42 THE INTERNAL ENVIRONMENT

Truth in a Test Tube

Light or dark? Clear or cloudy? A lot or a little? Asking about and examining urine is an ancient art (Figure 42.1). As early as 1500 B.C., physicians in India recorded that some people were producing copious amounts of sweet-tasting urine that attracted insects. In time, the disorder was named *diabetes mellitus*, which loosely translates as "passing honey-sweet water." Doctors still diagnose it by testing for sugar in urine, although they have replaced the taste test with chemical analysis.

Today physicians routinely check the sugar level, pH, protein content, and concentration of urine. Acidic urine can signal metabolic problems. Alkaline urine can signal a bacterial infection. Too much protein dissolved in urine might mean that the kidneys are not working properly. Excretion of too many solutes may be a sign of dehydration or problems with hormones that control kidney function. Also, specialized urine tests can detect chemicals produced by cancers of the kidney, bladder, and prostate gland.

Do-it-yourself urine tests have now become popular. If a woman is hoping to become pregnant, she can use one test to keep track of the amount of LH —luteinizing hormone—in her urine. About midway through a menstrual cycle, LH triggers ovulation, the release of an egg from an ovary. Another over-the-counter urine test can reveal whether or not she is pregnant. Older women can test for declining hormone levels in urine, which is a sign that they are entering menopause.

Not everyone is in a hurry to have their urine tested. Olympic athletes can be stripped of their medals when mandatory urine tests reveal they use prohibited drugs. Major League Baseball players agreed to urine tests only after repeated allegations that certain star players had taken prohibited steroids. The National Collegiate Athletic Association (NCAA) tests urine samples from about 3,300 student athletes per year for any performance-enhancing substances as well as "street drugs."

If you use marijuana, cocaine, Ecstasy, or other kinds of drugs, urine tells the tale. After the active ingredient of marijuana enters blood, the liver converts it to another

Figure 42.1 *This page,* a seventeenth-century physician and a nurse examining a urine specimen. Urine's consistency, color, odor, and—at least in the past—taste afford clues to health problems. Urine forms inside kidneys, and it provides clues to abnormal changes in the volume and composition of blood and interstitial fluid. *Facing page,* testing for the presence of drugs in urine samples.

IMPACTS, ISSUES

compound. Kidneys filter the blood and they add this telltale compound to the newly forming urine. It can take up to ten days for all of it to be metabolized and removed from the body. Until then, urine tests can detect it.

That urine is such a remarkable indicator of health, hormonal status, and drug use is a tribute to the urinary system. Each day, a pair of fist-sized kidneys filter all of the blood in an adult human body, and they do so more than thirty times. When all goes well, kidneys get rid of excess water and excess or harmful solutes, including many metabolites, toxins, hormones, and drugs.

So far in this unit, you have considered several organ systems that work to keep cells supplied with oxygen, nutrients, water, and other substances. Turn now to the kinds that maintain the composition, volume, and even the temperature of the internal environment.

Watch the video online!

How Would You Vote?

Many companies use urine testing to screen for drug and alcohol use among prospective employees. Some people say this is an invasion of privacy. Do you think employers should be allowed to require a person to undergo urine testing before being hired? See BiologyNow for details, then vote online.

Key Concepts

MAINTAINING THE EXTRACELLULAR FLUID

Animals continually produce metabolic wastes, and they gain and lose water and solutes. Yet the overall composition and volume of a body's extracellular fluid must be kept within a range that individual cells can tolerate. In humans, as in other vertebrates, a urinary system interacts with several organ systems in this task. Section 42.1

THE HUMAN URINARY SYSTEM

The human urinary system consists of two kidneys, two ureters, a bladder, and a urethra. Inside a kidney, millions of nephrons filter water and solutes from the blood on an ongoing basis. Most of this filtrate is returned to the blood. Water and solutes not returned to the blood by way of the kidneys leave the body as urine. Section 42.2

WHAT KIDNEYS DO

Urine forms by processes of filtration, reabsorption, and secretion. Hormonal and behavioral responses to shifts in the internal environment continually adjust its concentration. The hormones ADH and aldosterone, as well as a thirst mechanism, influence whether urine becomes concentrated or dilute during any given interval. Sections 42.3–42.6

ADJUSTING THE CORE TEMPERATURE

The temperature at the core of the animal body reflects a balance between heat produced through metabolism, heat absorbed from the environment, and heat lost to the environment. Body temperature is maintained within a favorable range with controls over metabolic activity and adaptations in body form and behavior. Sections 42.7, 42.8

Links to Earlier Concepts

Vertebrates, recall, originated in water, and some moved onto land (Section 26.2). This chapter explores mechanisms that made the move possible, including protein-mediated transport and osmosis (5.4, 5.5). You will be tapping your understanding of pH and buffer systems (2.6), and of the circulatory system (38.5), especially capillary function (38.8). This chapter tracks waste products of organic metabolism (41.6) and returns to the effects of pituitary hormones and adrenal glands on the internal environment (36.3, 36.8).

Thermal homeostasis will be easier to understand if you review water's temperature-stabilizing effects (2.5), the nature of energy flow (6.1), and mitochondrial function (8.4).

42.1 Gains and Losses in Water and Solutes

LINKS TO SECTIONS 26.2, 41.6

About 425 million years ago, some lineages of animals that evolved in salty water moved into freshwater habitats and onto dry land. They were able to do so partly because they brought along salty fluid inside their body tissues, as an internal environment for individual cells.

In most animals, recall, **interstitial fluid** fills tissue spaces between cells, and a circulatory system moves **blood** to and from tissues. Together, interstitial fluid and blood are **extracellular fluid** that functions as an internal environment for body cells. It does not matter whether the animal lives on land or in the water. The composition and volume of its internal environment must be maintained within rather narrow ranges that the body's individual cells can tolerate—a state called homeostasis. Interactions among organ systems bring about this fluid homeostasis (Figure 42.2).

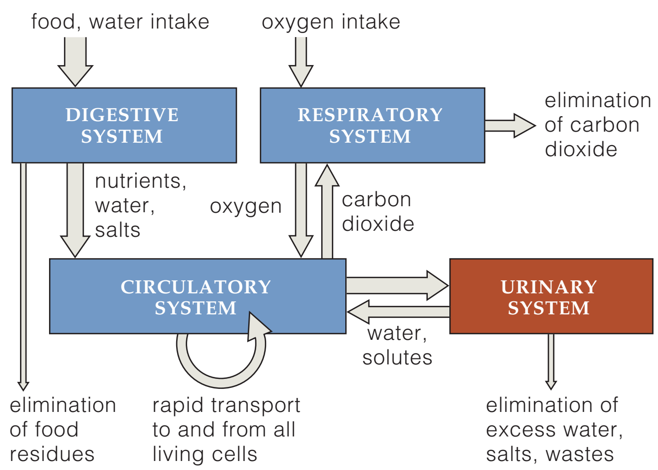


Figure 42.2 Overview of the functional links between the digestive, respiratory, circulatory, and urinary systems. Guided by the nervous and endocrine system, interactions among these systems contribute to maintaining homeostasis in the internal environment.

CHALLENGES IN WATER

Osmosis, recall, is the movement of water across some semipermeable membrane in response to differences in solute concentrations between regions (Chapter 5). In most marine invertebrates, such as crabs, interstitial fluid is like seawater in its concentrations of solutes, so little water is gained or lost by way of osmosis.

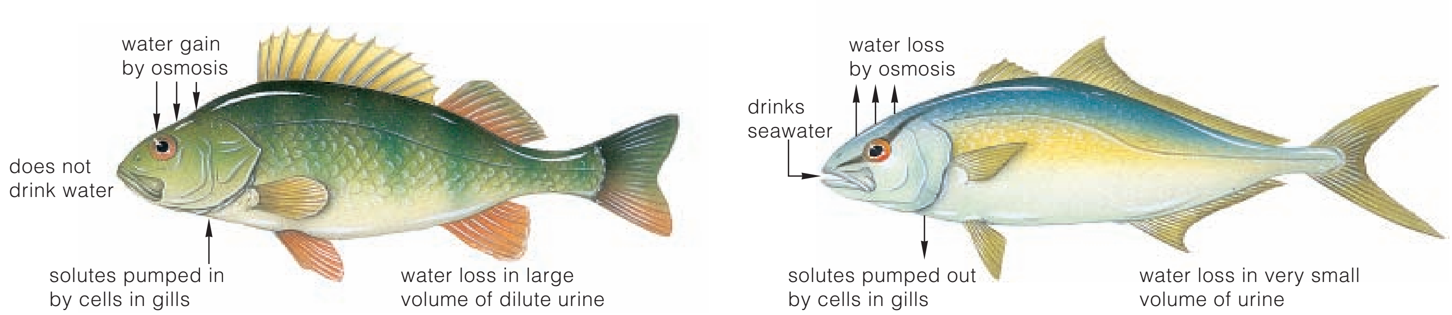
In vertebrates, body fluids are about one-third as salty as seawater. Vertebrates have a **urinary system**, a collection of interacting organs that counter shifts in the composition and volume of extracellular fluid. All have paired **kidneys** that filter blood, form urine, and help maintain the body's water–solute balance. **Urine**, a fluid excreted from the body, contains nitrogenous wastes and excess amounts of other solutes and water.

