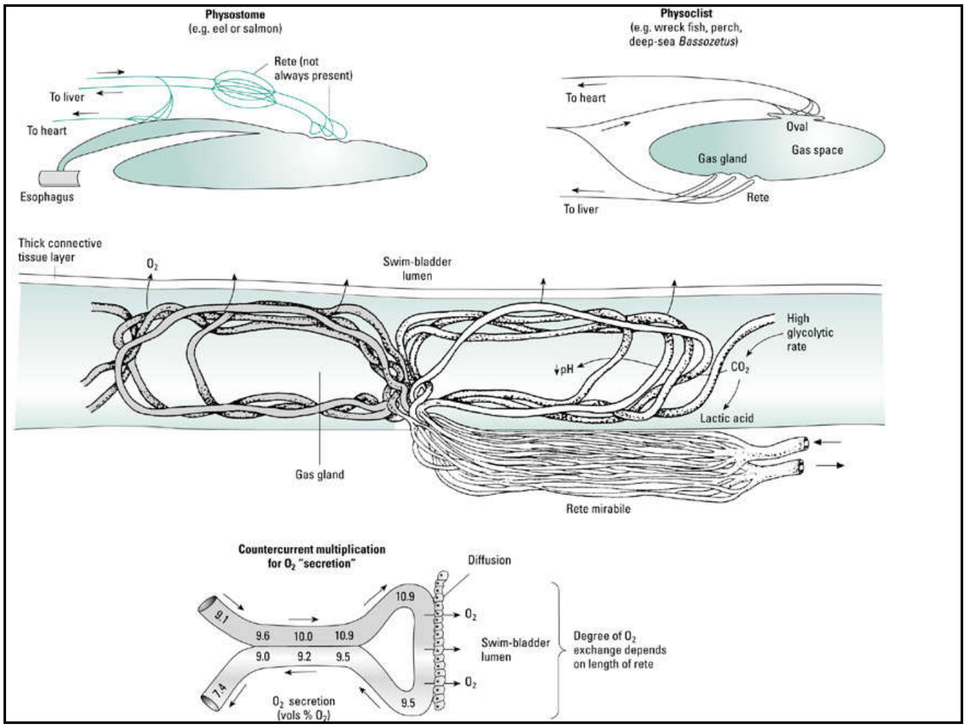
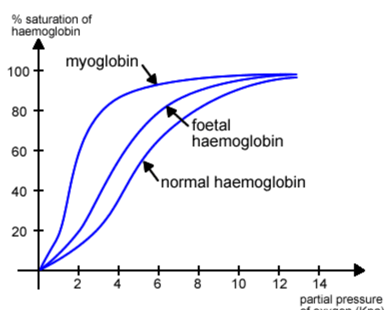


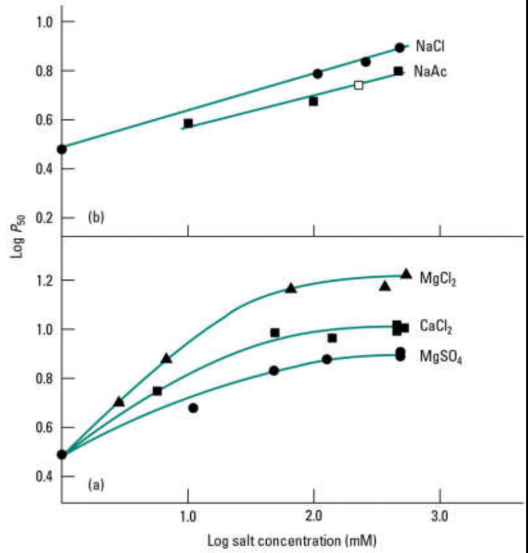
Hb forms

- 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)



Shifts in affinity

- **Physiological shifts**
  - Temperature lower
  - Increased salinity lower
- **Acclimation shifts**
  - Altitude (DPG) lower
- **Evolutionary trends**
  - Small vs. large body lower
  - More vs. less active lower
  - Air vs. water breather lower
  - Fetal vs. maternal
  - High vs. low altitude

A few examples…

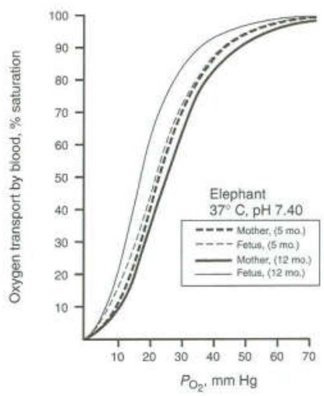


Figure 8.39 Oxygen dissociation curves in a fetal elephant (*Loxodonta africana*) at ages 5 and 12 months and of its mother as a function of external oxygen tension. Source: Modified from Riegel et al. (1967).

