Overview: A Balancing Act

- Physiological systems of animals operate in a fluid environment.
- Relative concentrations of water and solutes must be maintained within fairly narrow limits.
- **Osmoregulation** regulates solute concentrations and balances the gain and loss of water.

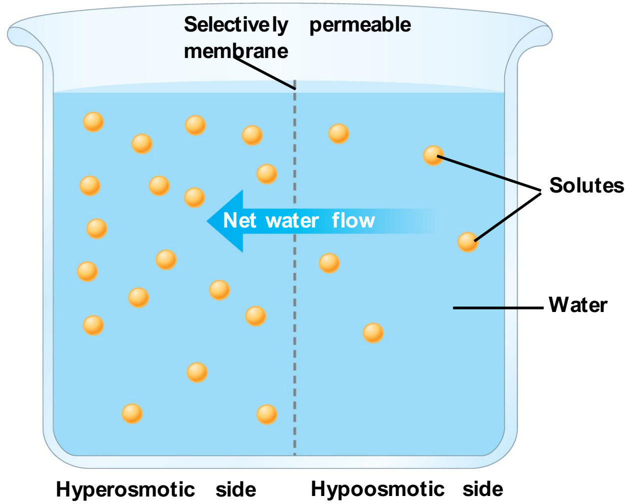
- Freshwater animals show adaptations that reduce water uptake and conserve solutes.
- Desert and marine animals face desiccating environments that can quickly deplete body water.
- **Excretion** gets rid of nitrogenous metabolites and other waste products.

How does an albatross drink saltwater without ill effect?

Osmoregulation balances the uptake and loss of water and solutes

- ***Osmoregulation*** is based largely on controlled movement of solutes between internal fluids and the external environment. Cells require a balance between osmotic gain and loss of water.
- ***Osmolarity*** = the solute concentration of a solution, determines the movement of water across a selectively permeable membrane.
- If two solutions are *isoosmotic*, the movement of water is equal in both directions.
- If two solutions differ in osmolarity, the net flow of water is from the hypoosmotic to the hyperosmotic solution.

Solute concentration and osmosis



Osmotic Challenges

- **Osmoconformers**, consisting only of some marine animals, are isoosmotic with their surroundings and do not regulate their osmolarity.
- **Osmoregulators** expend energy to control water uptake in a hypoosmotic environment and loss in a hyperosmotic environment.

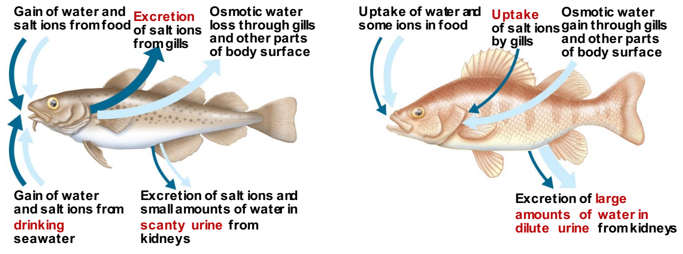
- Most animals are **stenohaline**; they cannot tolerate substantial changes in external osmolarity.
- **Euryhaline** animals can survive large fluctuations in external osmolarity.

Sockeye salmon = euryhaline osmoregulators

Marine Animals

- Most marine invertebrates are osmoconformers.
- Most marine vertebrates and some invertebrates are osmoregulators.
- Marine bony fishes are hypoosmotic to sea water. They lose water by osmosis and gain salt by diffusion and from food.
- They balance water loss by drinking seawater and excreting salts.

Osmoregulation in marine and freshwater bony fishes: a comparison: ***drinking, gills, urine …***



Osmoregulation in a **saltwater fish**

Osmoregulation in a **freshwater fish**

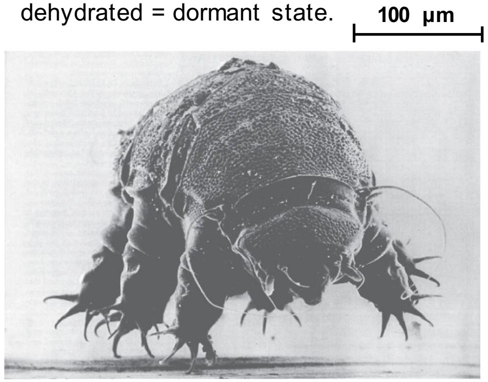
Freshwater Animals

- Freshwater animals constantly take in water by osmosis from their hypoosmotic environment.
- They lose salts by diffusion and maintain water balance by excreting large amounts of dilute urine.
- Salts lost by diffusion are replaced in foods and by uptake across the gills.

