

# CHAPTER 9

# Excretion and the Interaction of Systems

## Chapter Concepts

### 9.1 The Structures and Function of the Excretory System

- Each kidney receives blood that is processed to form urine, which drains through a ureter and into the urinary bladder for excretion.
- Each kidney contains over one million nephrons that process blood to form urine.

### 9.2 Urine Formation in the Nephron

- The functional unit of the kidney is the nephron.
- Each nephron filters blood, reabsorbs substances such as sodium and glucose for reuse in the body, and secretes excess or toxic substances such as urea to produce urine.

### 9.3 Excretory System Health

- Antidiuretic hormone (ADH) regulates the amount of water reabsorbed in the distal tubule.
- Aldosterone regulates the amount of salt that is reabsorbed or secreted.
- The acid-base balance of the blood is adjusted by the secretion of hydrogen ions and reabsorption of bicarbonate ions.
- Various technologies are used to solve problems involving dysfunctions and disorders of the excretory system.



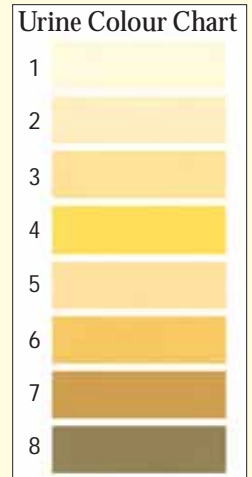
**T**oday, people commonly produce urine samples for chemical analysis to assess the health of the kidneys and organs of other body systems. This practice is far from modern, however. The first recorded evidence that people examined urine as a clue to the health of the body's internal environment appeared over two thousand years ago in Greece. It is likely, however, that keen observers from other cultures examined this liquid much earlier. This painting from the 1600s shows a physician examining a flask of urine from a woman who was experiencing swollen tissues. (This condition, known then as dropsy, is now referred to as edema.) The flask holding the urine, called a matula, was the symbol for the medical profession from the 1200s to the 1600s. This ancient practice of urine inspection has been replaced, improved, and quantified by the modern science of urology.



## Launch Lab

### Dehydration and Urine Colour

Athletes whose sweat loss exceeds fluid intake may become dehydrated during activity. Even slight dehydration (a 1–2 percent loss in body weight) has a negative effect. A doctor of sports medicine, L.E. Armstrong, devised a standardized reference chart for urine colour. Athletes can use this chart to determine their hydration. People who are well-hydrated produce urine that is “very pale yellow”, “pale yellow”, or “straw coloured.”



#### Materials

- 3 test tubes of simulated urine sample
- urine colour rating chart
- unlined white paper
- protective goggles and gloves

Validated in: Urinary Indices of Hydration Status, *Int. J. Sport Nutrition* 4: 265–279, 1994; Urinary Indices of Dehydration, Exercise and Rehydration, *Int. J. Sport Nutrition*, 8: 345–355, 1998; and Drinking behavior and perception of thirst in untrained women during heat Acclimation and outdoor training, *Int. J. Sport Nutr. & Exerc. Metab.* 13: 15–28, 2003. © Lawrence E. Armstrong, 2000; Human Kinetics Publishers

#### Procedure

1. Draw a data chart in your notebook similar to the one shown below.

Simulated Urine Sample	Match to Colour Chart	Interpretation
1		
2		
3		

2. Gather the materials listed.
3. Hold each sample in front of the unlined, white paper.
4. Match the sample to the Urine Colour Chart.

#### Analysis

1. Based on your observations, infer which sample(s) would indicate a person who is well-hydrated. Which sample indicates a person who is poorly hydrated? Which is the control?
2. Why would it be important for athletes to be able to assess their hydration during a game or practice?



Physicians consulted wheels such as this, which related colour, odour, taste, and other characteristics of urine with different ailments.

