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

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

### Marine Animals

- Most marine invertebrates are osmoconformers

- Most marine vertebrates and some invertebrates are osmoregulators

### Freshwater Animals

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

### Freshwater Animals

- 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

### 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

- Osmoregulation in a saltwater fish

### Figure 44.3b

- 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

Land Animals

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

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

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

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

Most excretory systems

- Produce urine by refining a filtrate derived from body fluids
  - Filtration
  - Reabsorption
  - Secretion
  - Excretion

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

- 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

**Malpighian Tubules**

- In insects and other terrestrial arthropods, malpighian tubules
  - Remove nitrogenous wastes from hemolymph and function in osmoregulation

**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

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

Figure 44.13b

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

Figure 44.13c, d

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

- 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

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

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

**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

**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**