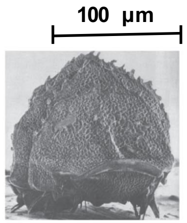
Animals That Live in Temporary Waters

- Some aquatic invertebrates in temporary ponds lose almost all their body water and survive in a dormant state.
- This adaptation is called **anhydrobiosis.**

Anhydrobiosis - adaptation… Hydrated = active state dehydrated = dormant state.



(a) Hydrated tardigrade

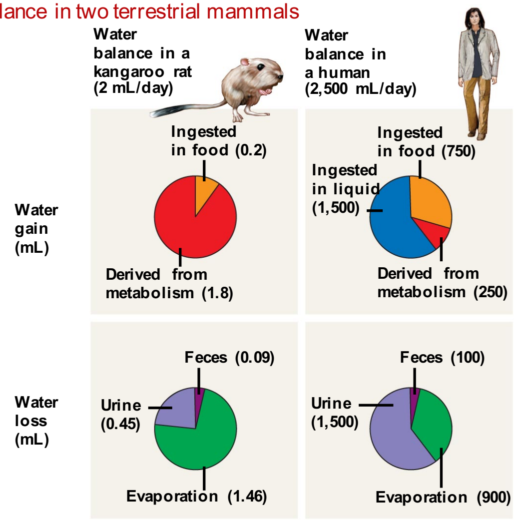


(b) Dehydrated tardigrade

Land Animals

- Land animals manage water budgets by drinking and eating moist foods and using metabolic water.
- Desert animals get major water savings from simple anatomical features and behaviors such as a nocturnal life style.

Water balance in two terrestrial mammals

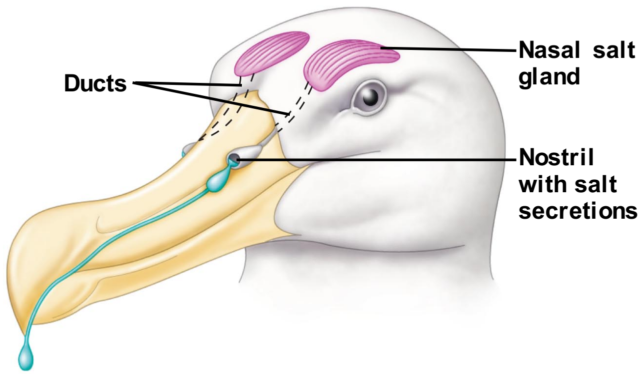


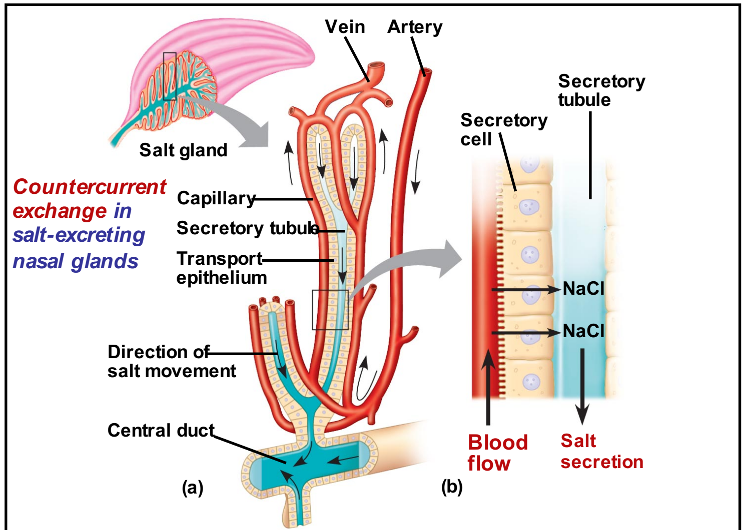
Energetics of Osmoregulation

- **Osmoregulators** must expend energy to maintain osmotic gradients. Animals regulate the composition of body fluid that bathes their cells.
- **Transport epithelia** are specialized epithelial cells that regulate solute movement.
- They are essential components of osmotic regulation and metabolic waste disposal. They are arranged in complex tubular networks
- An example is in salt glands of marine birds, which remove excess sodium chloride from the blood.

