Chapter 44

Osmoregulation and Excretion

PowerPoint Lectures for
Biology, Seventh Edition
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Lectures by Chris Romero

- Overview: A balancing act
- The physiological systems of animals
  - Operate in a fluid environment
- The relative concentrations of water and solutes in this environment
  - Must be maintained within fairly narrow limits

- Freshwater animals
  - Show adaptations that reduce water uptake and conserve solutes
- Desert and marine animals face desiccating environments
  - With the potential to quickly deplete the body water

Figure 44.1

- Osmoregulation
  - Regulates solute concentrations and balances the gain and loss of water
- Excretion
  - Gets rid of metabolic wastes

- Concept 44.1: 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

Osmosis

- Cells require a balance
  - Between osmotic gain and loss of water
- Water uptake and loss
  - Are balanced by various mechanisms of osmoregulation in different environments

Osmotic Challenges

- Osmoconformers, which are only marine animals
  - Are isoosmotic with their surroundings and do not regulate their osmolarity
- Osmoregulators expend energy to control water uptake and loss
  - In a hyperosmotic or hypoosmotic environment

- Most animals are said to be stenohaline
  - And cannot tolerate substantial changes in external osmolarity
- Euryhaline animals
  - Can survive large fluctuations in external osmolarity

Figure 44.2

Marine Animals

- Most marine invertebrates are osmoconformers
- Most marine vertebrates and some invertebrates are osmoregulators

- Marine bony fishes are hypoosmotic to sea water
  - And lose water by osmosis and gain salt by both diffusion and from food they eat
- These fishes balance water loss
  - By drinking seawater

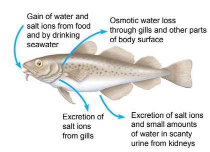


Figure 44.3a (a) Osmoregulation in a saltwater fish

Freshwater Animals

- Freshwater animals
  - Constantly take in water from their hypoosmotic environment
  - Lose salts by diffusion

- Freshwater animals maintain water balance
  - By excreting large amounts of dilute urine
- Salts lost by diffusion
  - Are replaced by foods and uptake across the gills

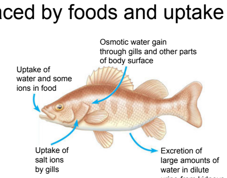


Figure 44.3b (b) Osmoregulation in a freshwater fish

Animals That Live in Temporary Waters

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

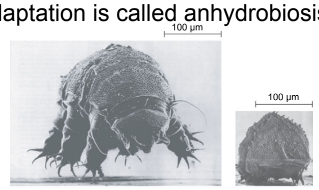


Figure 44.4a, b (a) Hydrated tardigrade (b) Dehydrated tardigrade

Land Animals

- Land animals manage their water budgets
  - By drinking and eating moist foods and by using metabolic water

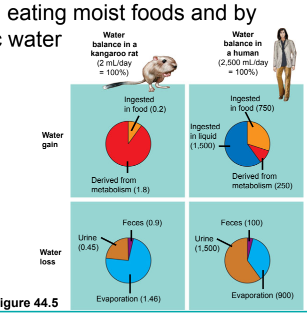


Figure 44.5

- Desert animals
  - Get major water savings from simple anatomical features

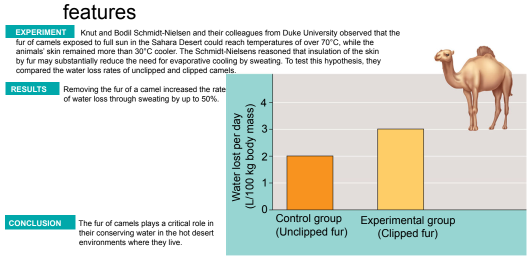


Figure 44.6

Transport Epithelia

- Transport epithelia
  - Are specialized cells that regulate solute movement
  - Are essential components of osmotic regulation and metabolic waste disposal
  - Are arranged into complex tubular networks

- An example of transport epithelia is found in the salt glands of marine birds
  - Which remove excess sodium chloride from the blood

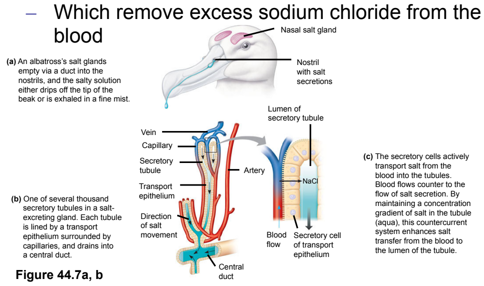


Figure 44.7a, b

- Concept 44.2: An animal's nitrogenous wastes reflect its phylogeny and habitat
- The type and quantity of an animal's waste products
  - May have a large impact on its water balance

- Among the most important wastes
  - Are the nitrogenous breakdown products of proteins and nucleic acids