# Overview of the Excretory System

## Section Outcomes

- In this section, you will
- **identify** the main structures and functions of the human excretory system
  - **explain** the function of the nephron
  - **dissect** a mammalian kidney and **observe** its structure

## Key Terms

excretory system  
excretion  
kidneys  
ureters  
urinary bladder  
urethra  
nephrons  
renal arteries  
glomerulus  
Bowman's capsule  
filtrate  
collecting duct  
renal veins

## BiologyFile

### FYI

Bladder size varies with different people, but a typical bladder usually holds a maximum of 600 mL of urine. By the time the bladder is about half-full, sensory receptors in the walls of the bladder send impulses to the spinal cord, which signals muscles in the innermost sphincter of the bladder to contract. Most people can suppress the urge to urinate for a short time by contracting the other sphincter.

In the functioning human organism, cells are provided with nutrients and oxygen by the activities of the digestive and respiratory systems. The circulatory system ensures that each of the trillions of cells in the body receives the substances it needs for metabolic activities. These activities—energy release, maintenance, and repair—result in waste products that change the balance of volume of water and the concentration and composition of dissolved substances in the body's fluids. The basic function of the **excretory system** is to regulate the volume and composition of body fluids by removing wastes and returning needed substances to the body for reuse.

## The Problem of Wastes

Imagine how your classroom would look if it were not cleaned each day and if the garbage can were left unemptied. Wastes—materials that are useless and unnecessary for normal functioning of your classroom—would build up over a period of time. Eventually, the environment of your classroom would become quite unhealthy.

The buildup of wastes in the human body has similar effects. In metabolic terms, a waste is any substance that is produced by the body and is present in excess of the body's needs. Examples of such wastes include carbon dioxide, water, ions such as those of sodium ( $\text{Na}^+$ ), chloride ( $\text{Cl}^-$ ), and hydrogen ( $\text{H}^+$ ), and compounds that result from the breakdown of proteins and nucleic acids. Any waste can pose a threat to health if it is allowed to accumulate. Some wastes, however, pose a greater immediate threat than others. This is especially true of nitrogenous (nitrogen-containing) wastes such as ammonia, urea, and uric acid. Ammonia is highly toxic but is quickly converted to the less toxic compound, urea, in the liver. Urea makes up the majority of nitrogenous

waste in the body, and about half of it is eliminated in urine. Uric acid is present in much lower concentrations; it also passes out of the body in urine.

## The Solution to Wastes: Excretion

**Excretion** is the process of separating wastes from the body fluids and eliminating them. Several body systems perform this function. The respiratory system excretes carbon dioxide and small amounts of other gases, including water vapour. The skin excretes water, salts, and some urea in perspiration. The digestive system excretes water, salts, lipids, and a variety of pigments and other cellular chemicals. (Note that the elimination of food residue—feces—is *not* considered to be a process of excretion.) Most metabolic wastes, however, are dissolved or suspended in solution and are excreted by the excretory (also called the urinary) system.

- 1 What is the basic function of the excretory system?
- 2 Identify four examples of metabolic wastes produced in the human body.
- 3 Why is it necessary for wastes to be removed from the body?

## The Organs of the Excretory System

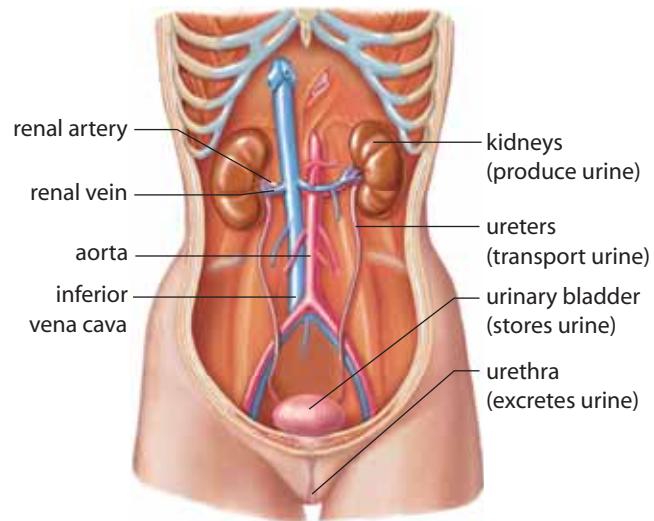
As shown in Figure 9.1, humans have two fist-sized **kidneys**, which are located in the area of the lower back on each side of the spine. If you stand up and put your hands on your hips with your thumbs meeting over your spine, your kidneys lie just above your thumbs. A large cushion of fat usually surrounds the kidneys. This fat layer, along with the lower portion of the ribcage, offers some protection for