How do seabirds eliminate excess salt from their bodies?

EXPERIMENT

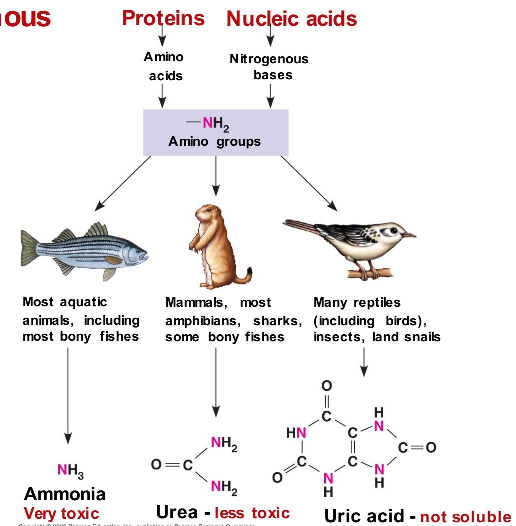




An animal's **nitrogenous wastes** reflect its phylogeny and habitat

- The type and quantity of an animal's waste products may greatly affect its water balance.
- Among the most important wastes are nitrogenous breakdown products of proteins and nucleic acids.
- Some animals convert **toxic ammonia** (NH_3) to less toxic compounds prior to excretion.

Nitrogenous wastes



Animals Excrete Different Forms of *Nitrogenous Wastes*

- ***Ammonia*** - *needs lots of water*. Animals release ammonia across whole body surface or through gills / aquatic animals.
- ***Urea*** - The liver of mammals and most adult amphibians converts ammonia to less toxic urea. The circulatory system carries urea to kidneys, where it is excreted. Conversion of ammonia to urea is *energetically expensive*; uses *less water* than ammonia.

Nitrogenous Wastes …

- ***Uric Acid*** - Insects, land snails, and many reptiles, including birds, mainly excrete **uric acid.** Uric acid is largely insoluble in water; can be secreted as a paste with *little water loss*. Uric acid is *more energetically expensive* to produce than urea.
- The kinds of nitrogenous wastes excreted depend on an animal's evolutionary history and habitat.
- The amount of nitrogenous waste is coupled to the animal's energy budget.

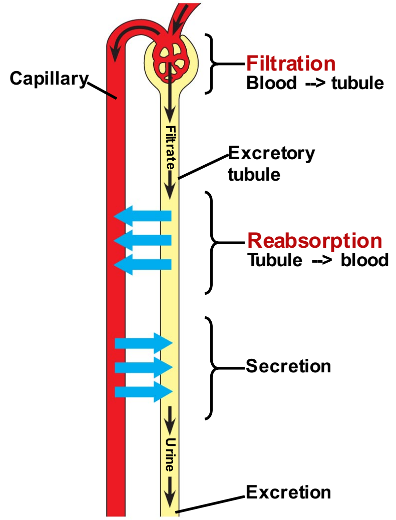
Diverse excretory systems are variations on a tubular theme

Excretory systems regulate solute movement between internal fluids and the external environment. Most excretory systems produce urine by refining a **filtrate** derived from body fluids.

Key functions of most excretory systems:

- ***Filtration***: pressure-filtering of body fluids
- ***Reabsorption***: reclaiming valuable solutes
- ***Secretion***: adding toxins and other solutes from the body fluids to the filtrate
- ***Excretion***: removing the filtrate from the system.