Freshwater fishes and amphibians gain water and lose solutes continually (Figure 42.3*a*). Neither kind of animal can drink water. Water moves into the internal environment by way of osmosis—by diffusing across thin respiratory surfaces and skin. Excess water leaves as dilute urine. The solute losses are balanced out by the intake of more solutes with meals and the active pumping of sodium into the cells of gills and skin at membrane transport proteins.

Compared to seawater, marine bony fishes contain less salt and continually lose water by osmosis. They gulp in seawater, and gill cells pump out any excess solutes (Figure 42.3*b*). Some of the dissolved wastes are excreted in a tiny volume of concentrated urine.

CHALLENGES ON LAND

Pioneers on land and their descendants faced intense sunlight, drying winds, more pronounced swings in temperature, water of variable salt content, and often no water at all. They kept their internal environment



a Freshwater bony fish (body fluids far saltier than surroundings)

b Marine bony fish (body fluids less salty than surroundings)

Figure 42.3 Water–solute balance in a freshwater fish (**a**) and saltwater fish (**b**).

from spinning out of control. How? *How did the land-dwelling descendants of marine animals maintain internal operating conditions and so keep their cells functioning?*

Think about how animals *gain water*. Water enters the gut in food and drink, and then is absorbed into the internal environment. It also is a product of many metabolic reactions. The volume of water that enters the gut during a given interval can be monitored and adjusted by the thirst mechanism, which we explain later in the chapter.

Unlike fishes, vertebrates on land do not *lose water* by way of osmosis. They lose it in controlled ways, mainly by **urinary excretion**. With this process, excess water and solutes exit the body as urine. Some water evaporates from respiratory surfaces, especially those in mammalian lungs. Also, mammals are the only animals that lose some water by way of sweating. In addition, very little water is still present in food residues that leave the body in feces.

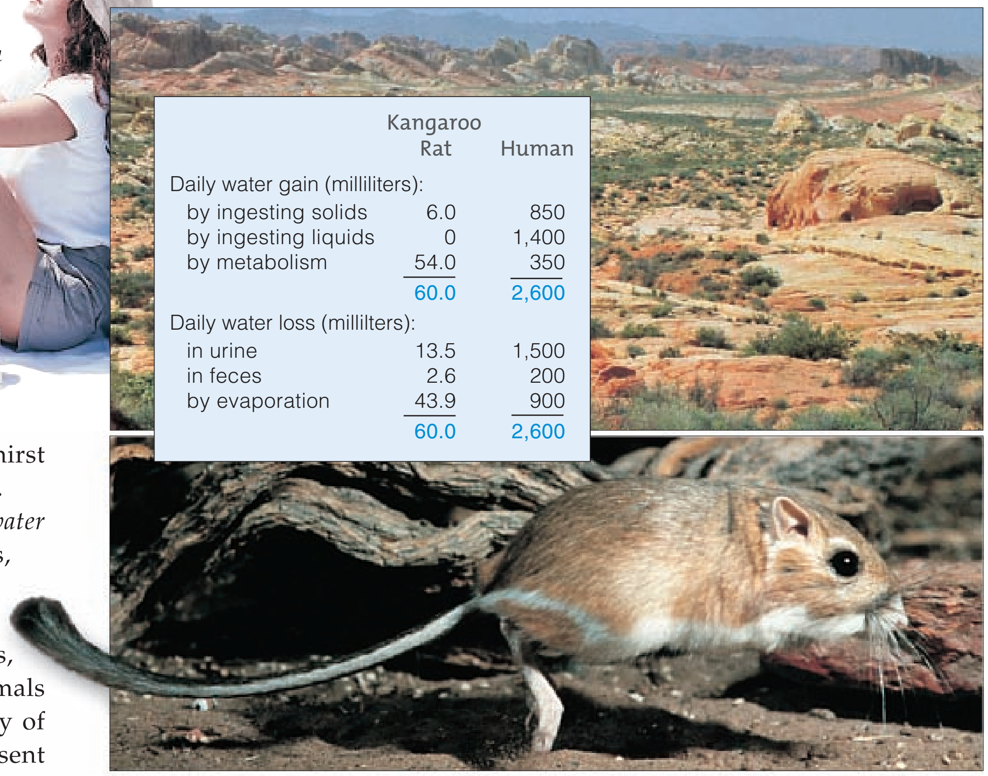
Now think about some processes that *add solutes* to extracellular fluid. Absorption of nutrients from the gut, secretions from cells, and the release of carbon dioxide wastes from aerobically respiring cells adds solutes. Air intake in the lungs adds oxygen to it.

Mammals *lose solutes* mainly in sweat, respiration, and urinary excretion. All exhale carbon dioxide, the most abundant waste material. Mammalian urine has ions and wastes that formed through metabolism. For example, toxic ammonia is formed as a by-product of protein metabolism. In the mammalian liver, ammonia is converted to **urea**, which is then excreted in urine. The distinctive yellowish color of urine comes from breakdown products of hemoglobin. In humans, other solutes that leave the body in urine are food additives, drugs, and many other synthetic chemicals.

Figure 42.4 compares the balancing act for humans and kangaroo rats. The daily gains and losses balance out in both, mainly by way of a urinary system.

In all animals in good health, daily gains in water and solutes balance the daily losses.

In all vertebrates, a urinary system counters unwanted shifts in the volume and composition of extracellular fluid. Paired kidneys filter blood, form urine, and help maintain solute levels within tolerable limits.



	Kangaroo Rat	Human
Daily water gain (milliliters):		
by ingesting solids	6.0	850
by ingesting liquids	0	1,400
by metabolism	54.0	350
	60.0	2,600
Daily water loss (millilters):		
in urine	13.5	1,500
in feces	2.6	200
by evaporation	43.9	900
	60.0	2,600

Figure 42.4 How a kangaroo rat gains and loses water, compared with humans. As in other animals, losses normally balance any gains in excess of the volume required to maintain the internal environment.

In a New Mexico desert, free water is scarce, except during a brief rainy season. A kangaroo rat waits out the heat of the day in a burrow, then forages at night for dry seeds and bits of plants. This tiny mammal hops rapidly and far, searching for seeds and fleeing from predators.

Hopping uses ATP energy and water, which seeds replace. Metabolic reactions release usable energy and water from carbohydrates and other compounds in seeds. Each day, "metabolic water" makes up a whopping 90 percent of a kangaroo rat's total water intake. Metabolic water is only about 12 percent of a human's total intake.

A kangaroo rat conserves and recycles water when it rests in its cool burrow. It moistens and warms air that it inhales. When it exhales, water condenses in its cooler nose, and some diffuses back into the body. When seeds are emptied from the kangaroo rat's cheek pouches, they soak up water dripping from the nose. The kangaroo rat reclaims water when it eats dripped-on seeds.

A kangaroo rat has no sweat glands and its feces hold only half the water that human feces do, relative to body size. It loses water when urinating, but its two specialized kidneys do not let it lose much. A kangaroo rat's kidneys excrete urine that is as much as three to five times more concentrated than yours.

42.2 Structure of the Urinary System

LINKS TO SECTIONS 38.5, 38.6

In the urinary system of humans and other mammals, kidneys filter water, mineral ions, organic wastes, and other substances from the blood flowing through them. They adjust the composition of this filtrate and return all but about 1 percent or so to the blood. The unreclaimed water, solutes, and wastes become urine.

COMPONENTS OF THE SYSTEM

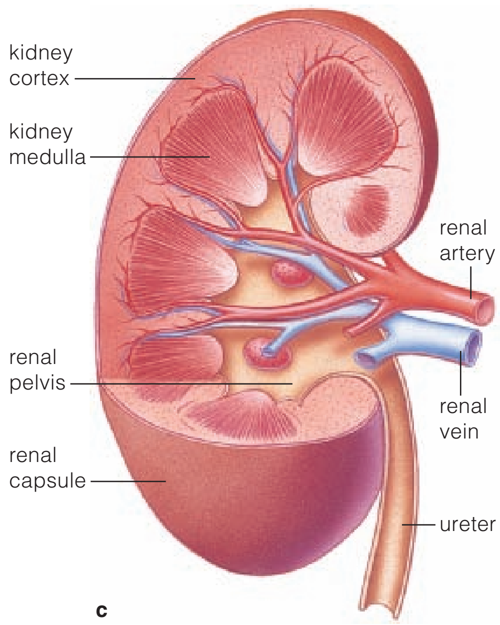
Again, a urinary system rids the body of metabolic wastes and adjusts water and solute concentrations in extracellular fluid. Drink too little water, gulp down salty potato chips, lose too much sodium in sweat, and the kidneys adjust how much water and salt the body excretes or saves. The human urinary system consists of two kidneys, two ureters, a urinary bladder, and a urethra. The kidneys are a pair of bean-shaped organs about the size of a typical adult fist. They are located between the peritoneal lining and abdominal cavity wall, where they flank the backbone (Figure 42.5*a*,*b*).