these vital organs. Although most people have two kidneys, humans are capable of functioning with only one. If one kidney ceases to work or if a single kidney is removed due to disease or because it is being donated to someone in need of a kidney, the single kidney increases in size to handle the increased workload.

The kidneys release urine into two muscular, 28-cm-long tubes called **ureters**. From the ureters, urine is moved by the peristaltic actions of smooth muscle tissue to the muscular **urinary bladder** where it is temporarily stored. Drainage from the bladder is controlled by two rings of muscles called sphincters. Both sphincters must relax before urine can drain from the bladder. The innermost sphincter is involuntarily controlled by the brain. During childhood we learn to voluntarily control relaxation of the other sphincter.

Urine exits the bladder and the body through a tube called the **urethra**. In males, the urethra is approximately 20 cm long and merges with the vas deferens of the reproductive tract to form a single passageway to the external environment. In females, the urethra is about 4 cm long and the reproductive and urinary tracts have separate openings.

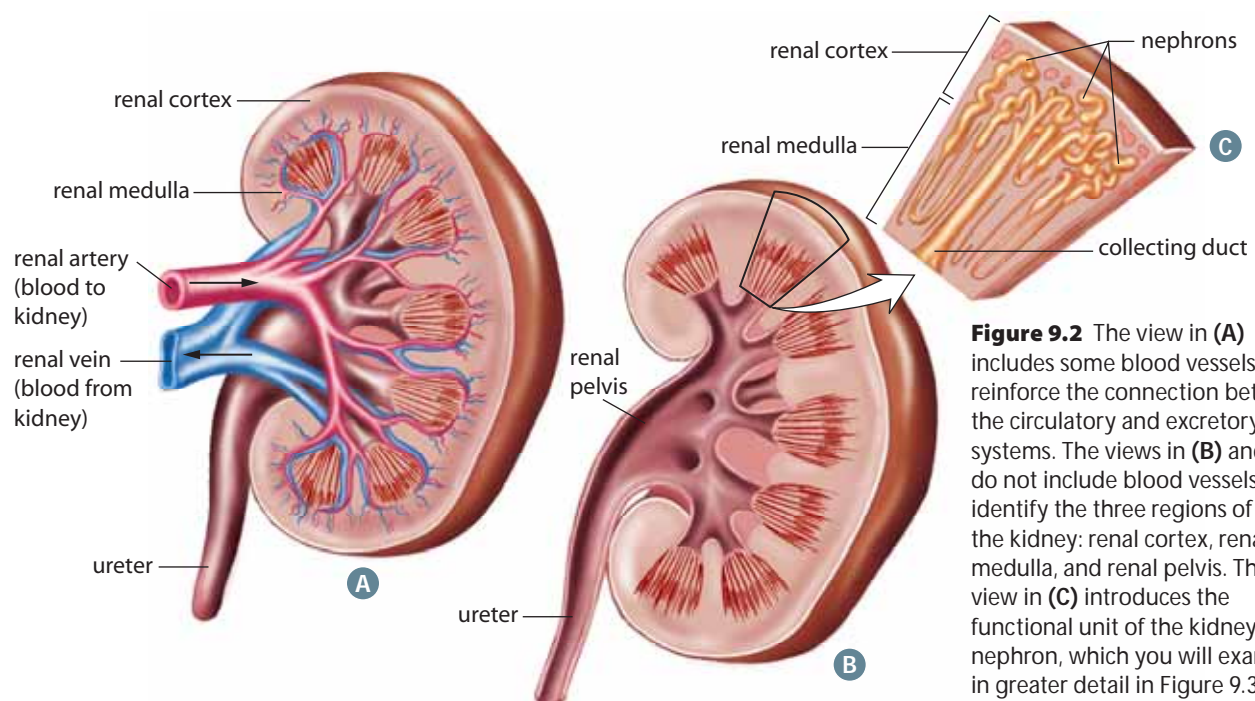