Key functions of excretory systems: an overview



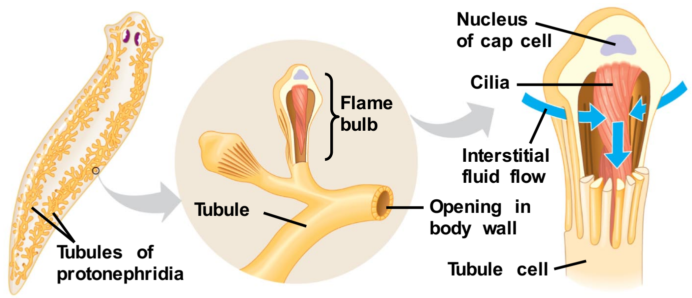
Survey of Excretory Systems

- Systems that perform basic excretory functions vary widely among animal groups. They usually involve a complex network of tubules.
- **Protonephridia** *flame cells / planaria*
- **Metanephridia** *earthworm / similar to nephrons*
- **Malpighian Tubules** *insects*
- **Nephrons** *= the function unit of the kidneys / humans.*

Protonephridia

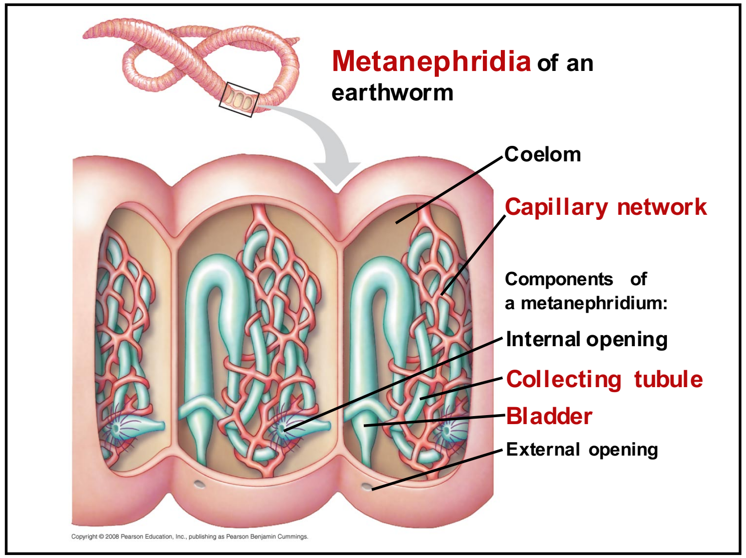
- A **protonephridium** is a network of dead-end tubules connected to external openings.
- The smallest branches of the network are capped by a cellular unit called a flame bulb.
- These tubules excrete a dilute fluid and function in osmoregulation.

Protonephridia: the flame bulb system of a planarian



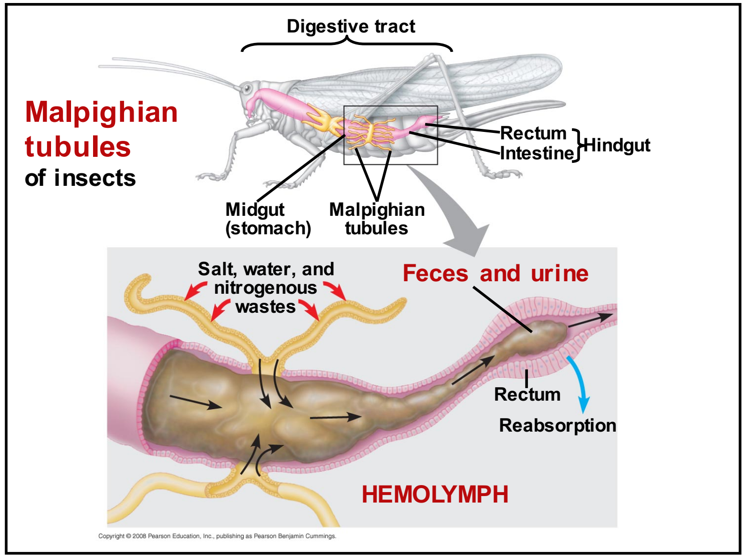
Metanephridia

- Each segment of an earthworm has a pair of open-ended **metanephridia**.
- Metanephridia consist of tubules that collect coelomic fluid and produce dilute urine for excretion.