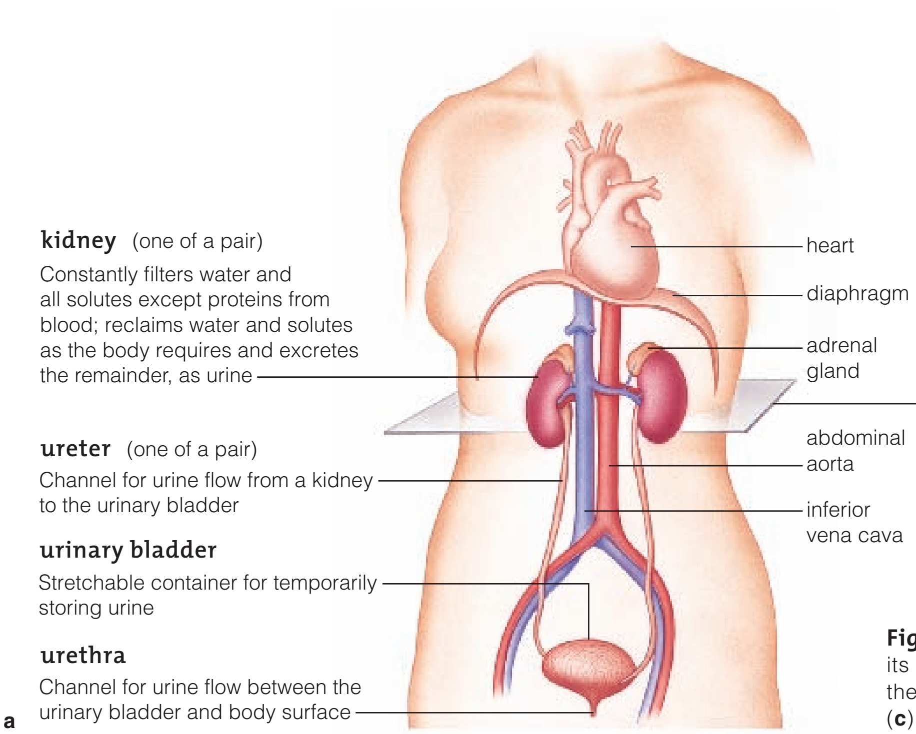
A thin but strong layer of dense connective tissue encapsulates each kidney (Figure 42.5*c*). Beneath this capsule is an outer tissue zone, the *kidney cortex*. The cortex is continuous with the *kidney medulla*, an inner zone with pyramid-shaped lobes of tissue. The lobes appear striated because each has a profusion of long tubes that extend down to a chamber, the renal pelvis.

Blood reaches each kidney by way of a renal artery, then flows through arterioles, capillaries, and venules in the cortex and medulla. The venules connect with a renal vein, which leads out of the kidney.

Urine forms in the kidneys, then enters one of two ureters that connect with a muscular sac: the urinary bladder. Stretch receptors inside the bladder wall are stimulated when urine expands and fills the sac. In a reflex response, smooth muscle in the wall contracts and forces urine into the urethra, a muscular tube that opens on to the body surface. An adult male's urethra is about 0.2 meter (8 inches) long and extends to the surface of the tip of the penis. The urethra of an adult female is less than 0.05 meter (2 inches) long.

After age two or three, urination can be voluntarily controlled by neural signals that act on a sphincter of skeletal muscle at the start of the urethra.





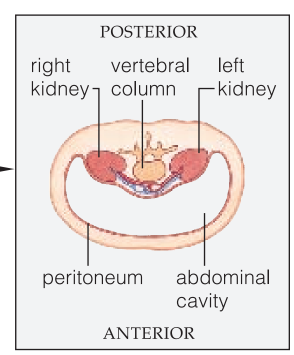
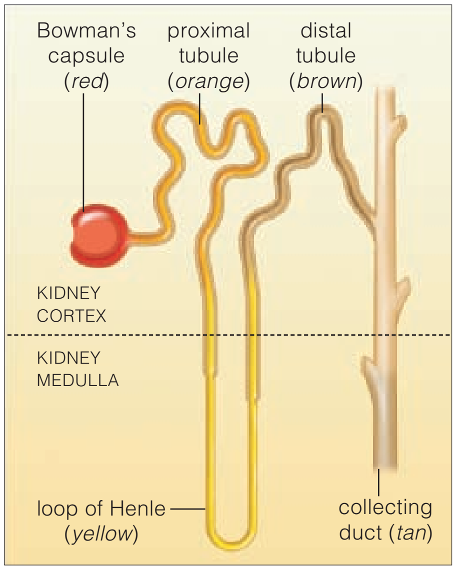


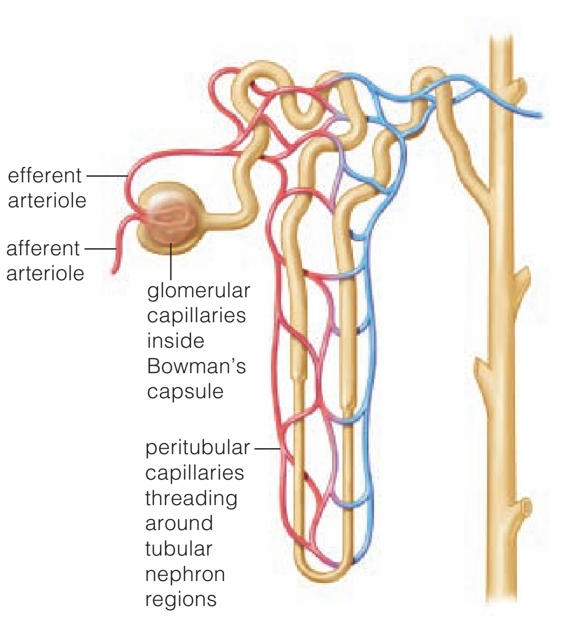
Figure 42.5 *Animated!* (**a**) Human urinary system and its functions. (**b**) Its paired kidneys are located in between the abdominal cavity's wall and its lining, the peritoneum. (**c**) Structural organization of a human kidney.

Figure 42.6 ***Animated!*** (**a**) Diagram of a nephron. Through their interactions with two sets of blood capillaries, nephrons are the kidney's functional units.

(**b**) The arterioles and blood capillaries associated with each nephron. Large gaps in the cell wall of the glomerular capillaries make the capillaries a hundred times more permeable than any others in the body. Only a thin basement membrane separates each capillary wall from cells of the inner layer of Bowman's capsule, which cloak the wall. Cells of this inner layer have long extensions that interdigitate with one another, like interlaced fingers. Fluid flows through the narrow slits between them.



a Bowman's capsule and tubular regions of one nephron, cutaway view.



b Blood vessels associated with the nephron.

THE NEPHRON

Each kidney contains more than a million **nephrons**, microscopically small functional units that are only one cell thick all along their length. A nephron starts in the kidney cortex, where its wall balloons outward like a cup (Figure 42.6*a*). The nephron continues in the cortex as a twisting, convoluted tube. It straightens as it descends into the kidney medulla, then ascends into the cortex. There, another convoluted region connects with a collecting duct. As many as eight nephrons may empty into the same duct, which extends through the kidney medulla and opens onto the renal pelvis.

Now build on this simple picture of the nephron's structure. At its cup-shaped entrance, called *Bowman's capsule,* the thin nephron wall doubles back on itself and encloses the walls of highly porous blood vessels clustered inside. These are the **glomerular capillaries** (Figure 42.6*b*). Bowman's capsule and the glomerular capillaries interact as a blood-filtering unit. The unit is known as a renal corpuscle.

Bowman's capsule collects fluid that is forced out, under pressure, from the glomerular capillaries. This fluid enters the *proximal* convoluted tubule. "Proximal" simply means it is the region closest to the start of the nephron. The next tubular region, the *loop of Henle*, plunges into the medulla, makes a hairpin turn, and ascends out of it. The *distal* tubule is the convoluted part most distant from the entrance to the nephron.

Inside the kidneys, the renal artery branches into *afferent* arterioles, one for each nephron, that delivers blood to glomerular capillaries. The capillaries rejoin and form an *efferent* arteriole, which carries away the blood that did not get filtered into Bowman's capsule. This arteriole quickly branches to form **peritubular capillaries** that thread all around the nephron (*peri–*, around). The peritubular capillaries rejoin as venules, which join the renal vein leading out of the kidney.

Urine forms continually by three processes that exchange water and solutes between all of the nephrons, glomerular capillaries, and peritubular capillaries. The processes are called glomerular filtration, tubular reabsorption, and tubular secretion. Remember, each human kidney has more than 1 million nephrons. Each minute, nephrons of both kidneys filter close to 125 milliliters of fluid from blood flowing past, which amounts to 180 liters (about 47.5 gallons) per day. This means that, for an average-sized adult, the two kidneys filter the entire volume of blood plasma 65 times each day!

The human urinary system has two kidneys, two ureters, and a urinary bladder. The kidneys filter water and solutes from blood. The body reclaims most of the filtrate. The rest flows as urine through ureters into a bladder that stores it. Urine is excreted to the body surface through a urethra.

Millions of nephrons, and two sets of blood capillaries that interact with each one, are the functional units of human kidneys. They form urine by three processes: glomerular filtration, tubular reabsorption, and tubular secretion.

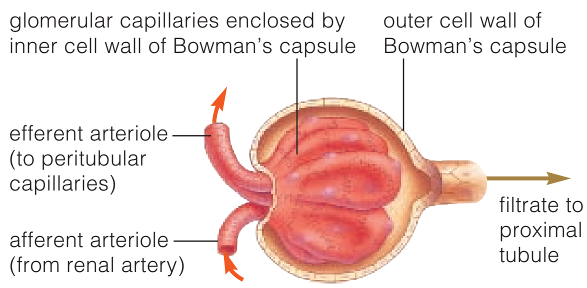
42.3 Urine Formation

LINKS TO SECTIONS 5.3–5.6, 38.8, 40.3, 41.5

Blood pressure drives water and solutes from blood into the nephron. Transport proteins and variations in permeability along the nephron's tubular parts affect which components of the filtrate return to blood or leave in urine. Figure 42.7 introduces the text's step-by-step account of how the urine forms by glomerular filtration, tubular reabsorption, and tubular secretion.

