CHAPTER 25

Control of the Internal Environment

Objectives

Introduction Explain how bears adjust during their time of dormancy.

Thermoregulation

25.1 Describe the four ways that heat is gained or lost by an animal.
25.2–25.4 Explain how animals thermoregulate.

Osmoregulation and Excretion

25.5 Describe the osmoregulatory problems and associated adaptations of freshwater and saltwater fish, arthropods, and terrestrial vertebrates.
25.6 Explain the need for and physiological consequences of sweating.
25.7 Explain how some animals are able to tolerate seasonal dehydration and how these adaptations can be put to use by humans.
25.8 Describe the three ways that animals eliminate nitrogenous wastes and the advantages and disadvantages of each method.
25.9 Describe the general and specific structure of the human kidney. Explain how this organ promotes homeostasis.
25.10 Describe the four major processes by which the human excretory system produces and eliminates urine.
25.11 Describe the key events in the process by which the kidneys convert filtrate into urine.
25.12 Explain how a dialysis machine works.

Homeostatic Functions of the Liver

25.13 Describe the many functions of the liver.

Key Terms

thermoregulation
endotherm
ectotherm
excretion
osmoregulation
countercurrent heat exchanger
torpor
hibernation
estivation
osmoconformer
osmoregulator
urine
ammonia
urea
uric acid
filtrate
ureter
urinary bladder
urethra
renal cortex
renal medulla
nephron
Bowman's capsule
collecting duct
glomerulus
proximal tubule
loop of Henle
distal tubule
filtration
reabsorption
secretion
excretion
dialysis
hepatic portal vessel

Word Roots

counter- = opposite (*countercurrent heat exchanger:* a special arrangement of blood vessels that helps trap heat in the body core and is important in reducing heat loss in many endotherms)

ecto- = outside; **-therm** = heat (*ectotherm:* an animal, such as a reptile, fish, or amphibian, that must use environmental energy and behavioral adaptations to regulate its body temperature)

endo- = inner (*endotherm:* an animal that uses metabolic energy to maintain a constant body temperature, such as a bird or mammal)

glomer- = a ball (*glomerulus:* a ball of capillaries surrounded by Bowman's capsule in the nephron and serving as the site of filtration in the vertebrate kidney)

osmo- = pushing; **-regula** = regular (*osmoregulation:* adaptations to control the water balance in organisms living in hypertonic, hypotonic, or terrestrial environments)

Lecture Outline

Introduction *Let Sleeping Bears Lie*

A. Animals survive fluctuations in the external environment because they have internal, homeostatic controls.
   1. **Thermoregulation** is the control of temperature.
   2. **Osmoregulation** is control of the concentration of water and dissolved solutes.
   3. **Excretion** is the disposal of nitrogen-containing wastes.

B. Animals vary in the ways they control body temperature .
   1. The concept of cold-blooded and warm-blooded animals is better replaced by the terms ectothermic and endothermic, because these terms focus on the processes animals use to control body heat.
   2. **Ectotherms** warm themselves by absorbing heat from the surrounding environment.
   3. **Endotherms** derive most of their body heat from their own metabolism.
   4. Some animals hibernate during the winter and the body temperature may drop as much as 30°C.
   5. Bears do not hibernate, but instead go dormant and maintain body temperatures only a few degrees below the normal temperature.
   6. Bears have several adaptations that allow a state of dormancy:
      a. Change in eating habits to increase weight and store the excess energy as fat
      b. Reduced blood flow to the extremities
      c. Fetal position during dormant sleep
      d. Dense fur and fat for excellent insulation.
      e. No eating, expelling waste, or urinating during the dormant state

C. This chapter covers the homeostatic control mechanisms of thermoregulation, osmotic control, and excretion.

I. Thermoregulation

Module 25.1 Heat is gained or lost in four ways.

A. Conduction is the direct transfer of heat between surfaces in contact.

B. Convection is the transfer of heat from air or liquid moving past a surface.

C. Radiation, the emission of electromagnetic energy, can transfer heat between two bodies not in contact.

D. Evaporative cooling is the loss of heat from a surface of liquid as the liquid is transformed into gas.

E. In each mechanism, heat is conducted from an area of higher temperature to one of lower temperature (Figure 25.1).

Module 25.2 Thermoregulation depends on both heat production and heat gain or loss.

Preview: Thermoreceptors (Module 29.3).

A. Endotherms generally alter their rate of heat production. For example, hormonal changes in birds or mammals will change metabolic rate. Muscle movement (moving around or shivering) generates additional heat (Figure 25.2A).