**Figure 9.1** The organs of the excretory system are two kidneys, two ureters, the urinary bladder, and the urethra. Some vessels of the circulatory system also are shown in this illustration. (The word “renal”, which appears in two of the labels, comes from the Latin word for kidney.) Although these vessels are not part of the excretory system, they are intimately connected with it. Why might that be?

- 4 List the structures of the human excretory system.
- 5 Through which of these structures does urine leave the body?

## The Kidneys: The Body’s Blood-Cleaners

Within each kidney, the mouth of its ureter flares open to form a funnel-like structure called the renal pelvis. The renal pelvis has cup-like extensions that receive urine from the renal tissue. As shown in Figure 9.2, this tissue is divided



**Figure 9.2** The view in (A) includes some blood vessels to reinforce the connection between the circulatory and excretory systems. The views in (B) and (C) do not include blood vessels, and identify the three regions of the kidney: renal cortex, renal medulla, and renal pelvis. The view in (C) introduces the functional unit of the kidney, the nephron, which you will examine in greater detail in Figure 9.3.

## BiologyFile

### FYI

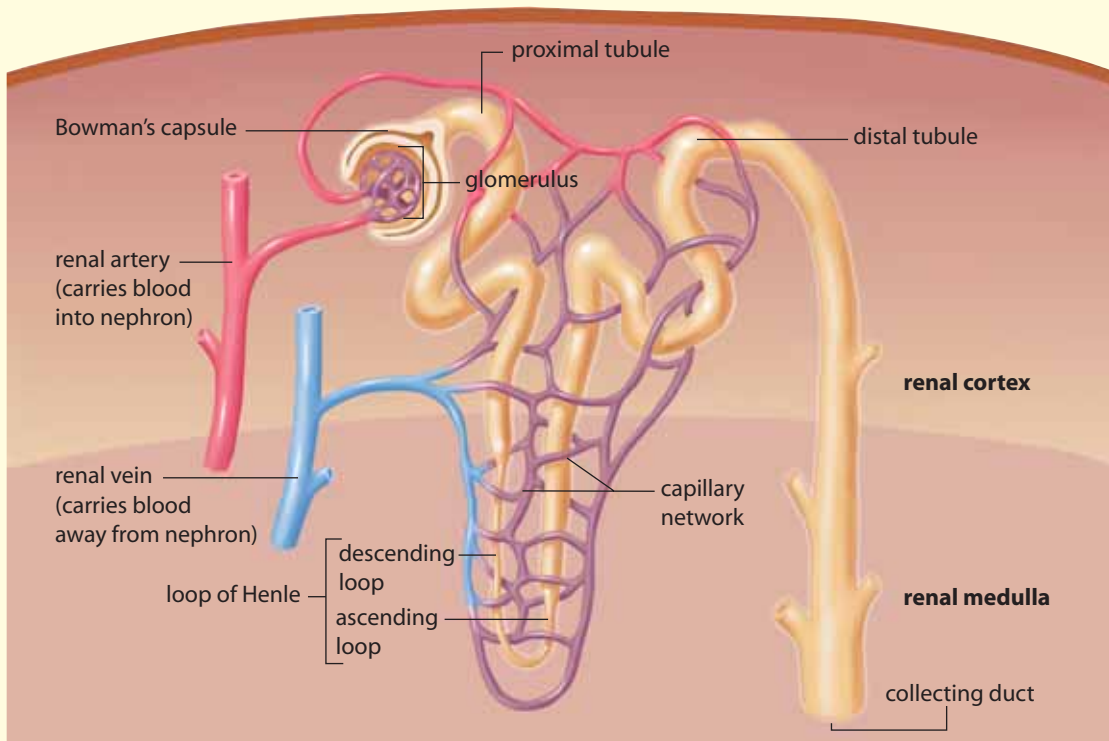
An average nephron would measure approximately 0.5 cm if it were stretched lengthwise.

into two sections: an outer renal cortex and an inner renal medulla.