GLOMERULAR FILTRATION

Blood pressure generated by the beating heart drives **glomerular filtration**, the first step of urine formation. In the glomerular capillaries inside Bowman's capsule of each nephron, the pressure forces out 20 percent of the volume of plasma. Collectively, the cell wall of the glomerular capillaries, the inner cell wall of Bowman's capsule, and the basement membrane between them are like a sieve. They do not let blood cells, platelets, or plasma proteins leave blood. They nonselectively let everything else—water, ions, glucose, amino acids, diverse toxins, and so forth—become the filtrate:



a **Filtration**. Water and solutes forced out across glomerular capillary wall collect in Bowman's capsule, which drains into the proximal tubule.

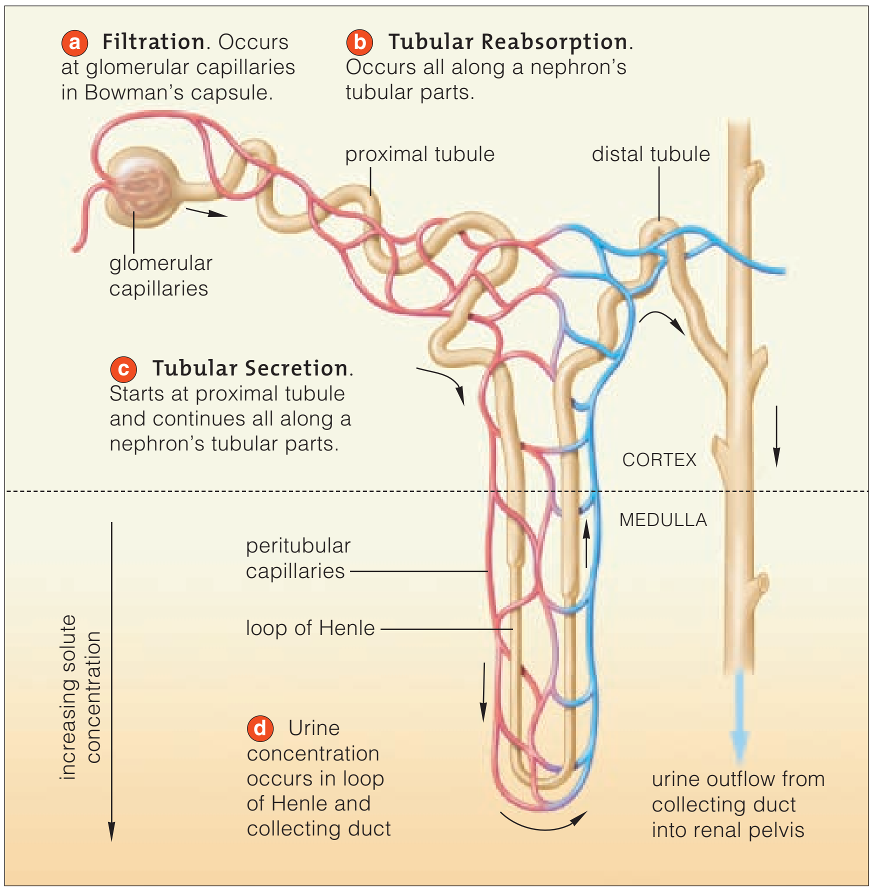


Figure 42.7 ***Animated!*** A nephron and associated blood capillaries. Solutes entering and leaving the nephron's tubular parts create a solute concentration gradient in interstitial fluid. The highest concentration is deep in the medulla.

(**a**) Glomerular filtration nonselectively moves water, ions, and solutes from blood into Bowman's capsule. (**b**) Most of the filtrate leaks or is transported out of the nephron's tubular parts into interstitial fluid, then is selectively reabsorbed into blood. (**c**) Secretion moves other solutes from blood into interstitial fluid, then into tubular parts of the nephron. (**d**) Urine becomes most concentrated as water moves by osmosis out of the loop of Henle and the collecting duct.

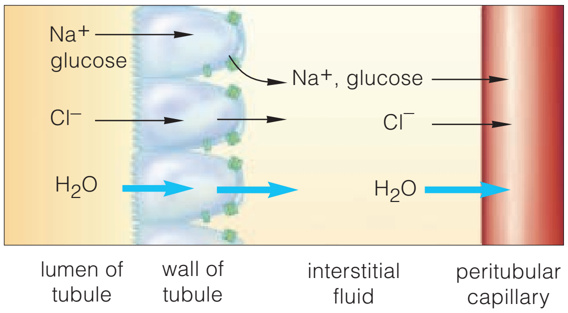
The volume of blood that kidneys must handle at any time is adjusted at afferent arterioles that deliver blood to the nephron. When intense exercise or stress makes blood pressure rise along the systemic circuit, these arterioles vasodilate in response to signals from sympathetic neurons. When the body rests and blood pressure decreases, the arterioles vasoconstrict. If too much fluid enters the body, then a reflex pathway will override the sympathetic signals. These blood vessels will vasodilate, and excess fluid will leave in urine.

The heart pumps out five liters or so of blood each minute. Between 20 and 25 percent goes right to the kidneys, which cleanse the blood even while helping to maintain homeostasis in the internal environment.

TUBULAR REABSORPTION

Only a fraction of the water and solutes making up the filtrate actually leaves the body. Instead, the nephron —especially the proximal tubule—gives back most of the filtrate, in the amounts required to maintain the volume and composition of the internal environment. By **tubular reabsorption**, a variety of substances leak or get pumped out of the nephron, diffuse through interstitial fluid, and then enter a peritubular capillary (Figure 42.7*c*). The process returns close to 99 percent of the filtrate's water, 100 percent of the glucose and amino acids, all but about 0.5 percent of the sodium ions (Na^+), and 50 percent of the urea to blood.

Cotransporters span the plasma membrane of cells making up the nephron's tubular wall. They resemble those cotransporters of cells in the lining of the small intestine (Section 41.5). Example: Passive transporters help Na^+ and glucose diffuse out of the filtrate, into tubule cells. Sodium–potassium pumps on the other free surface of the tubule cells actively transport Na^+ into interstitial fluid. Their pumping action sets up an electrochemical gradient. That gradient attracts more Na^+, Cl^-, and other negatively charged ions out of the filtrate, across the tubule wall, and on into interstitial fluid. One result is a solute concentration gradient, so water now moves into the cytoplasm of tubule cells and then into interstitial fluid by way of osmosis:

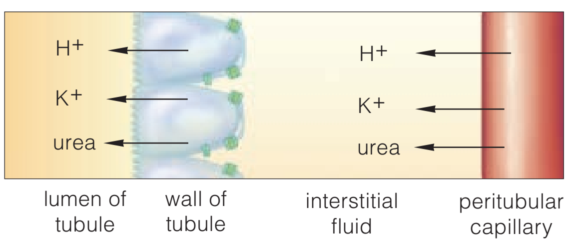


b **Tubular Reabsorption**. As filtrate flows through the proximal tubule, ions and some nutrients are actively and passively transported outward, into interstitial fluid. Water follows, by osmosis. Cells making up peritubular capillaries transport them into blood. Water again follows by osmosis.

The tubule wall and the capillary wall each have a certain number of transporters that can bind a specific substance, such as glucose or amino acids. When all of the transporters get saturated, some percentage of the substance is not reabsorbed and is excreted in urine.

TUBULAR SECRETION

Metabolism generates many ions, mainly H^+ and K^+. Together with urea and other wastes, these ions end up in blood. With **tubular secretion**, transporters in the wall of peritubular capillaries move the ions into interstitial fluid. Then transporters in the tubular wall of nephrons move them from interstitial fluid into the filtrate, so that they may now be excreted in urine:



c **Tubular Secretion**. Transporters move H^+, K^+, urea, and wastes out of peritubular capillaries. Transporters in tubular nephron regions move them into the filtrate.

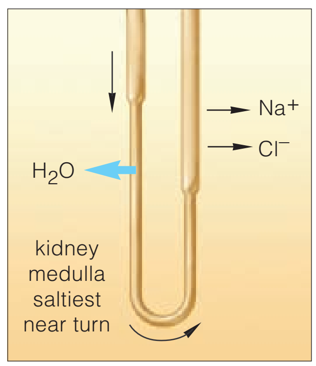
As you will read shortly, secretion of H^+ is essential to maintaining the body's acid–base balance.

CONCENTRATING THE URINE

Sip soda all day and your urine will be dilute; sleep eight hours and it will be concentrated. However, even the most dilute urine still has far more solutes than plasma or most of the body's interstitial fluid. It gets that way by a concentrating mechanism in kidneys.

Inside the kidney cortex, the filtrate is isotonic with interstitial fluid, so there is no net movement of water from one to the other. Interstitial fluid is hypertonic in the kidney medulla. It draws water out of the filtrate, by osmosis, along the loop of Henle's descending limb. The filtrate becomes most concentrated and attracts the most water near the loop's hairpin turn (Figure 42.7*d*). It actually becomes more and more concentrated just before the turn until it is as salty as interstitial fluid.