B. Endotherms and ectotherms may change their rate of heat gain or loss. Adjustments in coat thickness by muscles that raise and lower hairs change the insulating power of fur. Changes in blood flow to the skin can increase or decrease the temperature of the skin and subsequent heat loss by convection. Cooling also occurs by evaporation during sweating or panting (see Module 20.13).

C. The great white shark has a **countercurrent heat exchange** mechanism (see Module 22.4) that controls and conserves body heat. Heat carried by blood flowing outward from the animal's core is picked up by cooler blood flowing inward (Figure 25.2B, C).

Module 25.3 Behavior often affects body temperature.

A. Relocation to more suitable positions and migration to more suitable climates are used to increase or decrease body heat.

B. Bathing uses convection and, later, evaporative cooling to remove excess heat. An elephant has special, highly vascularized ears to help cool its blood (Figure 25.3).

Module 25.4 Reducing the metabolic rate saves energy.

A. Ectotherms, such as the gray tree frog, can spend much of the winter frozen. The extremely low metabolic rate means that the frog uses almost no energy all winter. A frog version of antifreeze prevents ice crystals from rupturing its cells.

B. In contrast to ectotherms, endotherms can remain active during severe weather. However, a large expenditure of energy is required to keep the body warm. Endotherms have several different adaptations that reduce energy needs.

C. **Torpor** is the temporary reduction in body activity to bypass times of cooler temperatures. Bats and hummingbirds use torpor to escape the requirements of keeping their bodies warm during cold days (bats) and nights (hummingbirds).

D. **Hibernation** is a type of long-term torpor practiced by squirrels and other mammals during cold winter months.

E. **Estivation** is a similar type of long-term torpor practiced during times of reduced food and water during summer months.

II. Osmoregulation and Excretion

Module 25.5 Osmoregulation: All animals balance the gain and loss of water and dissolved solutes.

Review: Mechanisms of transport: diffusion, osmosis, active transport (Modules 5.14–5.19).

A. The metabolic reactions of life depend on certain solute concentrations in cells. Cells of animals would lyse if there were a net gain of water, and crenate and die if there were a net loss of water. Animals acquire water in food and drink. Aquatic animals also gain and lose water through osmosis across body surfaces. Animals lose water in urine, feces, perspiration, and breath. Terrestrial animals also lose water through evaporation.

B. **Osmoconformers** are all aquatic animals that maintain their cells at solute concentrations essentially the same as the surrounding water. Examples include invertebrates such as jellies, flatworms, mollusks, and arthropods.

C. **Osmoregulators** maintain their body fluids with solute concentrations different from that of their surroundings. Examples include all freshwater animals, all land animals, and most marine vertebrates.

D. Freshwater fish constantly take in fresh water by osmosis. They control internal water and solute balance by taking up ions from food in the digestive system and gills, and by the production of large amounts of dilute urine via the excretory system (Figure 25.5A).

E. Saltwater fish have the opposite problem: They lose water by osmosis to their surroundings. They control internal solute concentration by drinking water, pumping out ions through the gills, and producing concentrated urine (Figure 25.5B).

F. Some fish, such as salmon, inhabit both fresh water and salt water at different phases in their lives. When they change habitats, they change strategies, using the freshwater mechanisms or saltwater mechanisms as necessary.

G. Land animals have osmoregulatory problems like marine fish. Only two groups of animals are successful land dwellers: the arthropods and the vertebrates. Both have solved osmoregulatory problems by having thick skins that inhibit water loss, complex excretory systems, and adaptations that protect fertilized eggs and developing embryos from drying out.

Module 25.6 Connection: Sweating can produce serious water loss.

A. Water loss is a more serious problem than salt loss to an athlete initially (Figure 25.6). A weight loss of 2% due to water loss during exercise can reduce athletic performance, while a 5% weight loss can cause serious injury.

B. Drinking water before, during, and after exercise reduces dehydration. If salts are needed, they should be very dilute or taken after water. Sport drinks may improve performance during sustained exercise.

Module 25.7 Some animals face seasonal dehydration.

A. Some animals are able to escape the problem of severe desiccation in their environments. One way is to lay drought-resistant eggs.

B. A few animals, such as water bears (tardigrades), escape the problem by drying up along with their environment (Figure 25.7). To protect their proteins against denaturation and otherwise keep internal structures intact, they replace water molecules with sugar molecules (trehalose). There are emerging pharmaceutical and agricultural applications for trehalose.