Embedded within the renal cortex and extending into the renal medulla are over one million microscopic structures called **nephrons**. Closely associated with these nephrons is a network of blood

vessels. The nephrons are responsible for filtering various substances from blood, transforming it into urine. To perform this function, each nephron is organized into three main regions: a filter, a tube, and a duct. These are outlined in the box below and highlighted in Figure 9.3.

### An Overview of the Nephron and its Three Functional Regions



**Figure 9.3** The structures of the nephron are labelled here to help outline the processes by which blood becomes urine in the nephron. The word “proximal” (in proximal tubule) means *nearby* and refers to the fact that this part of the tubule is located *near* the Bowman’s capsule. The word “distal” (in distal tubule) means *distant* and refers to the fact that this part of the tubule is located more *distantly* from the Bowman’s capsule.

1. **A Filter:** The filtration structure at the top of each nephron is a cap-like formation called the **Bowman’s capsule**. Within each capsule, a **renal artery** enters and splits into a fine network of capillaries called a **glomerulus** (pronounced “glow-MEER-you-lus”; the term means “little ball” in Latin). The walls of the glomerulus act as a filtration device. They are impermeable to proteins, other large molecules, and red blood cells, so these remain within the blood. Water, small molecules, ions, and urea—the main waste products of metabolism—pass through the walls and proceed further into the nephron. The filtered fluid that proceeds from the glomerulus into the Bowman’s capsule of the nephron is referred to as **filtrate**.
2. **A Tubule:** The Bowman’s capsule is connected to a small, long, narrow tubule that is twisted back on itself to form a loop. This long, hairpin loop is a reabsorption device. The tubule has three sections: the proximal tubule, the

loop of Henle, and the distal tubule. Like the small intestine, this tubule absorbs substances that are useful to the body, such as glucose and a variety of ions, from the filtrate passing through it. Unlike the small intestine, this tubule also secretes substances into the tissues surrounding it. (You will find out more about these twin processes of reabsorption and secretion in section 9.2.)

3. **A Duct:** The tubule empties into a larger pipe-like channel called a **collecting duct**. The collecting duct functions as a water-conservation device, reclaiming water from the filtrate passing through it so that very little precious water is lost from the body. The filtrate that remains in the collecting duct is a suspension of water and various solutes and particles. It is now called urine. Its composition is distinctly different from the fluid that entered the Bowman’s capsule. The solutes and water reclaimed during reabsorption are returned to the body via the **renal veins**.

Performing a dissection of a mammalian kidney

Observing and identifying the main structures of a mammalian kidney

## Identifying Structures of the Excretory System

In this investigation, you will perform a dissection of a sheep's kidney in order to identify the major parts of the organ. Note that your teacher may, instead, have you examine structures of the excretory system using a virtual dissection.

### Question

What features of a mammalian kidney can you identify?



### Safety Precautions

Extreme care must be taken when using dissecting instruments, particularly scalpels. To the extent possible, make cuts away from your body. The kidneys are preserved in a chemical solution. Wear plastic gloves, goggles, and an apron at all times, and work in a well-ventilated area. At the end of the lesson, wash your hands thoroughly. Dispose of all materials as instructed by your teacher, and clean your work area.

### Materials

- preserved sheep kidney
- dissecting instruments
- disposable plastic gloves
- plastic bag and tie (to store your specimen if necessary)
- newspapers and/or paper towels
- large tongs
- dissecting tray
- apron

### Procedure

1. Obtain a kidney and observe its external features. The renal capsule is a smooth semi-transparent membrane that is tightly bound to the outer surface of the kidney. You may notice fatty deposits clinging to the renal capsule. Identify and remove the renal capsule.
2. Under the renal capsule is the surface of the renal cortex. Locate the area where the renal blood vessels and the ureter are attached to the kidney.
3. Cut through the kidney lengthwise as shown in the photograph. Identify the renal cortex.
4. Locate the renal medulla. The renal medulla contains the collecting ducts. They are visible as a striped pattern throughout the medulla.
5. Locate the renal pelvis, which is continuous with the ureter.

