1. CO$_2$ transport
2. Acid/Base Balance
3. Osmoregulation
4. Kidney Function

Text:
Chapters 25-27
Push back seminar write-ups to 29 November if you wish.
CO₂ transport in blood

\[
\text{CO}_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-
\]

\[
\text{HCO}_3^- \leftrightarrow H^+ + CO_3^{2-}_{\text{carboxylate}}
\]

\[
\text{CO}_2 + OH^- \leftrightarrow HCO_3^-
\]

Proportions of CO₂, HCO⁻³ depend on pH, T, ionic strength of blood

At normal pH, Temp:
80% of CO₂ in form of bicarbonate ion HCO⁻³
5-10% dissolved in blood
10% in form of carbamino groups
(bound to amino groups of hemoglobin)

Haldane effect

- deox hemo has high affinity for H⁺ creating inc. [HCO₃⁻] in blood (more CO₂)
- recall equations on previous slide
Carbon Dioxide Transport:

Hill et al., 2004, Fig. 22.21

Hill et al., 2004, Fig. 22.22
**CO₂ transfer at tissue**

- enters/leaves blood as CO₂ (more rapid diffusion)
- passes thru RBCs
- CO₂ produced = O₂ released → no change in pH

- Chloride Shift
- Carbonic Anhydrase

---

**CO₂ transfer at lung**

- Band III protein
- Chloride Shift
- Carbonic Anhydrase

---

Band III protein

- Acidify RBC: facilitate
- HCO₃⁻ → CO₂

- Facilitated diffusion
- Facilitate
- HCO₃⁻ in RBC: influx

- Dec. in HCO₃⁻ in RBC: influx
- Maintain charge balance
Jacob-Stewart Cycle

(Eckert 13-17)

Move acid in or out of RBC
(e.g., help buffer CO$_2$ rise in plasma)

Vertebrate Physiology 437

Osmoregulation

• Eldon Braun
  Tuesday 08 Nov
Osmoregulation
- Ionic and Osmotic Balance
- Kidney Function

- life arose in salty sea
- extracellular fluids ~ similar

- dist’n limited by temperature and osmotic pressure (dehydration, ionic composition)

- terrestrial organisms (and their descendents) regulate internal environment (homeostasis)
- salt and water regulation (waste excretion)
- kidneys, salt glands, gills
**Obligatory Osmotic Exchanges**

1. **Gradients**
   - Frog in freshwater
   - Fish in ocean

2. **Surface-to-Volume Ratio**
   - Small animals dehydrate or hydrate more rapidly
   - Skin, and Respiratory surface
     (higher metabolism with higher per/gram respiratory surface)

3. **Integument Permeability**
   - Transcellular or Paracellular
   - Aquaporins = water channel proteins
   - Frogs vs. Lizards, Pelvic Patch etc.

4. **Feeding, Metabolism, Excretion**
   - Metabolic waste products
     ammonia, urea, etc.
   - Metabolic water (desert!)
   - Ingestion of salts
   - Kidneys, salt glands, gills (more later)

5. **Respiration**
   - Internalize respiratory surface
   - Temporal countercurrent system
     (dry and cool IN, becomes moist and warm; recover)
     (countercurrent blood flow also)
   - Temperature regulation vs. water conservation
   - Ectotherm vs. endotherm (in deserts)
Osmoregulation

- **Water Breathing**

1. **Fresh**

   **Blood osmolarity** 200-300 mosm/L
   Water ~ 50 mosm/L

   - hyperosmotic animals, danger of swelling, losing salts
   - get their water across skin
   - dilute urine
   - active uptake of salts across epithelium
   - fish gills, frog skin, etc.

2. **Salt** (~1,000 mosm/L)

   Most marine vertebrates hypo-osmotic
   (e.g., teleost or bony fishes)

   - danger of losing water, gaining too many salts
   - drink saltwater
   - excess salts actively secreted (gills, kidneys)
   - chloride cells for salt secretion
     (Pelis et al. paper)
Osmoregulation

-Air Breathing

Have to lose water to allow gas exchange

- Marine reptiles and marine birds can drink seawater and secrete salts in high [ ]
- SALT GLANDS
- Mammals rely on kidney

Kangaroo Rat
- Reduce Activity
- Remain in Cool Burrow
- Highly concentrated urine
- Very dry feces (rectal absorption)
- Metabolic water
Excretion of Nitrogenous waste