Module 25.8 Animals must dispose of nitrogenous wastes.

A. Nitrogen-containing wastes come mostly from the breakdown of proteins and nucleic acids.

B. Aquatic animals can dispose of nitrogenous wastes in the form of toxic **ammonia,** which diffuses readily in water (Figure 25.8).

C. Terrestrial animals must use energy to convert amino groups of proteins into less toxic compounds.

D. **Urea** is highly soluble in water, 100,000 times less toxic than ammonia, and excreted by mammals, amphibians, and a few fishes.

E. **Uric acid** is also less toxic than ammonia and is excreted by birds, insects, many reptiles, and snails. Because it is almost insoluble in water, uric acid is excreted in crystalline form, and thus has the benefit of conserving water.

F. The type of reproduction that a species has determines the method of nitrogen disposal. Live births or birth from a soft-shelled egg can use urea but birth from a hard-shelled egg must use uric acid.

Module 25.9 The excretory system plays several major roles in homeostasis.

A. The major roles include forming and excreting wastes in urine, and regulating the concentrations of water and solutes in body fluids.

B. The human excretory system includes two kidneys, a bladder, interconnecting ducts, and the associated vessels of the circulatory system. The system extracts about 180 liters of fluid (**"filtrate"**) from the 1100–2000 liters of blood passing through it per day, concentrating and storing 1.5 liters of urine for disposal (Figure 25.9A, B, C).

C. The kidney is the processing center of the excretory system. Blood enters and leaves each kidney through the renal artery and renal vein. Urine passes from the kidney to the **urinary bladder** via the **ureter** and from the bladder to the outside through the **urethra.**

D. The kidney is composed of the outer **renal cortex** and the inner **renal medulla.**

E. Thousands of blood filtering units, **nephrons,** are within the kidney. Each nephron is composed of tubules and associated blood vessels. Each extracts and refines a small amount of filtrate and releases a small quantity of urine (Figure 25.9D).

F. The nephron consists of a blood-filtering region **(Bowman's capsule)** and a filtrate refinery (the **proximal tubule, loop of Henle,** and **distal tubule**).

G. The blood vessel parts of the nephron include a ball of capillaries **(glomerulus)** where blood pressure forces water and solutes out of the blood and into the tubule, and a second, looser, capillary network that surrounds the region of the loop of Henle and helps refine the filtrate.

Module 25.10 Overview: The key functions of the excretory system are filtration, reabsorption, secretion, and excretion.

A. During **filtration,** water and other small molecules are forced by blood pressure through capillary walls into the nephron tubule.

B. During **reabsorption,** water and solutes still valuable to the body are reclaimed from the filtrate.

C. During **secretion,** excess ions, drugs, and toxins are secreted from the blood into the nephron tubule.

D. Upon **excretion,** the urine passes from the kidneys to the outside, by the ureters, urinary bladder, and urethra.

Module 25.11 From blood filtrate to urine: a closer look.

A. In Figure 25.11, capillaries are not shown; red arrows represent active reabsorption, blue arrows represent active secretion, pink arrows represent passive reabsorption (osmosis), and the intensity of the blue represents solute concentration in the interstitial fluid (Figure 25.11).

B. Small molecules travel between blood and nephron filtrate through the interstitial fluid.

C. Blood pressure forces water and most solutes into the Bowman's capsule of the nephron tubule from the glomerulus.

D. NaCl and H_2O are reabsorbed from—and excess H^+ ions secreted into—the filtrate in the proximal and distal tubules. The proximal and distal tubules are also the sites of secretion of toxins such as ammonia. The proximal tubule reabsorbs water and nutrients such as glucose and amino acids. The distal tubule may also secrete drugs or their metabolites such as penicillin.

E. The loop of Henle is the principal site of water reabsorption. NaCl and urea reabsorption along the descending limb of the loop of Henle only heightens the rate at which water is reabsorbed from the filtrate. The blood removes excess water in the interstitial fluid. The ascending limb of the loop of Henle is impermeable to water, and NaCl is first passively and then actively reabsorbed, maintaining the concentration gradient encountered by the descending limb of the loop of Henle (another example of a countercurrent mechanism).
NOTE: The type of environment in which an animal lives, and thus its need to conserve water, can be approximated by looking at its loops of Henle. The longer the loops of Henle, the greater the need for water conservation, and the more arid the environment in which the animal lives.