However, the loop of Henle's wall *after* the turn is impermeable to water. Transporters in the ascending limb actively pump out Na^+ and Cl^-, which makes interstitial fluid in the medulla even saltier—which draws out even more water before the hairpin turn:



d Solutes in interstitial fluid are the most concentrated deep in the kidney medulla. The gradient draws more and more water from the *descending* limb of the loop of Henle by osmosis. But Na^+, Cl^-, urea, and other solutes cannot cross the descending limb wall, so the filtrate becomes more concentrated as it approaches the loop of Henle's hairpin turn.

Transporters in the thick-walled *ascending* limb actively pump Na^+ out of the filtrate. Cl^- follows passively. Interstitial fluid gets saltier and attracts *more* water out of the descending limb and the collecting duct.

Remember countercurrent flow in fish gills? Here we see another countercurrent mechanism: Transporters are altering the composition of filtrate that is flowing in opposite directions inside the loop of Henle.

During glomerular filtration, blood pressure generated by heartbeats drives water and solutes into nephrons.

With tubular reabsorption, membrane transporters set up a Na^+ gradient that draws water, other ions, and selected solutes out of the filtrate and into peritubular capillaries.

By tubular secretion, transporters move urea, H^+, and K^+ from the capillaries into the nephron for excretion.

Mechanisms built into the loop of Henle concentrate urine.

42.4 Behavioral and Hormonal Adjustments

LINKS TO SECTIONS 35.1, 36.3, 36.7, 38.7

Changes in what you eat and drink, the temperature and humidity, and levels in activity affect water and solute gains and losses. Hormonal and behavioral mechanisms adjust the sense of thirst, and the concentration of urine, in response.

A THIRST MECHANISM

When you do not drink enough on a hot day, you get thirsty. Why? The solute concentration in blood has risen, which slows saliva secretion into the mouth. A drier mouth stimulates nerve endings that signal the **thirst center**, which is a region of the hypothalamus. The center also receives signals from osmoreceptors that detect the rise in the blood level of sodium inside the brain (Section 35.1). In response, the thirst center notifies other centers in the cerebral cortex, which in turn compel you to search for and drink fluid.

While thirst mechanisms are calling for the uptake of water, hormonal controls act to conserve the water already inside the body. As explained next, ADH and aldosterone act on cells in the walls of distal tubules and collecting ducts (Section 36.3 and Figure 42.8).

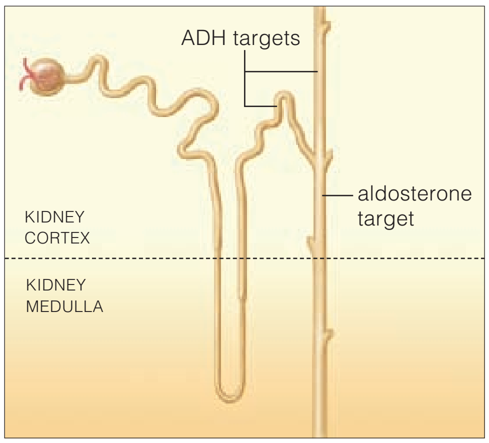


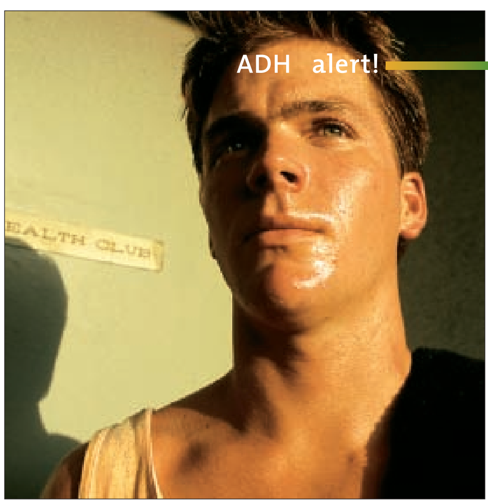
Figure 42.8 Sites of hormone action. ADH targets cells of distal tubules and parts of collecting ducts in the kidney cortex. Aldosterone targets distal tubule cells. Both hormones affect reabsorption. Directly or indirectly, they help the body conserve more water.

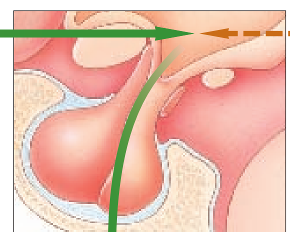
EFFECT OF ADH

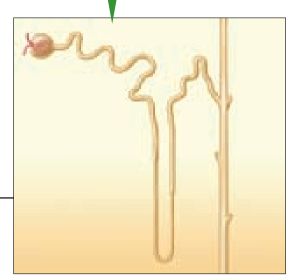
As another response to the osmoreceptor signals, the hypothalamus stimulates the pituitary gland to secrete antidiuretic hormone or **ADH**. After ADH binds with receptors on cells of distal tubules and collecting ducts, both tubes become more permeable. Water moves out of them, and peritubular capillaries reabsorb more of it, so less water departs in urine (Figure 42.9). In time, the volume of extracellular fluid rises and its solute levels decline, so ADH secretion slows.

Nausea and vomiting also trigger ADH secretion. So does a big drop in blood pressure; baroreceptors in the wall of some arteries can detect it (Section 38.7).

ADH works through **aquaporins** in target cells to step up water reabsorption. These passive transporters selectively allow water to diffuse across the plasma membrane. When ADH binds to membrane receptors on the cells of nephron and collecting duct walls, it stimulates cytoplasmic vesicles to move to the plasma







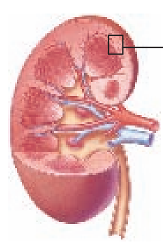


Figure 42.9 Feedback control of ADH secretion, one of the negative feedback loops from kidneys to the brain that helps adjust the volume of extracellular fluid. Nephrons in the kidneys reabsorb more water when we do not take in enough water or lose too much, as by profuse sweating.

membrane. The vesicles contain aquaporin subunits. As they reach and fuse with the plasma membrane, the subunits self-assemble into pores for water across tube walls. There they facilitate the rapid diffusion of water out of the filtrate, back into interstitial fluid.

EFFECT OF ALDOSTERONE

Any decrease in the volume of extracellular fluid also activates cells in the efferent arteriole that brings blood to the nephron. These cells release renin, an enzyme that sets in motion a chain of reactions. The outcome is that the adrenal gland above each kidney secretes **aldosterone**. This hormone stimulates production of sodium–potassium pumps and their insertion into the plasma membrane of cells in the collecting duct wall. As they pump more sodium out of the collecting ducts, water follows, by osmosis, into interstitial fluid. At the same time, they assist the diffusion of potassium into the ducts, and so urine becomes more concentrated.

ABNORMALITIES IN HORMONAL CONTROL

A metabolic disorder known as *diabetes insipidus* arises when the pituitary gland secretes too little ADH, when ADH receptors do not respond to ADH, or when the aquaporin proteins are modified or missing. The main symptom is the formation of large volumes of highly dilute urine (Section 36.7). Typically, insatiable thirst accompanies copious urine production.

Certain cancers, infections, and drugs, including some antidepressants, stimulate ADH oversecretion. With an excess of ADH, the kidneys retain too much water. With more water, solute concentrations in the interstitial fluid decrease. Water begins to move by osmosis from the interstitial fluid into body cells, which are now relatively hyperosmotic. At the same time, solutes move out of body cells into this fluid. This is bad news, especially for brain cells, which are highly sensitive to solute concentrations. Unless solute balances are restored, the outcome can be deadly.

Adrenal gland tumors may cause oversecretion of aldosterone, or *hyperaldosteronism*. This in turn causes fluid retention and high blood pressure. Kidney, liver, or heart problems also can raise the aldosterone level, sometimes with similar consequences.

ADH promotes water conservation at distal tubules and collecting ducts. Aldosterone promotes reabsorption of sodium, which indirectly increases water retention.

42.5 Acid–Base Balance

Besides maintaining the volume and composition of extracellular fluid, kidneys help keep it from getting too acidic or too basic (alkaline).

LINK TO SECTION 2.6

Hydrogen ions continuously enter extracellular fluid following amino acid breakdown, protein breakdown, lactate fermentation, and other metabolic processes. Even so, certain controls keep the H^+ concentration in extracellular fluid within a tight range—a state called an **acid–base balance**. Buffer systems, respiration, and urinary excretion contribute to the balancing act.

A **buffer system**, recall, involves substances that reversibly bind and release H^+ or OH^- ions, thereby minimizing pH changes as acidic or basic molecules enter or leave a solution (Section 2.6).

In humans, extracellular pH is maintained between 7.35 and 7.45. Any excess acids dissociate into H^+ and other fragments, and pH falls. The effect is minimized when excess hydrogen ions react with buffers, most notably the bicarbonate–carbonic acid buffer system:

$$H^+ + \underset{\text{BICARBONATE}}{HCO_3^-} \rightleftharpoons \underset{\text{CARBONIC ACID}}{H_2CO_3} \rightleftharpoons CO_2 + H_2O$$

When the pH of blood shifts, adjustments in the rate and magnitude of breathing offset that change. When the blood pH decreases, breathing quickens and CO_2 is expelled faster than it forms. As you can tell from the equation above, less CO_2 means less carbonic acid can form, so the pH rises. Slower breathing lets CO_2 accumulate, so more carbonic acid can form.