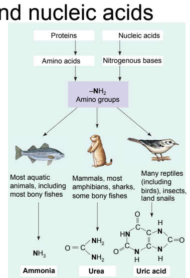


Figure 44.8

Forms of Nitrogenous Wastes

- Different animals
  - Excrete nitrogenous wastes in different forms

Ammonia

- Animals that excrete nitrogenous wastes as ammonia
  - Need access to lots of water
  - Release it across the whole body surface or through the gills

Urea

- The liver of mammals and most adult amphibians
  - Converts ammonia to less toxic urea
- Urea is carried to the kidneys, concentrated
  - And excreted with a minimal loss of water

Uric Acid

- Insects, land snails, and many reptiles, including birds
  - Excrete uric acid as their major nitrogenous waste
- Uric acid is largely insoluble in water
  - And can be secreted as a paste with little water loss

The Influence of Evolution and Environment on Nitrogenous Wastes

- The kinds of nitrogenous wastes excreted
  - Depend on an animal's evolutionary history and habitat
- The amount of nitrogenous waste produced
  - Is coupled to the animal's energy budget

- Concept 44.3: Diverse excretory systems are variations on a tubular theme
- Excretory systems
  - Regulate solute movement between internal fluids and the external environment

Excretory Processes

- Most excretory systems
  - Produce urine by refining a filtrate derived from body fluids

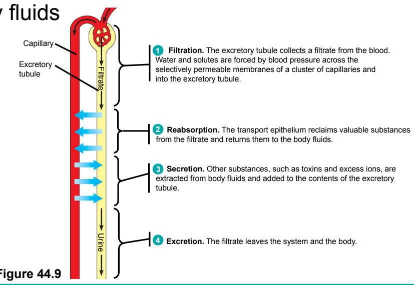


Figure 44.9

- Key functions of most excretory systems are
  - Filtration, pressure-filtering of body fluids producing a filtrate
  - Reabsorption, reclaiming valuable solutes from the filtrate
  - Secretion, addition of toxins and other solutes from the body fluids to the filtrate
  - Excretion, the filtrate leaves the system

Survey of Excretory Systems

- The systems that perform basic excretory functions
  - Vary widely among animal groups
  - Are generally built on a complex network of tubules

Protonephridia: Flame-Bulb Systems

- A protonephridium
  - Is a network of dead-end tubules lacking internal openings

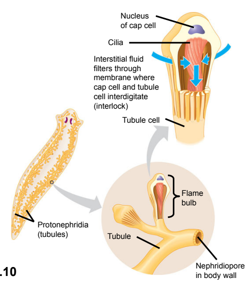


Figure 44.10

- The tubules branch throughout the body
  - And the smallest branches are capped by a cellular unit called a flame bulb
- These tubules excrete a dilute fluid
  - And function in osmoregulation

Metanephridia

- Each segment of an earthworm
  - Has a pair of open-ended metanephridia

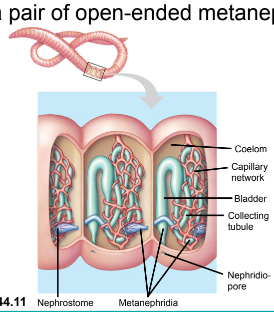


Figure 44.11

- 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

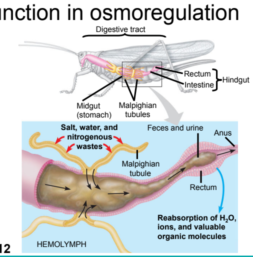


Figure 44.12

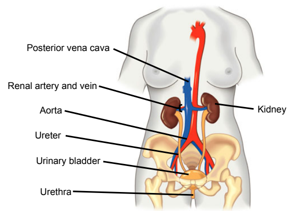
- Insects produce a relatively dry waste matter
  - An important adaptation to terrestrial life

Vertebrate Kidneys

- Kidneys, the excretory organs of vertebrates
  - Function in both excretion and osmoregulation

- Concept 44.4: Nephrons and associated blood vessels are the functional unit of the mammalian kidney
- The mammalian excretory system centers 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



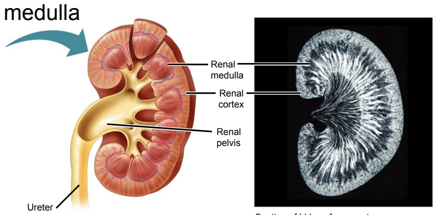
(a) Excretory organs and major associated blood vessels

Figure 44.13a

- Urine exits each kidney
  - Through a duct called the ureter
- Both ureters
  - Drain into a common urinary bladder

Structure and Function of the Nephron and Associated Structures

- The mammalian kidney has two distinct regions
  - An outer renal cortex and an inner renal medulla



Section of kidney from a rat

Figure 44.13b (b) Kidney structure

- The nephron, the functional unit of the vertebrate kidney
  - Consists of a single long tubule and a ball of capillaries called the glomerulus