Malpighian Tubules

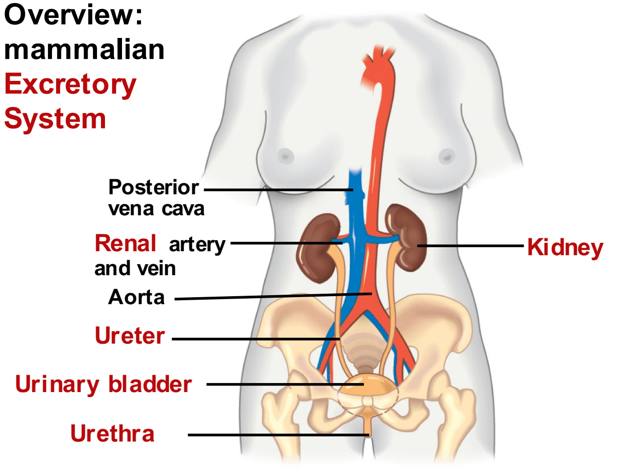
- In insects and other terrestrial arthropods, **Malpighian tubules** remove nitrogenous wastes from hemolymph and function in osmoregulation.
- Insects produce a relatively dry waste matter, an important adaptation to terrestrial life.



Kidneys : Nephrons = the Functional Unit

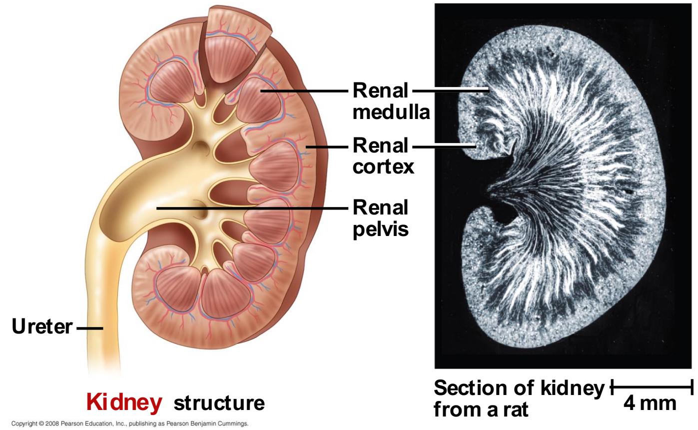
- Kidneys = excretory organs of vertebrates, function in both excretion and osmoregulation.
- Mammalian excretory systems center on paired kidneys, which are also the principal site of water balance and salt regulation.
- Each kidney is supplied with blood by a **renal artery** and drained by a **renal vein.**
- Urine exits each kidney through a duct called the **ureter.**
- Both ureters drain into a common **urinary bladder**, and urine is expelled through a **urethra.**

Overview: mammalian **Excretory System**

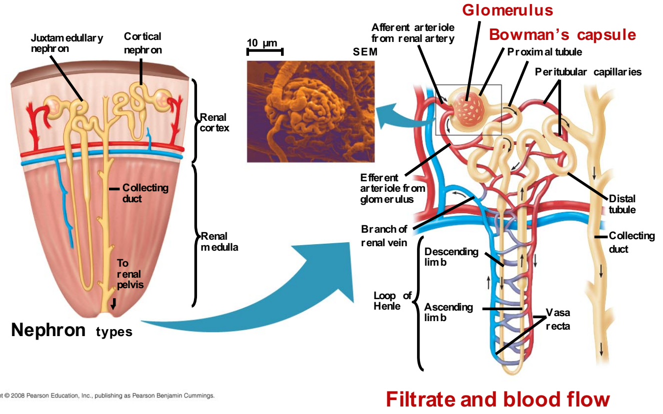


Excretory organs and major associated blood vessels

The **mammalian kidney** has two distinct regions: an **outer renal cortex** and an **inner renal medulla**



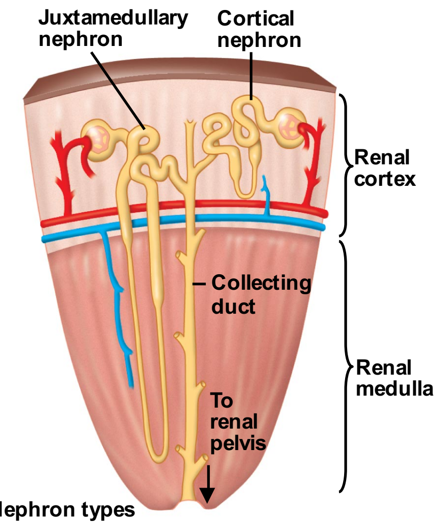
Nephron = the **Functional Unit** of the **Kidney**



- The **nephron** = the functional unit of the vertebrate kidney, consists of a single long tubule and a ball of capillaries called the **glomerulus.**
- **Bowman's capsule** surrounds and receives filtrate from the **glomerulus** capillaries.

