Hb forms

- Both myoglobin and fetal hemoglobin have greater affinity
- Fetal hb – facilitates oxygen transfer across placenta
- Myoglobin – storage of oxygen in muscle
Other modifiers of oxygen affinity

- **Ions** – implications for osmoconformers

- **Organic compounds** - 2,3-Diphosphoglycerate (DPG)

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Shifts in affinity

- **Physiological shifts**
  - Temperature
  - Increased salinity

- **Acclimation shifts**
  - Altitude (DPG)

- **Evolutionary trends**
  - Small vs. large body
  - More vs. less active
  - Air vs. water breather
  - Fetal vs. maternal
  - High vs. low altitude
A few examples...

Figure 8.39 Oxygen dissociation curves in a fetal elephant (*Loxodonta africana*) at ages 5 and 12 months and of its mother as a function of external oxygen tension. Source: Modified from Riegel et al. (1967).

Figure 8.41 Oxygen dissociation curves in rodents as a function of external oxygen tension and whether the squirrels burrow or are arboreal and whether they hibernate or remain normothermic. Source: Modified from Boggs et al. (1984).

Figure 8.42 Oxygen dissociation curves for eight lowland mammals and the highland vicuña (*Vicugna vicugna*) and llama (*Lama glama*) and for six lowland birds and the highland rhea (*Rhea pennata*) and Andean goose (*Choephaga melanoptera*) as a function of external oxygen tension. Source: Modified from Hall et al. (1936).
Arthropods

- Gills, Trachea, lungs
- Higher affinity in full aquatic breathers
- Lowest affinity in full terrestrial breathers

**CO₂ release**

- 5-10% of CO₂ carried in blood cells
- **Carbonic anhydrase** — catalyst for formation of bicarbonate
- HCO₃⁻ diffuses out, Cl⁻ in to balance charge
- Osmolarity and Cl⁻ ions facilitate further dumping of O₂
Chemoreceptors, ventilation control

- Ventilation rate regulated by chemoreceptors
  - pH of cerebral spinal fluid
  - pH and O₂ levels in plasma

- Note that oxygen bound to hemoglobin is not directly monitored

- Low plasma PO₂ stimulates kidney to produce **erythropoietin**

CO Poisoning

- CO binds permanently to Hb, blocking O₂ binding site
- CO affinity ~200x greater than O₂ affinity
- Once bound to CO, the affinity for the other three bound O₂ increases.
- Overall O₂ content remains high none is dropped off at tissues
- CO₂ levels remain normal
- Since O₂ and CO₂ levels normal, ventilation rate never increases
Fish - synthesis
• Larvae rely on cutaneous exchange, switch to gills as scales develop and body size increases
• Gills
  – Counter current exchange
  – Gill area greater: more active, marine, warm water
• Bimodal breathing common
  – Variability in gas bladder function
  – Oxygen availability variable (primarily freshwater)
  – Air breathers retain gills for CO₂ release
  – Freshwater fish also use gills for ammonia release
• Elasmobranchs
  – Some ram ventilators
  – No air bladder, liver lipids for buoyancy

Amphibians - synthesis
• Gills, skin and lungs
  – Greater reliance on lungs for terrestrial forms
  – Gills often lost in metamorphosis, retained in aquatic forms for CO₂ release
  – Lungs filled by buccal pump, no diaphragm, may be lost (Plethodontidae) or reduced (Sirenidae)
• Hearts lack interventricular septum
• Terrestrial forms
  – Higher BMR
  – Higher oxygen capacity (blood volume, hematocrit)
  – Larger Bohr, root shifts
Altitude Adaptations

- ↓ PO₂
- ↑ hematocrit
- ↓ blood cell size
- ↑ concentration of respiratory pigments in blood cells
- ↑ lung volume (plastic and evolutionary response)
- Higher Hb affinity (curve shifted left)
- Many successful high altitude birds due to lung efficiency

Altitude and organophosphates

- Acclimation - DPG shifts curve to the right (lower affinity)
- Evolutionary change shifts curve to the left (higher affinity)
Burrows

- $\uparrow$ CO$_2$ $\downarrow$ O$_2$
- More extreme in less porous soils (clay vs. sand)
- $\uparrow$ Hb affinity (curve shifted left)
- Thermally buffered
- Torpor lowers BMR

![Gas composition of a burrow atmosphere and body temperature of a golden hamster (Meriones auratus) occupying the burrow as a function of time. Source: Modified from Kuhnen (1986).](image)

Diving Mammals

- Sperm whales – 1500 m
- Weddel seal – 1 hour
- Pressure issues
  - **Nitrogen narcosis** and **Decompression sickness** (the bends)
    - Solution is to empty lungs before dive, no air spaces in sinuses or inner ear
- Energetics
  - Post dive lactate levels for some species lower than expected
  - Spleen stores large volume of oxygenated blood, released during dive
Diving Mammals

- Oxygen debt has to be repaid at surface
- Paying debt at surface means no access to food resources...need to minimize surface time
- Shallow divers
  - Large lungs
  - Lower blood volume
  - Less muscle myoglobin
  - 6 dives at 15 minutes, 4 minutes recovery for each = 90 out of 114 minutes diving
- Deep divers
  - Small lungs (collapse into solid organ)
  - Large blood volume (spleen storage)
  - More muscle myoglobin
  - A 45 minute diver requires 70 minute recovery = 45 out of 115 minutes diving

Diving Response

- Triggered by cold water on face
  - Apnoea
  - Bradycardia
  - Reduced BMR
  - Reduced body temp
  - Reduced blood flow to viscera
  - Cutaneous exchange (reptiles)
  - Emptying of spleen (mammals)
  - Lactate produced not released in blood until dive completed
Cutaneous exchange in diving reptiles

- Several species can lower BMR enough to overwinter under water (green sea turtles)
- Release of CO$_2$ more effective than O$_2$ uptake
- Use of rectal exchange debated, may be for buoyancy

Major themes

- Energy and energy budgets
- Biochemical processes, sources of ATP
- Patterns of energy use and storage
- Measures and patterns of metabolic rate
- Chemistry of gasses, gasses in various habitats
- Physics, anatomy and physiology of gas exchange
- Respiratory pigments
- Synthesis and specific adaptations (diving, burrowing etc).