- When amino acids catabolized, amino group (-NH$_2$) is released (deamination)
- If not reused, need to excrete because toxic
- Three main ways to dispose:

1. **ammonia** (most toxic, requires lots water)
   - ammonotelic' (NH$_3$)

2. **urea** (need 10% of water of NH$_3$, but costs ATP)
   - ureotelic' (2N)

3. **uric acid** (white pasty substance, low solubility, need 1% water as NH$_3$) ‘uricotelic’ (4N)

- Disposal depends on water availability

---

**Table 9.3** Metabolic end products of the major groups of foodstuffs. Ammonia from protein metabolism may be excreted as such or may be synthesized into other N-containing excretory products; purines from nucleic acids may be excreted as such or as any of a number of degradation products, including ammonia.

<table>
<thead>
<tr>
<th>Foodstuff</th>
<th>End product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbohydrate</td>
<td>CO$_2$ + H$_2$O</td>
</tr>
<tr>
<td>Fat</td>
<td>CO$_2$ + H$_2$O</td>
</tr>
<tr>
<td>Protein</td>
<td>NH$_3$, Urea</td>
</tr>
<tr>
<td>Nucleic acids</td>
<td>Purines, Uric acids</td>
</tr>
<tr>
<td></td>
<td>Allantoin, NH$_3$</td>
</tr>
<tr>
<td></td>
<td>Allatofic acid, Urea</td>
</tr>
<tr>
<td></td>
<td>NH$_3$</td>
</tr>
</tbody>
</table>

**Figure 9.13** Different groups of vertebrates use different compounds as their major nitrogenous excretory product. There are many exceptions to the general pattern indicated in this diagram, most of them related to environmental factors rather than to phylogenetic relationships. See text for further details.

Knut Schmidt-Nielsen 1997
Table 9.4 Major nitrogen excretory products in various animal groups.

<table>
<thead>
<tr>
<th>Animal</th>
<th>Major end product of protein metabolism</th>
<th>Adult habitat</th>
<th>Embryonic environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aquatic invertebrates</td>
<td>Ammonia</td>
<td>Aquatic</td>
<td>Aquatic</td>
</tr>
<tr>
<td>Teleost fish</td>
<td>Ammonia, some urea</td>
<td>Aquatic</td>
<td>Aquatic</td>
</tr>
<tr>
<td>Elasmobranchs</td>
<td>Urea</td>
<td>Aquatic</td>
<td>Aquatic</td>
</tr>
<tr>
<td>Crocodiles</td>
<td>Ammonia, some uric acid</td>
<td>Semiaquatic</td>
<td>Cleidoic egg</td>
</tr>
<tr>
<td>Amphibians, larval</td>
<td>Ammonia</td>
<td>Aquatic</td>
<td>Aquatic</td>
</tr>
<tr>
<td>Amphibians, adult</td>
<td>Urea</td>
<td>Semiaquatic</td>
<td>Aquatic</td>
</tr>
<tr>
<td>Mammals</td>
<td>Urea</td>
<td>Terrestrial</td>
<td>Aquatic</td>
</tr>
<tr>
<td>Turtles</td>
<td>Urea and uric acid</td>
<td>Terrestrial</td>
<td>Cleidoic egg</td>
</tr>
<tr>
<td>Insects</td>
<td>Uric acid</td>
<td>Terrestrial</td>
<td>Cleidoic egg</td>
</tr>
<tr>
<td>Land gastropods</td>
<td>Uric acid</td>
<td>Terrestrial</td>
<td>Cleidoic egg</td>
</tr>
<tr>
<td>Lizards</td>
<td>Uric acid</td>
<td>Terrestrial</td>
<td>Cleidoic egg</td>
</tr>
<tr>
<td>Snakes</td>
<td>Uric acid</td>
<td>Terrestrial</td>
<td>Cleidoic egg</td>
</tr>
<tr>
<td>Birds</td>
<td>Uric acid</td>
<td>Terrestrial</td>
<td>Cleidoic egg</td>
</tr>
</tbody>
</table>

*The role of cleidoic eggs is discussed later in this chapter.