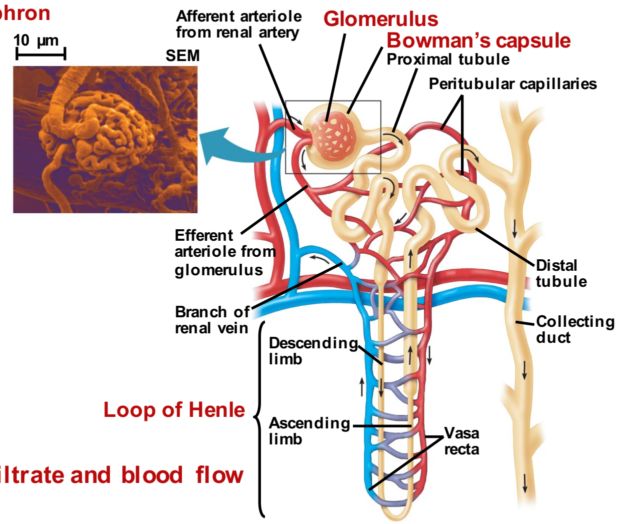
Nephron

Functional Unit of the Kidney



Nephron types

Nephron



Filtrate and blood flow

Filtration : Glomerulus --> Bowman's Capsule

- ***Filtration*** occurs as *blood pressure* = ***hydrostatic pressure*** forces fluid from the blood in the ***glomerulus*** *to lumen of* ***Bowman's capsule***.
- Filtration of small molecules is nonselective.
- The filtrate contains salts, glucose, amino acids, vitamins, nitrogenous wastes, and other small molecules.

Pathway of the Filtrate

- From Bowman's capsule, the filtrate passes through three regions of the nephron: the **proximal tubule** --> **loop of Henle** --> **distal tubule…**
- Fluid from several nephrons flows into a **collecting duct** ---> **renal pelvis** ---> **ureter**.
- **Cortical nephrons** are confined to the renal cortex, while **juxtamedullary nephrons** have loops of Henle that descend into the renal medulla.

Blood Vessels Associated with the Nephrons

- Each nephron is supplied with blood by an **afferent arteriole** = a branch of the renal artery that divides into the capillaries.
- The capillaries converge as they leave the glomerulus, forming an **efferent arteriole**.
- The vessels divide again, forming the peritubular **capillaries**, which surround the proximal and distal tubules.

- **Vasa recta** are capillaries that serve the loop of Henle.
- The vasa recta and the loop of Henle function as a countercurrent system.
- The mammalian kidney conserves water by producing urine that is much more concentrated than body fluids.

The nephron is organized for stepwise processing of blood filtrate

Proximal Tubule

- ***Reabsorption*** of ions, water, and nutrients takes place in the proximal tubule.
- Molecules are transported actively and passively from the filtrate into the interstitial fluid and then capillaries.
- Some toxic materials are secreted into the filtrate.
- The *filtrate volume decreases*.

Descending Limb of the Loop of Henle

- Reabsorption of water continues through channels formed by **aquaporin** proteins.
- Movement is driven by the high osmolarity of the interstitial fluid, which is hyperosmotic to the filtrate.
- The filtrate becomes increasingly concentrated.

Ascending Limb of the Loop of Henle

- In the ascending limb of the loop of Henle, salt but not water is able to diffuse from the tubule into the interstitial fluid.
- The filtrate becomes increasingly dilute.

Distal Tubule

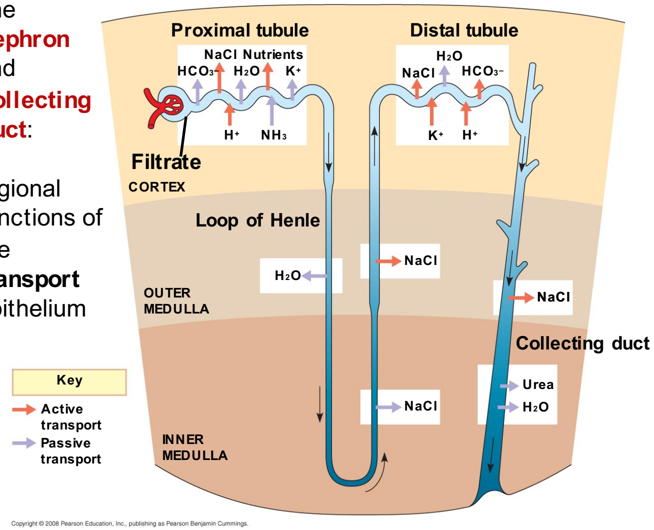
- The distal tubule regulates the K^+ and NaCl concentrations of body fluids.
- The controlled movement of ions contributes to pH regulation.