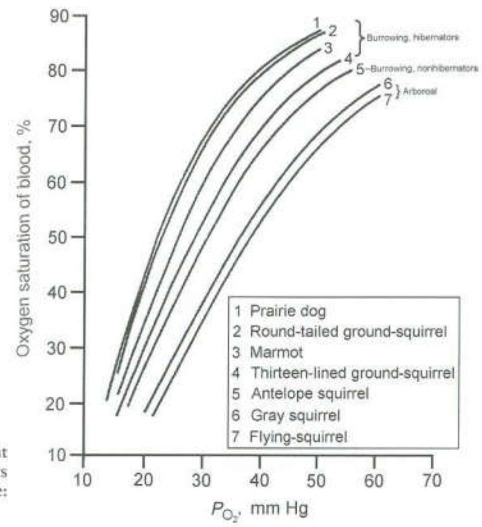


Figure 8.41 Oxygen dissociation curves in rodents as a function of external oxygen tension and whether the squirrels burrow or are arboreal and whether they hibernate or remain normothermic. Source: Modified from Boggs et al. (1984).

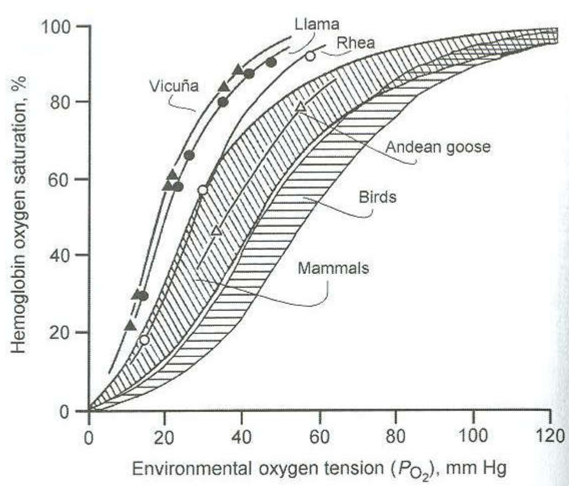
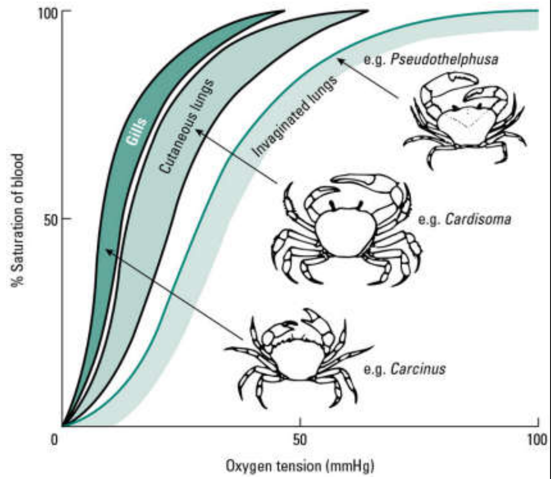


Figure 8.42 Oxygen dissociation curves for eight lowland mammals and the highland vicuña (*Vicugna vicugna*) and llama (*Lama glama*) and for six lowland birds and the highland rhea (*Rhea pennata*) and Andean goose (*Choephaga melanoptera*) as a function of external oxygen tension. Source: Modified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

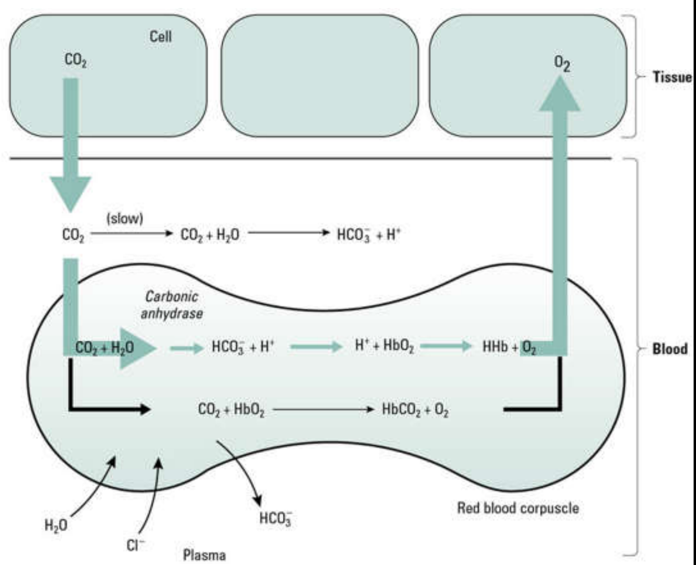
Arthropods

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



CO_2 release

- 5-10% of CO_2 carried in blood cells
- **Carbonic anhydrase** – catalyst for formation of bicarbonate
- HCO_3^- diffuses out, Cl^- in to balance charge
- Osmolarity and CL^- ions facilitate further dumping of O_2