### Analysis

1. Based on your specimen, draw a labelled sketch of the kidney that includes the following structures.
 

a) renal capsule	d) renal pelvis
b) renal cortex	e) renal vein
c) renal medulla	f) renal artery
2. Refer to Figures 9.2 and 9.3 and your sketch from question 1. Draw a new sketch of your specimen that shows the regions of the kidney in which you would expect to observe the following nephron structures: glomerulus, proximal tubule, loop of Henle, distal tubule, and collecting duct.



The renal capsule provides a thin layer of protection for the outer tissues of the kidney.



Remember to cut away from you as you open the kidney.



Internal features of the kidney

A more detailed account of the nephron's function in forming urine follows in Section 9.2.

6 Name the three regions of the kidney.

7 Trace, in general terms, either in words or with a sketch, the movement of blood through the nephron from the renal artery to the renal vein.

## Section 9.1 Summary

- The human excretory system regulates the composition of the blood by removing wastes and excess substances from the blood plasma.
- The excretory system is responsible for removing liquid waste from the body.
- The kidneys are the primary excretory organs and are major organs of homeostasis.
- Kidney tissue is organized into three regions: cortex, medulla, and renal pelvis.
- The kidneys are composed of millions of functional units called nephrons that filter the waste from the blood and produce urine.
- Urine leaves the kidney through tubes called ureters. It passes into the bladder and exits the body through the urethra.

### Section 9.1 Review

1. Use word processing software to create a flow chart that traces the flow of urine through the various structures in the excretory system. **ICT**
2. Use word processing or spreadsheet software to create a table that lists the main structures of the human excretory system and identifies their functions. **ICT**
3. Describe the functions of the excretory system.
4. a) Use graphics software to sketch a cross-section of a mammalian kidney and label its three regions. **ICT**  
b) Identify the region(s) of the kidney where you would find the following structures: glomerulus, proximal tubule, loop of Henle, distal tubule, and the collecting duct.
5. Use graphics software to sketch the basic plan of the nephron. On your sketch indicate the part of the nephron where:
  - a) blood enters
  - b) filtrate is formed
  - c) urine is excreted **ICT**
6. Use word processing or spreadsheet software to draw a chart or table that explains the following terms with respect to the nephron: a filter, a tubule, and a duct. **ICT**
7. Summarize the relationship among the human digestive, respiratory, circulatory, and excretory systems.



## SECTION 9.2

# Urine Formation in the Nephron

### Section Outcomes

- In this section, you will
- **explain** the function of the nephron in maintaining the composition of blood plasma
  - **describe** the function of the kidney in excreting metabolic wastes and expelling them into the environment

### Key Terms

glomerular filtration  
tubular reabsorption  
tubular secretion  
water reabsorption  
proximal tubule  
loop of Henle  
distal tubule

Refer again to Figure 9.2. Note that the upper portions of each nephron are located in the renal cortex of the kidney, while the lower portions are located in the renal medulla of the kidney. Note also the presence of vessels of the circulatory system in association with the nephrons. These details indicate that nephrons are surrounded by the tissues of the medulla and cortex. Nephrons are also closely associated with a network of blood vessels that spreads throughout this surrounding tissue. Thus, any substances that are secreted from the nephrons enter the surrounding tissues of the kidney. Most of these substances return to the bloodstream through the network of blood vessels. The remainder leaves the body in the form of urine.