Collecting Duct

- The collecting duct carries filtrate through the medulla to the renal pelvis.
- Water is lost as well as some salt and urea, and the filtrate becomes more concentrated.
- Urine is hyperosmotic to body fluids.

The **Nephron** and **Collecting Duct**:

regional functions of the **transport** epithelium



Solute Gradients and Water Conservation

- *Urine is much more concentrated than blood.*
- Cooperative action + precise arrangement of the loops of Henle and collecting ducts are largely responsible for the osmotic gradient that concentrates the urine.
- *NaCl and urea contribute to the osmolarity of the interstitial fluid, which causes reabsorption of water in the kidney and concentrates the urine.*

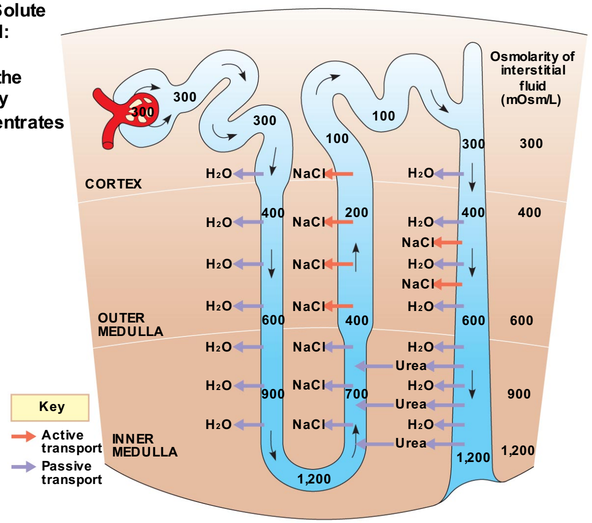
The Two-Solute Model

- In the proximal tubule, filtrate volume decreases, but its osmolarity remains the same
- The **countercurrent multiplier system** involving the loop of Henle maintains a high salt concentration in the kidney.
- This system allows the vasa recta to supply the kidney with nutrients, without interfering with the osmolarity gradient.
- *Considerable energy is expended to maintain the osmotic gradient* between the medulla and cortex.

- The collecting duct conducts filtrate through the osmolarity gradient, and more water exits the filtrate by osmosis.
- Urea diffuses out of the collecting duct as it traverses the inner medulla.
- Urea and NaCl form the osmotic gradient that enables the kidney to produce urine that is hyperosmotic to the blood.

Two Solute Model:

How the kidney concentrates urine



Adaptations of the Vertebrate Kidney to Diverse Environments

- The form and function of nephrons in various vertebrate classes are related to requirements for osmoregulation in the animal's habitat.

Mammals

- The juxtamedullary nephron contributes to water conservation in terrestrial animals.
- Mammals that inhabit dry environments have long loops of Henle, while those in fresh water have relatively short loops.

Birds and Other Reptiles

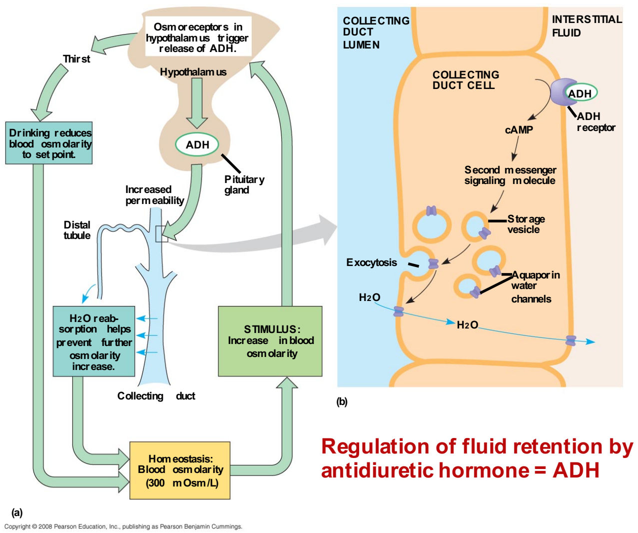
- Birds have shorter loops of Henle but conserve water by excreting ***uric acid*** instead of urea.
- Other reptiles have only cortical nephrons but also excrete nitrogenous waste as uric acid.

