Chapter 44.

Regulating the Internal Environment
Homeostasis

- Living in the world organisms had a choice:
  - regulate their **internal** environment
    - maintain relatively constant internal conditions
  - conform to the **external** environment
    - allow internal conditions to fluctuate along with external changes

reptiles fluctuate with external conditions  mammals internally regulate
Homeostasis

- Keeping the balance
  - animal body needs to coordinate many systems all at once
    - temperature
    - blood sugar levels
    - energy production
    - water balance & waste disposal
    - nutrients
    - ion balance
    - cell growth
  - maintaining a “steady state” condition
Homeostasis

- **Osmoregulation**
  - solute balance & gain or loss of water
- **Excretion**
  - elimination of nitrogenous wastes
- **Thermoregulation**
  - maintain temperature within tolerable range
Unicellular → Multi-cellular

- All cells in direct contact with environment
- Direct exchange of nutrients & waste with environment

- Internal cells no longer in direct contact with environment
- Must solve exchange problem
- Have to maintain the “internal ocean”

Warm, dilute ocean waters
What are the issues?

Diffusion is not adequate for moving material across more than 1 cell barrier.
Solving exchange problem

- Had to evolve exchange systems for:
  - distributing nutrients
    - circulatory system
  - removing wastes
    - excretory system

overcoming the limitations of diffusion
Osmoregulation

- Water balance
  - freshwater = hypotonic
    - manage water moving into cells
    - salt loss
  - saltwater = hypertonic
    - manage water loss from cells
    - salt accumulation
  - land
    - manage water loss
    - need to conserve water

Why do all land animals have to conserve water?

- always need water for life
- always lose water (breathing & waste)
- may lose life while searching for water
Water & salt...

- Salt secreting glands of marine birds remove salt from blood allowing them to drink sea water during months at sea
  - secrete a fluid much more salty than ocean water

How does structure of epithelial cells govern water regulation?

- different proteins in membranes
  - sea birds **pump salt out** of blood
  - freshwater fish **pump salts** into blood from water
Waste disposal

- What waste products?
  - what do we breakdown?
    - carbohydrates = \( \text{CHO} \rightarrow \text{CO}_2 + \text{H}_2\text{O} \)
    - lipids = \( \text{CHO} \rightarrow \text{CO}_2 + \text{H}_2\text{O} \)
    - proteins = \( \text{CHON} \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{N} \)
    - nucleic acids = \( \text{CHOPN} \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{P} + \text{N} \)
  - relatively small amount in cell

NH\(_2\) = ammonia

Animals can't store proteins

\[ \begin{align*}
\text{H} & \quad \text{N} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \dot{\text{C}} \quad \dot{\text{C}} \quad \text{OH} \\
\text{R} & \\
\end{align*} \]

\[ \text{CO}_2 + \text{H}_2\text{O} \]

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Nitrogenous waste disposal

- Ammonia (NH$_3$)
  - very toxic
    - carcinogenic
  - very soluble
    - easily crosses membranes
  - must dilute it & get rid of it... *fast!*

- How you get rid of N-wastes depends on
  - who you are (evolutionary relationship)
  - where you live (habitat)
N waste

- **Ammonia**
  - most toxic
  - freshwater organisms

- **Urea**
  - less toxic
  - terrestrial

- **Uric acid**
  - least toxic
  - egg layers
  - most water conservative
Freshwater animals

- **Nitrogen waste disposal in water**
  - if you have a lot of water you can dilute ammonia then excrete
    - freshwater fish pass ammonia continuously through gills
      - need to excrete a lot of water anyway so excrete very dilute urine
    - freshwater invertebrates pass ammonia through their whole body surface
Land animals

- Nitrogen waste disposal on land
  - evolved less toxic waste product
    - need to conserve water
    - urea = less soluble = less toxic
  - kidney
    - filter wastes out of blood
    - reabsorb $H_2O$
    - excrete waste
      - urine = urea, salts, excess sugar & $H_2O$
        - urine is very concentrated
        - concentrated NH$_3$ would be too toxic
Urea

- $2\text{NH}_2 + \text{CO}_2 = \text{urea}$
  - combined in liver
- Requires energy to produce
  - worth the investment of energy
- Carried to kidneys by circulatory system
Egg-laying land animals

- Nitrogen waste disposal in egg
  - no place to get rid of waste in egg
  - need even less soluble molecule
    - uric acid = less soluble = less toxic
  - birds, reptiles, insects
Uric acid

- Polymerized urea
  - large molecule
  - precipitates out of solution
    - doesn’t harm embryo in egg
      - white dust in egg
    - adults excrete white paste
      - no liquid waste
      - white bird poop!