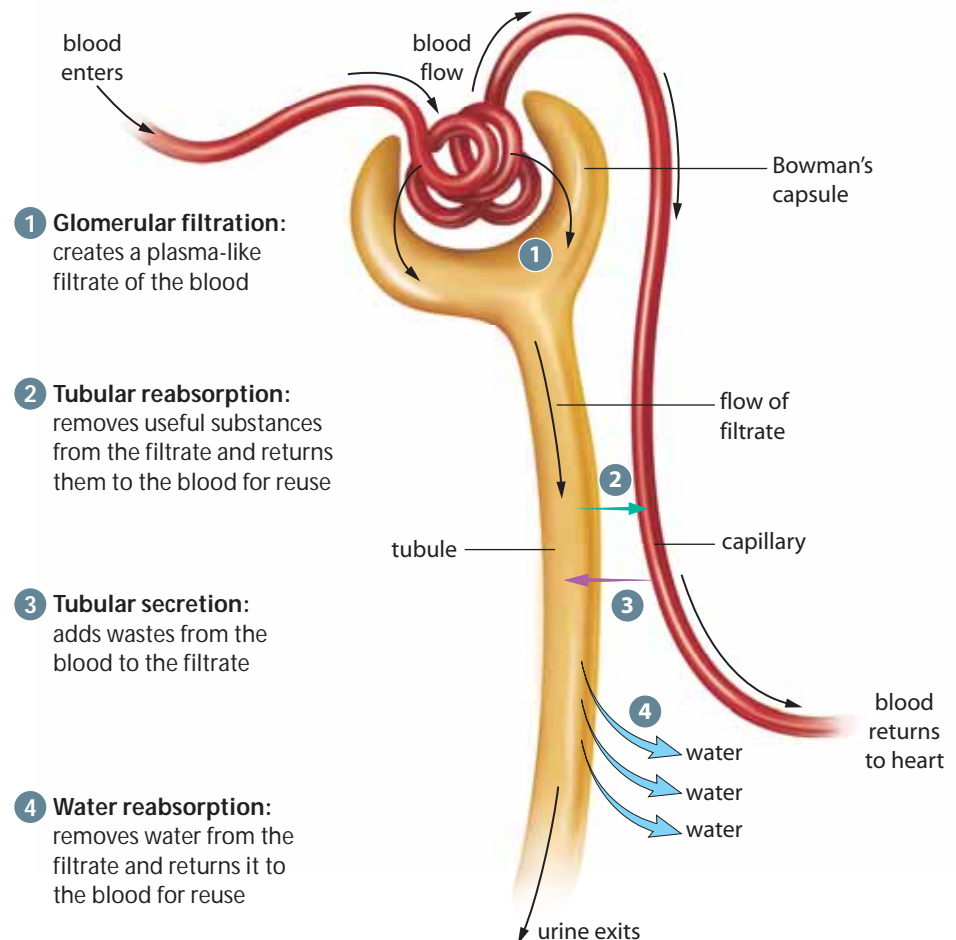
Four processes are crucial to the formation of urine. These processes are outlined below and summarized in Figure 9.4.

**Glomerular filtration** moves water and solutes, except proteins, from blood plasma into the nephron. (Recall that this filtered fluid is called filtrate.)

**Tubular reabsorption** removes useful substances such as sodium from the filtrate and returns them into the blood for reuse by body systems.

**Tubular secretion** moves additional wastes and excess substances from the blood into the filtrate.

**Water reabsorption** removes water from the filtrate and returns it to the blood for reuse by body systems.



**Figure 9.4** This simplified depiction of the nephron outlines the four main steps in the process of forming urine. The tubule has been depicted in a straight line to help you focus on the processes, rather than on the parts.



## BiologyFile

### FYI

Getting blood to and from the nephron involves a specialized series of arteries and veins. First, blood flowing to the kidneys comes directly from the aorta as it passes through the abdomen. The renal arteries enter the kidney through the renal medulla, or centre. As they travel to the cortex they branch into arterioles, which finally give rise to the fine capillaries of the glomerulus. Capillaries also enmesh the nephron; they feed into renal venules that join renal veins. Filtered blood returning to the circulation travels through the renal veins to join the vena cava and return directly to the heart.