Control of bicarbonate reabsorption and secretion of H^+ can adjust the pH inside kidneys. Reabsorbed bicarbonate moves into peritubular capillaries, where it can buffer excess acid. H^+ secreted into tubule cells combines with phosphate or ammonia ions. In either form, it can be disposed of in the urine.

The importance of this balancing act becomes clear when *metabolic acidosis* develops. This condition arises if kidneys cannot excrete enough of the H^+ released during metabolism. It can be life threatening.

The kidneys, buffering systems, and the respiratory system interact to neutralize acids. They tightly control the acid–base balance of extracellular fluid, so that it is neither too acidic nor too basic (alkaline) for cell functions.

By reversible reactions, a bicarbonate–carbon dioxide buffer system neutralizes excess H^+. Shifts in the rate and depth of breathing affect this buffer system, hence the pH of blood.

The kidneys also can shift the pH of blood when they adjust bicarbonate reabsorption and H^+ secretion.

42.6 When Kidneys Break Down

LINKS TO SECTIONS 16.8, 36.7, 38.9, 41.8

At this point, you probably have figured out that good health depends on nephron function. Whether by illness or accident, when nephrons of both kidneys are damaged and no longer performing their regulatory and excretory functions, ***renal failure*** *follows. It can be irreversible.*

Causes of Renal Failure In the United States, most kidney problems are outcomes of *diabetes mellitus*, and *high blood pressure* accounts for many more cases. As you read in Sections 36.7 and 38.9, these chronic disorders can damage blood vessels, including capillaries that interact with nephrons. Some people are genetically predisposed to infections or conditions that damage kidneys. Kidneys also fail after lead, arsenic, pesticides, or other toxins enter the body. On rare occasions, repeated high doses of aspirin and some other drugs damage them beyond repair.

High-protein diets force the kidneys to work overtime to dispose of nitrogen-rich breakdown products (Section 41.8). Such diets also increase the risk for *kidney stones*. These hardened deposits form when uric acid, calcium, and other wastes settle out of urine and collect in the renal pelvis.

Figure 42.10 What kidney trouble? Karole Hurtley has attitude as well as energy. At thirteen, she was the national champion for her age group and karate belt level. She also lives with renal failure.

Karole gets regular checkups from a home dialysis nurse for Denver's Children's Hospital. Her dad jokes that Karole takes so many pills that she rattles when she walks and is pricked "a gazillion times a year" for blood tests.

Eight or nine times a night, while Karole sleeps, a peritoneal dialysis machine beside her bed pumps a special solution into her torso and filters out waste products that her kidneys no longer can remove. She still embraces an active life-style. Inspirational attitude? You bet.

Most kidney stones are washed away in urine, but one can become lodged in a ureter or the urethra and cause severe pain. Any stone that blocks urine flow invites infections and permanent kidney damage.

We usually measure kidney function in terms of the rate of filtration through the glomerular capillaries. Renal failure occurs when the filtration rate falls by half, regardless of whether it is caused by low blood flow to the kidneys or by damaged tubules or blood vessels. Renal failure can be fatal. Wastes build up in the blood and interstitial fluid. The pH rises. The resulting changes in the concentrations of other ions, most notably Na^+ and K^+, interfere with metabolism.

Kidney Dialysis At one time or another, about 13 million people in the United States have experienced renal failure. A kidney dialysis machine is used to restore proper solute balances. Like kidneys, it selectively adjusts solutes in blood. "Dialysis" simply refers to exchanges of solutes across any artificial membrane between two different solutions.

With *hemodialysis*, the machine is connected to a vein or an artery. It pumps blood through semipermeable tubes submerged in a warm solution of salts, glucose, and other substances. As blood flows through the tubes, the wastes dissolved in it diffuse out, so that solute concentrations are returned to normal levels. Cleansed, solute-balanced blood is allowed to flow back into the patient's body.

With *peritoneal dialysis*, a fluid of a specific composition is pumped into a patient's abdominal cavity. It exchanges solutes with extracellular fluid, and then it is drained out. In this case the peritoneum, the lining of the abdominal cavity, functions as the membrane for dialysis.

Kidney dialysis is able to keep a person alive through an episode of temporary kidney failure. When the kidney damage is permanent, dialysis must be continued for the rest of a person's life or until a kidney becomes available for transplant surgery (Figure 42.10).

Regarding Kidney Transplants Each year in the United States, about 12,000 people are the recipients of *kidney transplants*. More than 40,000 others remain on the waiting list because there is a shortage of suitable donors. Most transplanted kidneys are made available from people who agreed to donate them after their death. Increasingly, more are becoming available from living donors, most often from a relative, spouse, or friend. A transplant from a living donor stands a better chance of success than one from a deceased person. A single kidney is adequate to maintain good health, so risks to a living donor are mainly related to the surgery—unless the donor's remaining kidney fails.

The benefits of organs from living donors, a lack of donated organs, and high dialysis costs have led some to suggest that people should be allowed to sell a kidney. Critics argue that it is unethical to tempt people to risk their health for money. Section 16.8 describes another potential alternative—*xenotransplantation*. Some day, genetically modified pigs may become organ factories.

42.7 Heat Gains and Losses

We turn now to another major aspect of homeostasis. How does the body maintain the core of its internal environment within a tolerable temperature range when the surroundings become too hot or cold?

HOW THE CORE TEMPERATURE CAN CHANGE

The core temperature of an animal body rises when heat from the surroundings or metabolism builds up. When warm, a body loses heat to cool surroundings. The core temperature stabilizes when the rate of heat loss balances the rate of heat gain and production. The heat content of any complex animal depends on a balancing act between gains and losses:

change in body heat = heat produced + heat gained − heat lost

Heat is gained and lost through exchanges at the body surfaces. Radiation, conduction, convection, and evaporation are processes that drive these exchanges.

Thermal radiation is the emission of heat from any object in the form of radiant energy. Radiant energy from the sun can heat animals. Also, a metabolically active animal itself produces and radiates heat.

By **conduction**, heat is transferred between objects in direct contact with each other. An animal loses heat when it rests on objects cooler than it is. If it contacts objects that are warmer, the animal will gain heat.

By **convection**, moving air or water transfers heat. Conduction plays a part; heat moves down a thermal gradient between the body and air or water next to it. Mass transfer also plays a part. The heated air is less dense, and so it moves away from the body.

By **evaporation**, a liquid converts to gaseous form and heat is lost in the process. Evaporation from body surfaces cools the body; water molecules carry energy away with them. Evaporative heat loss rises with dry air and breeze. High humidity and still air slow it.

ENDOTHERM? ECTOTHERM? HETEROTHERM?

Fishes, amphibians, and reptiles are warmed mostly by heat gained from the environment rather than by metabolically generated heat. These animals are called **ectotherms**, which means "heated from outside." They can only adjust behaviorally to rising or falling outside temperatures. Most species have low metabolic rates and not much insulation. A rattlesnake (Figure 42.11*a*) is one example. When its body is cold, it basks in the sun. When hot, the snake moves into shade.

Most birds and mammals are **endotherms**, which means "heat from within." They have relatively high metabolic rates. Compared to, say, a foraging lizard of the same weight, a foraging mouse uses thirty times *more* energy. Metabolic heat helps endotherms remain active across a wider range of temperatures. Fur, fat, or feathers function as insulating layers and minimize heat transfers (Figure 42.11*b*).

Some birds and mammals are **heterotherms**. They can maintain a fairly constant core temperature some of the time but let it shift at other times. For example, hummingbirds have very high metabolic rates when foraging for nectar during the day. At night, metabolic activity decreases so much that the bird's body may become almost as cool as the surroundings.

Warm climates favor the ectotherms, which do not have to spend as much energy as endotherms do on maintaining the core temperature. In tropical regions, reptiles have the advantage, because they can spend more energy on reproduction and other tasks. There they exceed mammals in numbers and diversity. In all cool or cold regions, however, most vertebrates tend to be endotherms. As one example, you will not find reptiles running around in the arctic.

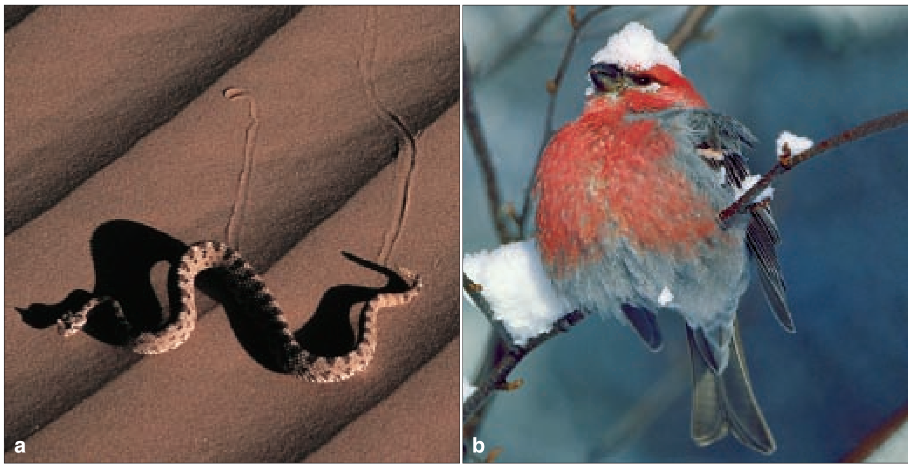


Figure 42.11 (**a**) Sidewinder, an ectotherm. (**b**) Pine grosbeak, an endotherm, using fluffed feathers as insulation against winter cold.