And that folks... is why a male bird doesn’t have... a penis!
Mammalian System

- Key functions
  - filtration
    - body fluids (blood) collected
    - water & soluble material removed
  - reabsorption
    - reabsorb needed substances back to blood
  - secretion
    - pump out unwanted substances to urine
  - excretion
    - remove excess substances & toxins from body
Mammalian kidney

- Urinary system filters blood & helps maintain water balance (osmoregulation)
  - pair of bean-shaped kidneys
  - supplied with blood
    - renal artery
    - renal vein

Diagram of the urinary system with labels for Adrenal gland, Inferior vena cava, Renal vein and artery, Aorta, Ureter, Urinary bladder, and Urethra.
Mammalian Kidney

(a) Adrenal gland
Inferior vena cava
Renal vein and artery
Aorta
Ureter
Urinary bladder
Urethra

(b) Kidney
Cortical nephron
Nephron tubule
Juxtamedullary nephron
Renal cortex
Renal medulla
Collecting duct
Renal pelvis
Renal medulla
Renal cortex
Ureter
Kidney & Nephron

- Renal pelvis
- Renal medulla
- Renal cortex
- Ureter

nephron

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Nephron

- **Functional units of kidney**
  - 1 million nephrons per kidney

- **Function**
  - remove urea & other solutes (salt, sugar…)

- **Process**
  - liquid of blood (plasma) filtered into nephron
  - selective recovery of valuable solutes

that’s called a “counter current exchange system”
Mammalian kidney

- Interaction of circulatory & excretory systems
- Circulatory system
  - glomerulus = ball of capillaries
- Excretory system
  - nephron
  - Bowman’s capsule
  - loop of Henle
    - descending limb
    - ascending limb
  - collecting duct
Nephron: Filtration

- Filtered out
  - $\text{H}_2\text{O}$
  - glucose
  - salts / ions
  - urea

- Not filtered out
  - cells
  - proteins
Nephron: Re-absorption

- **Proximal tubule**
  - reabsorbed
    - **NaCl**
      - active transport $\text{Na}^+$
      - $\text{Cl}^-$ follows by diffusion
    - **H}_2\text{O**
    - **glucose**
    - **HCO}_3^{-**
      - bicarbonate
      - buffer for blood pH
Nephron: Re-absorption

- **Loop of Henle**
  - **descending limb**
    - many aquaporins in cell membranes
    - high permeability to $\text{H}_2\text{O}$
    - low permeability to salt
  - reabsorbed
    - $\text{H}_2\text{O}$
Nephron: Re-absorption

- Loop of Henle
  - ascending limb
    - low permeability to $H_2O$
    - $Cl^-$ pump
    - $Na^+$ follows by diffusion
  - reabsorbed
    - salts
      - maintains osmotic gradient
Nephron: Re-absorption

- Distal tubule
  - reabsorbed
    - salts
    - \( H_2O \)
    - \( HCO_3^- \)
      - bicarbonate
Nephron: Reabsorption & Excretion

- Collecting duct
  - reabsorbed
    - H₂O
  - excretion
    - urea passed through to bladder
Osmotic control in nephron

- How is all this re-absorption achieved?
  - tight osmotic control to reduce the energy cost of excretion
  - as much as possible, use diffusion instead of active transport
Summary

- **Not filtered out (remain in blood)**
  - cells
  - proteins

- **Reabsorbed: active transport**
  - Na^+ 
  - amino acids
  - Cl^- 
  - glucose

- **Reabsorbed: diffusion**
  - Na^+ 
  - Cl^- 

- **Reabsorbed: osmosis**
  - H_2O

- **Excreted**
  - urea
  - H_2O
  - any excess solutes
Maintaining Water Balance

- **Monitor blood osmolarity**
  - amount of dissolved material in blood

**High solutes**

- **Dehydration**
- **Increased osmolality of plasma**
- **Osmoreceptors in hypothalamus**
- **Posterior pituitary gland**
  - **Increased ADH secretion**
  - **Increased water intake**
  - **Increased reabsorption of water**

**ADH** = anti-diuretic hormone
Maintaining Water Balance

- High blood osmolarity level
  - too many solutes in blood
    - dehydration, salty foods
  - release ADH (anti-diuretic hormone) from pituitary (in brain)
  - increases permeability of collecting duct & reabsorption of water in kidneys
    - increase water absorption back into blood
    - decrease urination
  - also stimulates thirst = drink more

Alcohol inhibits ADH... makes you urinate a lot!
Maintaining Water Balance

- Low blood osmolarity level or low blood pressure

Low solutes

renin activates angiotensinogen

angiotensin triggers aldosterone

aldosterone increases absorption of NaCl & H₂O in kidney

Oooh... zymogen!
Maintaining Water Balance

- Low blood osmolarity level or low blood pressure
  - JGA releases renin in kidney
  - renin converts angiotensinogen to angiotensin
  - angiotensin causes arterioles to constrict
    - increase blood pressure
  - angiotensin triggers release of aldosterone from adrenal gland
  - increases reabsorption of NaCl & H₂O in kidneys
    - puts more water & salts back in blood

Why such a rapid response system?
Any Questions??

![Image of a bat](image)