_2 = 600 g



Gases and Erythrocytes



CO_2 conversion to HCO_3^-

CO_2 release from HCO_3^-

$$R = \frac{\dot{V}_{CO_2}}{\dot{V}_{O_2}}$$

Respiratory ratio: 0.7-1.0

Schedule for Term Paper