LINKS TO SECTIONS 2.5, 6.1

The core temperature of the internal environment is being maintained when heat losses balance heat gains. Ectotherms gain heat mainly from the outside, endotherms generate most from within. Heterotherms do both at different times.

Animals gain and lose heat by way of thermal radiation, conduction, convection, and evaporation. Different kinds make distinct morphological, physiological, and behavioral adjustments to changes in environmental temperatures.

42.8 Temperature Regulation in Mammals

LINKS TO SECTIONS 2.5, 8.4, 28.3, 35.2, 39.3

Section 28.3 introduced the negative feedback controls that govern increases in human body temperature. Now compare the controls that generally come into play when mammals are subjected to heat stress and cold stress.

The hypothalamus, again, contains centers that help control the core temperature of the mammalian body. These hypothalamic centers receive input from many thermoreceptors inside skin and from others deep in the body (Figure 35.2). When the temperature deviates from a set point, the centers integrate the responses of skeletal muscles, smooth muscle of arterioles in the skin, and sweat glands. Negative feedback loops back to the hypothalamus inhibit the responses when the core temperature returns to the set point. Dromedary camels can recalibrate the set point so that it is *higher* during the hottest time of day (Figure 42.12).

RESPONSES TO HEAT STRESS

When any mammal becomes too hot, the temperature control centers in the hypothalamus issue commands for **peripheral vasodilation**: the diameter of the blood vessels in skin increases. More blood flows to the skin and delivers more metabolic heat that can be given up to the surroundings (Table 42.1).

Another response to heat stress, **evaporative heat loss**, occurs at moist respiratory surfaces and across skin. Animals that sweat lose some water this way. For instance, humans and some other mammals have sweat glands that release water and solutes through pores at the skin's surface. Remember Section 33.6? An average-sized adult human has 2–1/2 million or more sweat glands. For every liter of sweat produced, about 600 kilocalories of heat energy leave the body by way of evaporative heat loss.

Sweat dripping from skin dissipates little heat. The body cools greatly when sweat evaporates. On humid days, the air's high water content slows evaporation rates, so sweating is less effective at cooling the body. When you exercise strenuously, sweating helps offset heat production by skeletal muscles.

With the exception of marine species, nearly all mammals (and only mammals) can sweat. Many rely more on behavioral responses, such as licking fur or panting. "Panting" refers to shallow, rapid breathing. It assists evaporative water loss from the respiratory tract, nasal cavity, mouth, and tongue (Figure 40.22).

Sometimes peripheral blood flow and evaporative heat loss cannot counter heat stress, and *hyperthermia* follows. Core temperature rises above normal. As you read earlier in Chapter 28, a human body temperature above 105°F (41.5°C) can be dangerous.

What about a fever? Recall, from Section 39.3, that **fever** is not itself an illness. It is one of the responses to infection. When activated by a threat, macrophages release signaling molecules that stimulate part of the brain to secrete prostaglandins. These local signaling molecules cause the hypothalamus to allow the core temperature to rise a bit above the normal set point. The rise makes the body less hospitable for invaders and calls up more immune responses. Generally, the hypothalamus does not let the core temperature rise above 105°F. When a fever exceeds that point or when it lasts more than a few days, the condition causing it is life threatening and medical evaluation is essential.

RESPONSES TO COLD STRESS

Selectively distributing blood flow, fluffing hair, and shivering are all mammalian responses to cold stress. Birds make similar responses but maintain a higher

Figure 42.12 Short-term adaptation to desert heat stress. Dromedary camels are heterotherms; they let the core temperature rise by as much as 14 degrees during the hottest hours of the day, then let it fall at night. A hypothalamic mechanism raises the internal thermostat, so to speak, and doing so has no adverse effects.

Table 42.1 Mammalian Responses to Core Temperature Shifts

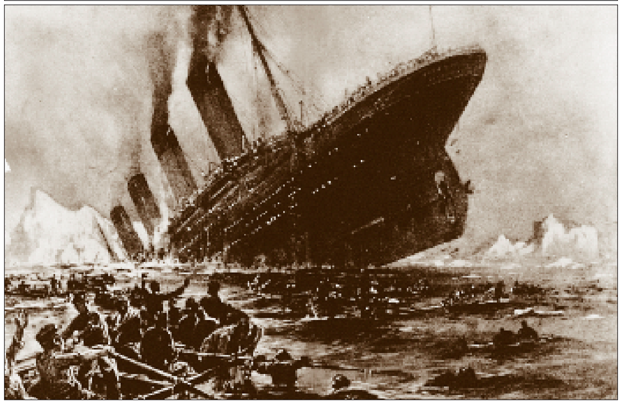
Stimulus	Main Responses	Outcome
Heat stress	Widespread vasodilation in skin; behavioral adjustments; in some species, sweating, panting	Dissipation of heat from body
	Decreased muscle action	Heat production decreases
Cold stress	Widespread vasoconstriction in skin; behavioral adjustments (e.g., minimizing surface parts exposed)	Conservation of body heat
	Increased muscle action; shivering; nonshivering heat production	Heat production increases

Figure 42.13 Two responses to cold stress.

(**a**) Polar bears (*Ursus maritimus*, "bear of the sea"). A polar bear stays active even during severe arctic winters. It does not get too chilled after swimming because the coarse, hollow guard hairs of its coat shed water quickly. Thick, soft underhair traps heat. Brown adipose tissue, about 11.5 centimeters (4–1/2 inches) thick, insulates and helps generate metabolic heat.

(**b**) In 1912, the *Titanic* collided with an immense iceberg on her maiden voyage. It took about 2–1/2 hours for the *Titanic* to sink and rescue ships arrived in less than two hours. Even so, 1,517 bodies were recovered from the calm sea. All of the dead had on life jackets; none had drowned. Hypothermia killed them.

a



b

Table 42.2 Mammalian Physiological Responses to Increases in Cold Stress

Core Body Temperature	Physiological Responses
36°–34°C (about 95°F)	Shivering response; rise in respiration, metabolic heat output. Peripheral vasoconstriction, more blood deeper in body. Dizziness, nausea set in.
33°–32°C (about 91°F)	Shivering response ends. Metabolic heat output declines.
31°–30°C (about 86°F)	Capacity for voluntary motion is lost. Eye and tendon reflexes inhibited. Consciousness is lost. Cardiac muscle action becomes irregular.
26°–24°C (about 77°F)	Ventricular fibrillation sets in (Section 38.9). Death follows.

body temperature. Peripheral thermoreceptors detect cool outside temperatures and alert the hypothalamus, which signals smooth muscle in arterioles that service the skin to contract. Such a response to cold stress is called **peripheral vasoconstriction**. When arterioles in skin constrict, less metabolic heat reaches the body surfaces. When your fingers or toes are chilled, all but 1 percent of the blood that would usually flow to skin is diverted to other regions of the body.

Also, muscle contractions make hairs (or feathers) "stand up." This **pilomotor response** creates a layer of still air next to skin. It helps reduce convective and radiative heat loss. Forms of behavior also reduce heat loss from exposed surfaces, as when polar bear cubs cuddle against their mother (Figure 42.13*a*).

With prolonged cold exposure, the hypothalamus commands skeletal muscles to contract ten to twenty times each second. Although this **shivering response** increases heat production, it has a high energy cost.

Long-term or severe cold exposure also leads to a hormonal response—an increase in thyroid activity that raises the rate of metabolism. This **nonshivering heat production** mainly targets cells of *brown* adipose tissue, which has a large number of mitochondria. In this tissue, the main function of aerobic respiration is to generate heat; producing ATP is secondary.

Animals that hibernate or are active in cold regions, as well as the young of many others, contain brown adipose tissue. In human infants, this tissue accounts for about 5 percent of body weight. Unless exposure to cold is ongoing, the tissue shrinks as we age. Some Japanese and Korean commercial divers who harvest shellfish in frigid waters retain brown adipose tissue. Male Finlanders who work outside through the year also have a bit of it.

Failure to protect against cold leads to *hypothermia*, a condition in which core temperature plummets. In humans, a decline to 95°F changes brain function and causes confusion. Severe hypothermia can spiral into coma and death (Figure 42.13*b* and Table 42.2).

Temperature shifts are detected by thermoreceptors that send signals to an integrating center in the hypothalamus.

This center serves as the body's thermostat and calls for adjustments that maintain core temperature.

Mammals counter cold stress by vasoconstriction in skin, behavioral adjustments, increased muscle activity, and shivering and nonshivering heat production.

Mammals counter heat stress by widespread peripheral vasodilation in skin and evaporative water loss.

http://biology.brookscole.com/starr11

Summary

Section 42.1 Blood and interstitial fluid make up the extracellular fluid. Maintaining the volume and solute concentration of extracellular fluid is a vital aspect of homeostasis. All organisms must balance solute and fluid gains with solute and fluid losses. In vertebrates, that balancing act is the main function of the kidneys and other components of a urinary system.