Freshwater Fishes, Amphibians, Marine Bony Fishes

- Freshwater fishes conserve salt in their distal tubules and excrete large volumes of dilute urine.
- Kidney function in amphibians is similar to freshwater fishes. Amphibians conserve water on land by reabsorbing water from the urinary bladder.
- Marine bony fishes are hypoosmotic compared with their environment and excrete very little urine.

Hormonal circuits link kidney function, water balance, and blood pressure

- *Mammals control the volume and osmolarity of urine* by nervous and hormonal control of water and salt reabsorption in the kidneys.
- **Antidiuretic hormone = ADH** increases water reabsorption in the distal tubules and collecting ducts of the kidney. An increase in osmolarity triggers the release of ADH, which helps to conserve water.
- Mutation in ADH production causes severe dehydration and results in diabetes insipidus.
- Alcohol is a diuretic - it inhibits the release of ADH.



Regulation of fluid retention by antidiuretic hormone = ADH

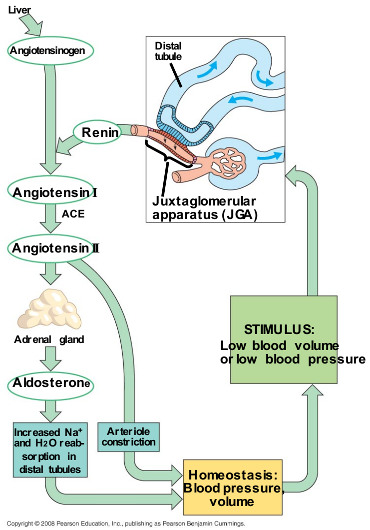
The Renin-Angiotensin-Aldosterone System

- The **renin-angiotensin-aldosterone system RAAS** is part of a complex feedback circuit that functions in homeostasis.
- A drop in blood pressure near the glomerulus causes the **juxtaglomerular apparatus = JGA** to release the enzyme renin.
- Renin triggers the formation of the peptide **angiotensin II.**

- Angiotensin II
  - Raises blood pressure and decreases blood flow to the kidneys
  - Stimulates the release of the hormone **aldosterone**, which increases blood volume and pressure.

Regulation of blood volume and pressure by RAAS

The Renin-Angiotensin-Aldosterone System



Homeostatic Regulation of the Kidney

- ADH and RAAS both increase water reabsorption, but only RAAS will respond to a decrease in blood volume.
- Another hormone, **atrial natriuretic peptide ANP**, opposes the RAAS.
- ANP is released in response to an increase in blood volume and pressure and inhibits the release of renin.

Summary Review

Animal	Inflow/Outflow	Urine
Freshwater fish	Does not drink water; Salt in active transport by gills; H_2O in; Salt out	Large volume of urine; Urine is less concentrated than body fluids
Bony marine fish	Drinks water; Salt in; H_2O out; Salt out - active transport by gills	Small volume of urine; Urine is slightly less concentrated than body fluids
Terrestrial vertebrate	Drinks water; Salt in (by mouth); H_2O and salt out	Moderate volume of urine; Urine is more concentrated than body fluids

You should now be able to:

1. Distinguish between the following terms: isoosmotic, hyperosmotic, and hypoosmotic; osmoregulators and osmoconformers; stenohaline and euryhaline animals.
2. Define osmoregulation, excretion, anhydrobiosis.
3. Compare the osmoregulatory challenges of freshwater and marine animals.
4. Describe some of the factors that affect the energetic cost of osmoregulation.

5. Describe and compare the protonephridial, metanephridial, and Malpighian tubule excretory systems.
6. Using a diagram, identify and describe the function of each region of the nephron.
7. Explain how the loop of Henle enhances water conservation.
8. Describe the nervous and hormonal controls involved in the regulation of kidney function.

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