Excretion of Nitrogenous waste
- ammonia converted to non-toxic glutamine in the body for transport

- ammonia toxic because
  - increases pH,
  - competes with K⁺ for ion transport,
  - alters synaptic transmission

Knut Schmidt-Nielsen 1997
Osmoregulatory Mechanisms

- Apical surface (faces lumen and outside world)
- Basal surface (faces body and extracellular fluid)

- Active movement of ions/salts requires \textbf{ATP}
- Movement of water follows movement of ions/salts

Gradients established and used...to move ions, water
Fish Gills  *Chloride cells* involved in osmoregulation
-(recall Pelis et al. paper on smolting)
-lots of *mitochondria* to power ATPases
-mechanism similar in nasal glands (birds and reptiles), and shark rectal gland

Kidney Functions:

-Osmoregulation
-Blood *volume* regulation
-Maintain proper *ion concentrations*
-Dispose of metabolic *waste* products
-**pH** regulation (at ~ 7.4)
-Dispose of *toxins* and foreign substances

*How* does the kidney accomplish this?
Mammalian Kidney
- Paired
- 1% body mass
- 20% blood flow

- urine contains:
  - water
  - metabolic byproducts (e.g., urea)
  - excess salts etc.

- from ureter to urinary bladder
  (smooth muscle, sphincter, inhibition)
- out via urethra during micturition

Mammalian Kidney Anatomy
Nephron Anatomy

1 - Proximal tubule
2 - Loop of Henle
   - descending
   - ascending
3 - Distal tubule

- numerous nephrons empty into collecting duct
- collecting ducts empty into renal pelvis
Kidney Processes- overview

1. FILTRATION
   blood --> filtrate

2. REABSORPTION
   filtrate --> blood

3. SECRETION
   blood --> filtrate

All 3 involved in final Urine Composition

(Eckert 14-21)
### Table 9.2

Table 9.2 The maximum concentrating ability of various mammals is correlated with the animal, desert animals having the highest concentrations and fresh-water animals the lowest.

<table>
<thead>
<tr>
<th>Animal</th>
<th>Urine maximum osmotic concentration (Osm liter⁻¹)</th>
<th>Urine/plasma concentration ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beave</td>
<td>0.52</td>
<td>2</td>
</tr>
<tr>
<td>Pig</td>
<td>1.1</td>
<td>3</td>
</tr>
<tr>
<td>Human</td>
<td>1.4</td>
<td>4</td>
</tr>
<tr>
<td>White rat</td>
<td>2.9</td>
<td>9</td>
</tr>
<tr>
<td>Cat</td>
<td>3.1</td>
<td>10</td>
</tr>
<tr>
<td>Kangaroo rat</td>
<td>5.5                Dipodomys</td>
<td>14</td>
</tr>
<tr>
<td>Sand rat</td>
<td>6.3</td>
<td>17</td>
</tr>
<tr>
<td>Hopping mouse</td>
<td>9.4</td>
<td>25</td>
</tr>
</tbody>
</table>

* B. Schmidt-Nielsen and O’Dell (1961).
* MacMillen and Lee (1967).

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**Figure 9.10** Excretion of phenol red by the bullfrog. The amount added to the urine by tubular secretion remains constant, indicating that the tubular maximum for phenol red is 14.20. (Forast 1940)

Knut Schmidt-Nielsen 1997

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**Diagram**

- Short, wide afferent arteriole = Low-resistance input pathway
- Flow controlled by vasoconstriction of afferent arteriole
- Sympathetic innervation tends to constrict

Humans:
- 125 ml/min or
- 180 L/day

**Diagram Text**

- Filtration
- Viral capsule
- Glomerul

**Legend**

- Filtrate
- Efferent arteriole plus vasa recta = High-resistance outflow pathway

---

**Equation**

\[ \text{Filtration plus secretion} \]

\[ \text{Mosm} = 1000 \]

\[ \text{U/P} \]
Filtration:

**Bowman's capsule**
- 3 layers
  1. **Glomerular endothelial cells**
     - 100x leakier than other capillary walls
  2. **Basement membrane**
     - negatively charged glycoproteins
     - repel plasma proteins by charge
  3. **Epithelial cells**
     - podocytes create slits

**Filtrate** = protein-free and cell-free plasma

**Glomerular Filtration Rate (GFR)**
- **Humans:** 125 ml/min or 180 L/day (60x plasma vol.)
proteins and larger molecules remain

About 20% of the plasma and solutes that enter glomerulus end up in BC

Bowman's capsule

1. Starvation Implications?

2. Kidney Stone Implications?

(Bowman's capsule)

(Eckert 14-22)