F. This results in a high concentration of NaCl in the interstitial fluid surrounding the distal tubule and the first part of the collecting tubule. Water can then be reabsorbed from the filtrate in the upper collecting duct.

G. Until the collecting duct enters the medulla, urea tends to remain in the filtrate because the nephron is relatively impermeable to it.

H. In the medulla, the collecting duct is permeable to urea and some urea moves into the interstitial fluid. This increases the concentration of the interstitial fluid of the medulla even more, enhancing water reabsorption.

I. Much of the reabsorption of water is under the control of ADH (antidiuretic hormone). ADH is released from a control center in the brain. Excessive urine production is called diuresis and ADH counters this problem.
Preview: ADH is produced by the hypothalamus and released from the posterior pituitary (Table 26.3 and Module 26.5).
NOTE: The reason alcohol acts as a diuretic is that alcohol consumption inhibits the release of ADH.

Module 25.12 Connection: Kidney dialysis can be a lifesaver.

A. Kidney failure or impaired function can lead to death from a buildup of solutes and toxins in the blood. The most common causes of kidney failure are hypertension and diabetes (Modules 23.10 and 26.9).

B. Kidney dialysis machines function like kidneys, but receive and return blood from a person's vein. The word **dialysis** means to separate.

C. The machine removes small molecules from the blood, using selectively permeable membranes to allow only water and desired solutes to pass out with the dialyzing solution.

D. Dialysis does not cure the afflicted individual, but only prolongs life. Kidney transplant from a cadaver or live donor is the only cure, for now (discuss stem cells).

III. Homeostatic Functions of the Liver

Module 25.13 The liver is vital in homeostasis.

A. This organ can perform many different functions because its cells are capable of a wide range of metabolic activities.

B. Substances absorbed by the GI tract travel to the liver via the **hepatic portal vessel** (or hepatic portal vein) (Figure 25.13). The liver then modifies and detoxifies absorbed substances prior to their distribution to the rest of the body via the heart.

C. The liver prepares nitrogenous wastes (synthesizes urea from ammonia) for disposal by the kidneys.

D. It converts certain toxic compounds (alcohol, drugs) into inactive compounds that the kidneys will remove.
NOTE: The liver enzyme system MEOS (microsomal ethanol oxidizing system) detoxifies drugs and alcohol consumed in excess. But the risk of a drug overdose increases when drugs are consumed together with excessive alcohol.

E. The liver regulates glucose levels (maintained at about 0.1%) in the blood by interconverting glycogen and glucose.

Class Activities

1. Some fish move between saltwater and freshwater environments. Have your class consider how these fish might cope with these contrasting osmoregulatory problems.
2. Ask your class to consider what the length of the loop of Henle can tell you about the environment in which an animal lives. Perhaps you can approach this by showing your class images of kidneys.

Transparency Acetates

Figure 25.1	Mechanisms of heat exchange
Figure 25.2B	Circulatory mechanisms that conserve heat in the great white shark
Figure 25.2C	Countercurent heat exchange
Figure 25.5A	Osmoregulation in a freshwater fish, a perch
Figure 25.5B	Osmoregulation in a saltwater fish, a cod
Figure 25.8	Nitrogen-containing metabolic waste products
Figure 25.9	Anatomy of the human excretory system
Figure 25.10	Major functions of the excretory system

Figure 25.11	Reabsorption and secretion in a nephron
Figure 25.12	Kidney dialysis
Figure 25.13	The hepatic portal system

Media

See the beginning of this book for a complete description of all media available for instructors and students. Animations and videos are available in the Campbell Image Presentation Library. Media Activities and Thinking as a Scientist investigations are available on the student CD-ROM and web site.

Animations and Videos	File Name
Nephron Introduction Animation	25-11-1-NephronIntroAnim.mov
Bowman's Capsule Animation	25-11-2-BowmansCapsuleAnim.mov
Loop of Henle Animation	25-11-3-LoopOfHenleAnim.mov
Collecting Duct Animation	25-11-4-CollectingDuctAnim.mov
Effect of ADH Animation	25-11-5-EffectOfADHAnim.mov

Activities and Thinking as a Scientist	Module Number
Web/CD Thinking as a Scientist: *How Does Temperature Affect Metabolic Rate in Daphnia?*	25.2
Web/CD Activity 25A: *Structure of the Human Excretory System*	25.9
Web/CD Activity 25B: *Nephron Function*	25.11
Web/CD Activity 25C: *Control of Water Reabsorption*	25.11
Web/CD Thinking as a Scientist: *What Affects Urine Production?*	25.11