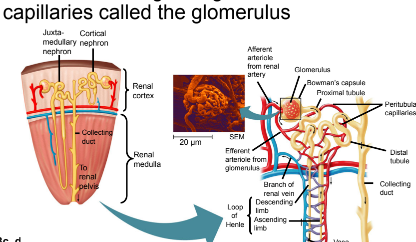


Figure 44.13c, d

(c) Nephron

(d) Filtrate and blood flow

Filtration of the Blood

- Filtration occurs as blood pressure
  - Forces fluid from the blood in the glomerulus into the lumen of Bowman's capsule

- Filtration of small molecules is nonselective
  - And the filtrate in Bowman's capsule is a mixture that mirrors the concentration of various solutes in the blood plasma

Pathway of the Filtrate

- From Bowman's capsule, the filtrate passes through three regions of the nephron
  - The proximal tubule, the loop of Henle, and the distal tubule
- Fluid from several nephrons
  - Flows into a collecting duct

Blood Vessels Associated with the Nephrons

- Each nephron is supplied with blood by an afferent arteriole
  - A branch of the renal artery that subdivides into the capillaries
- The capillaries converge as they leave the glomerulus
  - Forming an efferent arteriole
- The vessels subdivide again
  - Forming the peritubular capillaries, which surround the proximal and distal tubules

From Blood Filtrate to Urine: A Closer Look

- Filtrate becomes urine
  - As it flows through the mammalian nephron and collecting duct

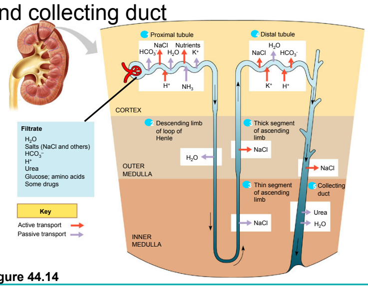


Figure 44.14

- Secretion and reabsorption in the proximal tubule
  - Substantially alter the volume and composition of filtrate
- Reabsorption of water continues
  - As the filtrate moves into the descending limb of the loop of Henle

- As filtrate travels through the ascending limb of the loop of Henle
  - Salt diffuses out of the permeable tubule into the interstitial fluid
- The distal tubule
  - Plays a key role in regulating the K^+ and NaCl concentration of body fluids
- The collecting duct
  - Carries the filtrate through the medulla to the renal pelvis and reabsorbs NaCl

- Concept 44.5: The mammalian kidney's ability to conserve water is a key terrestrial adaptation
- The mammalian kidney
  - Can produce urine much more concentrated than body fluids, thus conserving water

Solute Gradients and Water Conservation

- In a mammalian kidney, the cooperative action and precise arrangement of the loops of Henle and the collecting ducts
  - Are largely responsible for the osmotic gradient that concentrates the urine

- Two solutes, NaCl and urea, contribute to the osmolarity of the interstitial fluid
  - Which causes the reabsorption of water in the kidney and concentrates the urine

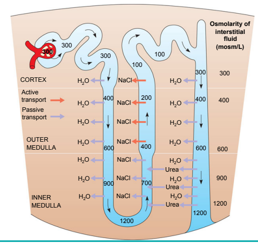


Figure 44.15

- The countercurrent multiplier system involving the loop of Henle
  - Maintains a high salt concentration in the interior of the kidney, which enables the kidney to form concentrated urine

- The collecting duct, permeable to water but not salt
  - Conducts the filtrate through the kidney's 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

Regulation of Kidney Function

- The osmolarity of the urine
  - Is regulated 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

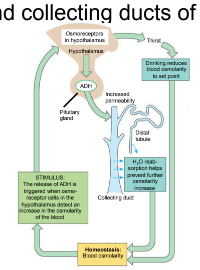


Figure 44.16a (a) Antidiuretic hormone (ADH) enhances fluid retention by making the kidneys reclaim more water.

- The renin-angiotensin-aldosterone system (RAAS)
  - Is part of a complex feedback circuit that functions in homeostasis

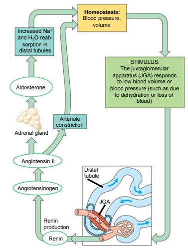


Figure 44.16b (b) The renin-angiotensin-aldosterone system (RAAS) leads to an increase in blood volume and pressure.

- Another hormone, atrial natriuretic factor (ANF)
  - Opposes the RAAS

- The South American vampire bat, which feeds on blood
  - Has a unique excretory system in which its kidneys offload much of the water absorbed from a meal by excreting large amounts of dilute urine

Figure 44.17

- Concept 44.6: Diverse adaptations of the vertebrate kidney have evolved in different environments
- The form and function of nephrons in various vertebrate classes
  - Are related primarily to the requirements for osmoregulation in the animal's habitat

- Exploring environmental adaptations of the vertebrate kidney

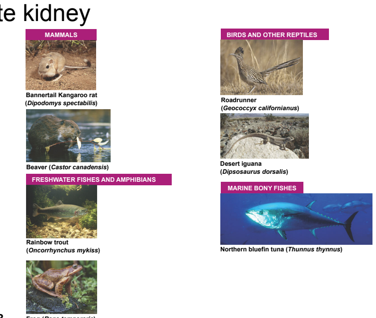


Figure 44.18