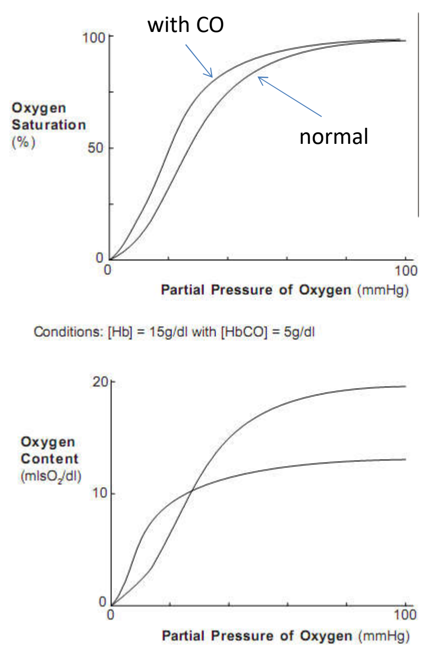


Chemoreceptors, ventilation control

- Ventilation rate regulated by chemoreceptors
  - pH of cerebral spinal fluid
  - pH and O_2 levels in plasma
- Note that oxygen bound to hemoglobin is not directly monitored
- Low plasma PO_2 stimulates kidney to produce **erythropoietin**

CO Poisoning

- CO binds permanently to Hb, blocking O_2 binding site
- CO affinity ~200x greater than O_2 affinity
- Once bound to CO, the affinity for the other three bound O_2 increases.
- Overall O_2 content remains high none is dropped off at tissues
- CO_2 levels remain normal
- Since O_2 and CO_2 levels normal, ventilation rate never increases



Fish - synthesis

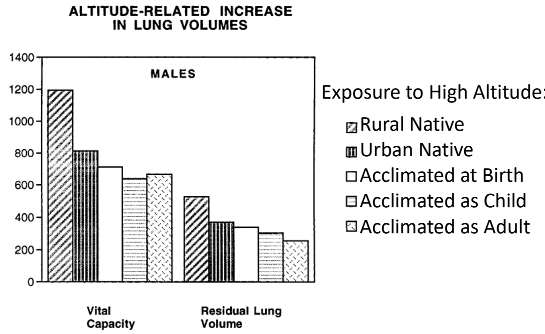
- Larvae rely on cutaneous exchange, switch to gills as scales develop and body size increases
- Gills
  - Counter current exchange
  - Gill area greater: more active, marine, warm water
- Bimodal breathing common
  - Variability in gas bladder function
  - Oxygen availability variable (primarily freshwater)
  - Air breathers retain gills for CO_2 release
  - Freshwater fish also use gills for ammonia release
- Elasmobranchs
  - Some ram ventilators
  - No air bladder, liver lipids for buoyancy

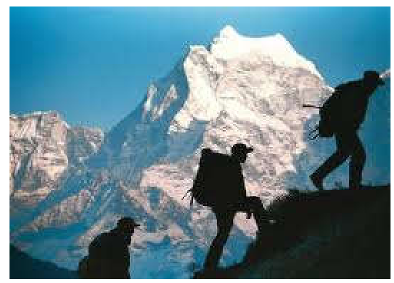
Amphibians - synthesis

- Gills, skin and lungs
  - Greater reliance on lungs for terrestrial forms
  - Gills often lost in metamorphosis, retained in aquatic forms for CO_2 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

- ↓ PO_2
- ↑ 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

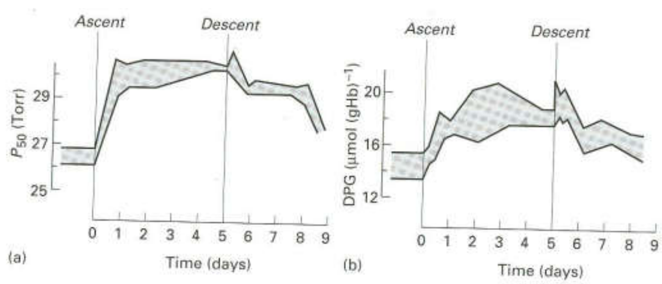


Fig. 14.54 (a) Acclimatory changes in haemoglobin affinity in humans at altitude (4510 m) for 5 days, and (b) the associated change in erythrocyte diphosphoglycerate (DPG) concentrations. (Adapted from Bouverc 1985.)