Mammals gain water by absorption from the gut and metabolism. They lose it by urinary excretion, evaporation from body surfaces, and in exhalations and in feces. They gain solutes by absorption from the gut, secretion, respiration, and metabolism. Solutes are lost in urine and feces, and by respiration and sweating.

Section 42.2 The human urinary system consists of a pair of kidneys, a pair of ureters, a urinary bladder, and the urethra. The renal artery delivers blood into kidneys, where it branches into efferent arterioles.

Tubular structures called nephrons, and certain blood capillaries that interact with them, are the functional units that cleanse the blood and form urine.

A nephron starts in the kidney cortex at Bowman's capsule. It continues as a proximal convoluted tubule, a loop of Henle that descends into and ascends out of the kidney medulla, and a distal convoluted tubule that empties into a collecting duct. All collecting ducts drain into the renal pelvis.

Bowman's capsule and the set of highly permeable glomerular capillaries within it are a blood-filtering unit, called a renal corpuscle. Most of the filtrate that enters Bowman's capsule is reabsorbed along the nephron's tubular regions and is returned to blood by way of peritubular capillaries that thread around the nephron. The portion of the filtrate that is not returned is excreted from the urethra, as urine.

BiologyNow

Explore the anatomy of the human urinary system and kidneys with the animation on BiologyNow.

Section 42.3 Urine forms in nephrons by three processes: filtration, reabsorption, and secretion.

Filtration. Blood pressure drives water and small solutes (not proteins) out of the highly leaky glomerular capillaries and into Bowman's capsule, the entrance to tubular parts of the nephron.

Reabsorption. Water and solutes to be conserved move out of the tubular parts, then into peritubular capillaries. The tubules retain a small volume of water and solutes.

Secretion Urea, H^+, and some other solutes move out of peritubular capillaries and into the nephron for excretion, in urine.

BiologyNow

Learn about the processes that form urine with the animation on BiologyNow.

Section 42.4 Sensory receptors that detect high solute concentrations in the internal environment or a low blood volume signal a hypothalamic thirst center. Signals from the hypothalamus stimulate water-seeking behavior and call for secretion of the hormone ADH. ADH and aldosterone are two hormones that affect reabsorption in the kidneys.

ADH is secreted by the pituitary gland and promotes water reabsorption across the walls of the proximal tubule and collecting ducts, so urine becomes more concentrated. Aldosterone is secreted by the adrenal cortex and promotes sodium reabsorption into the distal tubule. Because water follows sodium, the action of this hormone indirectly causes water to be conserved.

Section 42.5 The urinary system, buffer systems, and the respiratory system all contribute to maintaining the body's acid–base balance. The urinary system can excrete H^+ in the urine and reabsorb bicarbonate.

Section 42.6 When kidneys fail, frequent dialysis or a kidney transplant is required to sustain life.

BiologyNow

Read the InfoTrac article "The Kidney Swap: Adventures in Saving Lives," Denise Grady and Anahad O'Connor, The New York Times, *October 2004.*

Section 42.7 Animals produce metabolic heat. To maintain a core temperature, heat gains (by metabolism and from the surrounding environment) must balance heat losses to the environment.

For ectotherms, the core temperature depends more on heat exchange with the environment than on metabolic heat. These animals can regulate their core temperature mainly by modifications in their behavior.

For endotherms (most birds and mammals), a high metabolic rate is the primary source of heat. Their core temperature is governed largely by controls over the production and loss of metabolic heat.

For heterotherms, the core temperature is tightly controlled some of the time and allowed to fluctuate with environmental temperatures at other times.

Section 42.8 In mammals, the hypothalamus is the main integrating center for the control of temperature. It receives signals from thermoreceptors and stimulates responses in smooth muscle in arterioles, sweat glands, and other effectors. The core temperature is maintained by behavioral, metabolic, and physiological responses.

Self-Quiz

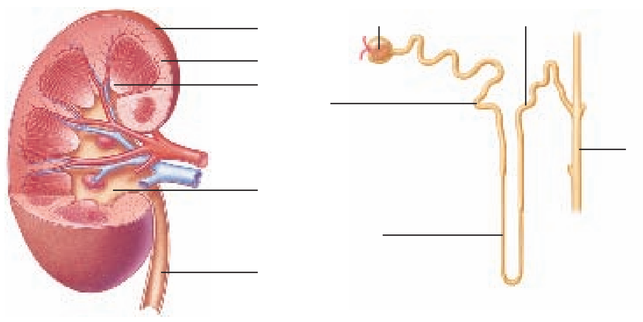
Answers in Appendix II

1. A freshwater fish gains most of its water by ______ .
   a. drinking c. osmosis
   b. eating food d. transport across the gills

2. Bowman's capsule, the start of the tubular part of a nephron, is located in the ______ .
   a. kidney cortex c. renal pelvis
   b. kidney medulla d. renal artery

3. Fluid filtered into Bowman's capsule flows directly into the ______ .
   a. renal artery c. distal tubule
   b. proximal tubule d. loop of Henle

4. Label the structures in the following diagrams and name their functions:



5. Water and small solutes from blood enter nephrons during ______ .
   a. filtration
   b. tubular reabsorption
   c. tubular secretion
   d. both a and c

6. Kidneys return most of the water and small solutes back to blood by way of ______ .
   a. filtration
   b. tubular reabsorption
   c. tubular secretion
   d. both a and b

7. ADH binds to receptors on distal tubules and collecting ducts making them ______ permeable to ______ .
   a. more; water
   b. less; water
   c. more; sodium
   d. less; sodium

8. Increased sodium reabsorption at distal tubules ______.
   a. will make the urine more concentrated
   b. will make the urine more dilute
   c. is caused by insertion of aquaporins
   d. both a and c

9. Match each structure with a function.

____ ureter	a. start of nephron
____ Bowman's capsule	b. delivers urine to body surface
____ urethra	c. carries urine from kidney to bladder
____ collecting duct	d. secretes ADH
____ pituitary gland	e. target of aldosterone

10. The main control center for maintaining the temperature of the mammalian body is in the ______ .
   a. anterior pituitary
   b. kidney cortex
   c. adrenal cortex
   d. hypothalamus

11. Negative feedback loops that maintain a mammal's core temperature involve ______ .
   a. the hypothalamus
   b. receptors in skin
   c. receptors in deep tissue
   d. all of the above

12. Is this statement true or false: Thirst behavior is initiated and controlled exclusively by a thirst center in the hypothalamus.

13. Match each term with the most suitable description.

____ endotherm	a. environment dictates core temperature
____ ectotherm	b. metabolism dictates core temperature
____ convection	c. heat transfer between objects that are in direct contact
____ conduction	d. water, air current transfers heat
____ thermal radiation	e. emission of radiant energy

Additional questions are available on **Biology Now™**

Critical Thinking

1. Protein breakdown produces toxic ammonia. In all mammals, ammonia is converted to urea, which can only be eliminated when dissolved in water in urine. Birds and reptiles convert it to uric acid, a solid that can be excreted when mixed with a small amount of water. It takes twenty to thirty times more water to excrete 1 gram of urea than it does to excrete 1 gram of uric acid. Formulate a hypothesis regarding how this difference might relate to the species richness of birds, mammals, and reptiles in different environments. Devise a way to test your hypothesis.

2. The kangaroo rat kidney efficiently excretes a tiny volume of urine (Section 42.1). Compared to a human nephron, its nephrons have a loop of Henle that is proportionally much longer. Explain how this helps the kangaroo rat conserve water.

3. Drinking too much water can be a bad thing (Figure 42.14). As marathoners or other endurance athletes sweat heavily and drink lots of water, their sodium levels drop. The resulting *water intoxication* can be fatal. Why is the sodium balance so important?

4. Two-thirds of the water and solutes that the body reclaims by tubular reabsorption are reclaimed in the proximal tubule region of nephrons. Proximal tubule cells have great numbers of mitochondria and demand a great deal of oxygen. Explain why.

5. Licorice (*Glycyrrhiza*) is used as a remedy in Chinese traditional medicine and also is a flavoring for candy. When licorice is eaten, one of its components triggers the formation of a compound that mimics aldosterone and binds to receptors for it. Based on this information, explain why people who have high blood pressure are advised to avoid eating much licorice.

6. Animals that live in cold habitats continually lose heat to their environment. Ectotherms are few and endotherms often show morphological adaptations to cold. Compared to closely related species that live in warmer areas, cold dwellers tend to have smaller appendages. For example, relative to its body size, the arctic hare has ears that are far shorter than those of hares that live in more temperate zones. Also, animals adapted to cool climates tend to be larger than related species that evolved in warmer places. For example, the largest bear species is the polar bear and the largest penguin is Antarctica's emperor penguin.

Think about heat transfers between animals and their habitat, then explain why smaller appendages and larger overall body size are advantageous in very cold climates.

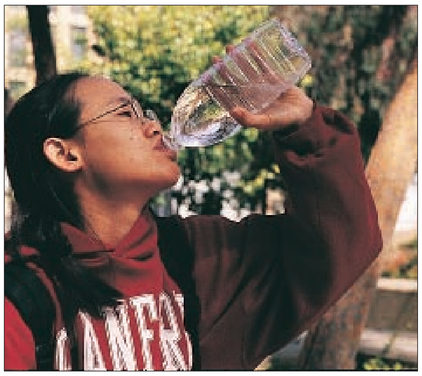


Figure 42.14 Excessive water intake during an endurance event—not a good idea.