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

Burrows

- ↑ CO_2 ↓ O_2
- More extreme in less porous soils (clay vs. sand)
- ↑ Hb affinity (curve shifted left)
- Thermally buffered
- Torpor lowers BMR

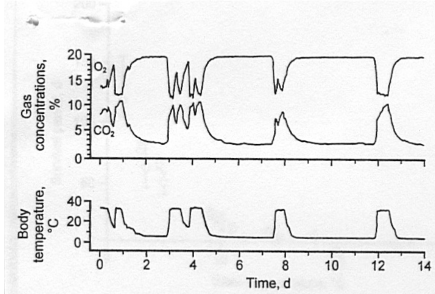


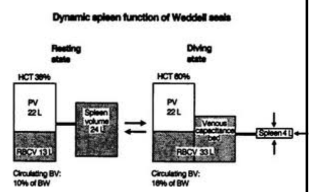
Figure 8.40 Gas composition of a burrow atmosphere and body temperature of a golden hamster (*Mesocricetus auratus*) occupying the burrow as a function of time. Source: Modified from Kuhnen (1986).

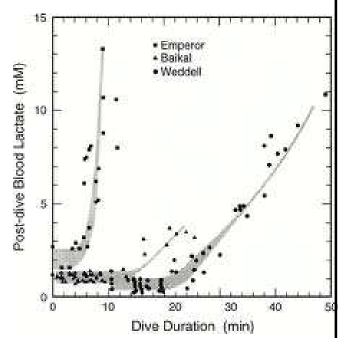
Diving Mammals

- 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

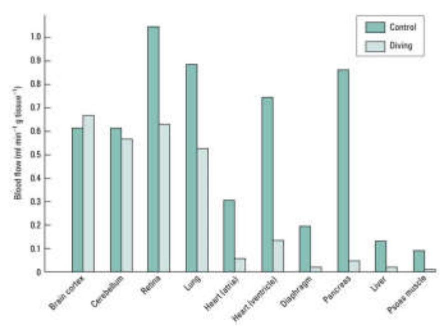
- Oxygen debt has to be repaid at surface
- Paying debt at surface means no access food resources…need to minimize surface time
- Shallow divers
  - Large lungs
  - Lower blood volume
  - Less muscle myoglobin
  - 6 dives at 15 minutes, 4 minutes recovery for each = 90 out of 114 minutes diving
- Deep 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

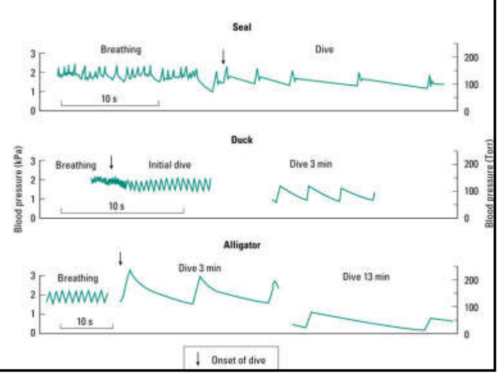




Diving Response

- 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

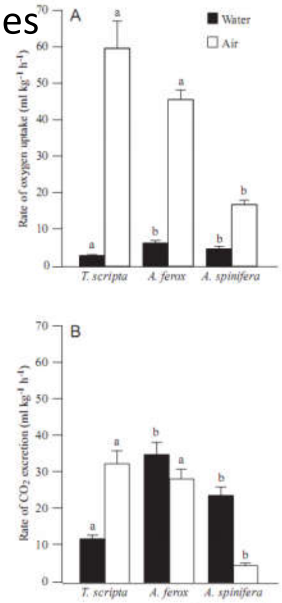


Fig. 1. Resting mean aquatic and aerial $\dot{V}_{O_2}$ (A) and $\dot{V}_{CO_2}$ (B) in *Trachemys scripta* (*N*=23), *Apalone ferox* (*N*=15) and *Apalone spinifera* (*N*=7). Letter groups indicate those species that are not significantly different from each other within each variable measured. Values are means + S.E.M.

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).