## Glomerular Filtration Filters Blood

The formation of urine starts with glomerular filtration. This process forces some of the water and dissolved substances in blood plasma from the glomerulus into the Bowman's capsule. (Keep in mind that this process is occurring in *millions* of nephrons, all at the same time. Here, you are focussing your attention only on a single nephron.) Two factors contribute to this filtration. One factor is the permeability of the capillaries of the glomerulus. Unlike capillaries in other parts of the body, capillaries of the glomerulus have many pores in their tissue walls. These pores are large enough to allow water and most dissolved substances in the blood plasma to pass easily through the capillaries and into the Bowman's capsule. On the other hand, the pores are small enough to prevent proteins and blood cells from entering. The other factor is blood pressure. Blood pressure within the glomerulus is about four times greater than it is in capillaries elsewhere in the body. The great rush of blood through the glomerulus provides the force for filtration.

Each day, 1600 L to 2000 L of blood passes through your kidneys, producing about 180 L of glomerular filtrate. This filtrate is chemically very similar to blood plasma, as you can see in Table 9.1.

**Table 9.1** Concentration of Selected Chemicals in Plasma and Glomerular Filtrate

Chemicals	Blood Plasma (g/L)	Glomerular Filtrate (g/L)
Protein	44.4	0.0
Sodium (Na <sup>+</sup> )	3.0	3.0
Chloride (Cl <sup>-</sup> )	3.5	3.5
Glucose	1.0	1.0
Urea	0.3	0.3

Essentially, the filtrate is identical to blood plasma, minus proteins and blood cells. Further changes to this fluid lie ahead on its way to becoming urine.

- 8 Describe the two factors that contribute to glomerular filtration.
- 9 Compare the composition of the filtrate once it leaves the glomerulus with that of blood plasma.

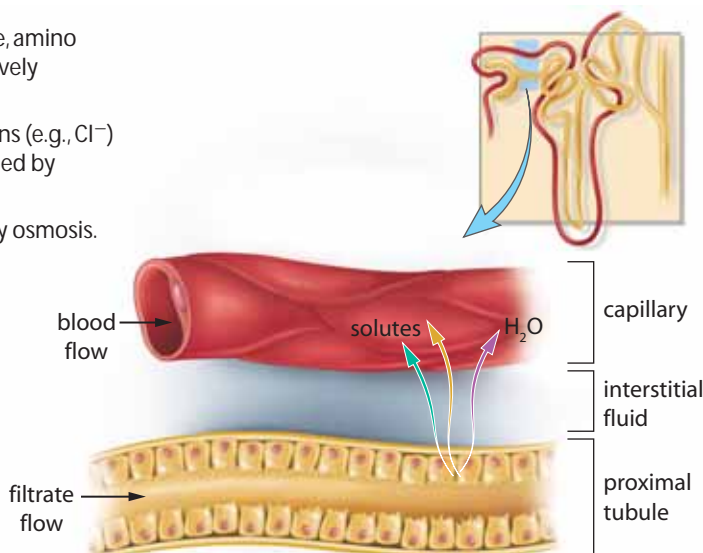
## Tubular Reabsorption: Recovery of Substances in the Proximal Tubule

About 65 percent of the filtrate that passes through the entire length of the **proximal tubule** (including the loop of Henle) is reabsorbed and returned to the body. Figure 9.5 shows that this process

- Nutrients (e.g., glucose, amino acids, Na<sup>+</sup>, K<sup>+</sup>) are actively reabsorbed.
- Negatively charged ions (e.g., Cl<sup>-</sup>) are passively reabsorbed by electrical attraction.
- Water is reabsorbed by osmosis.

### Transport mechanism

- active transport
- passive transport
- osmosis



**Figure 9.5** Reabsorption of substances and ions in the proximal tubule.

of reabsorption involves both active and passive transport mechanisms. The cells of the proximal tubule are richly endowed with mitochondria, which use the energy-releasing power of ATP to drive the active transport of sodium ions ( $\text{Na}^+$ ), glucose, and other solutes back into the blood. Negatively charged ions tag along passively, attracted by the electrical charge on the transported ions. Water follows the ions by osmosis, so it, too, is reabsorbed into the blood flowing through the capillaries.

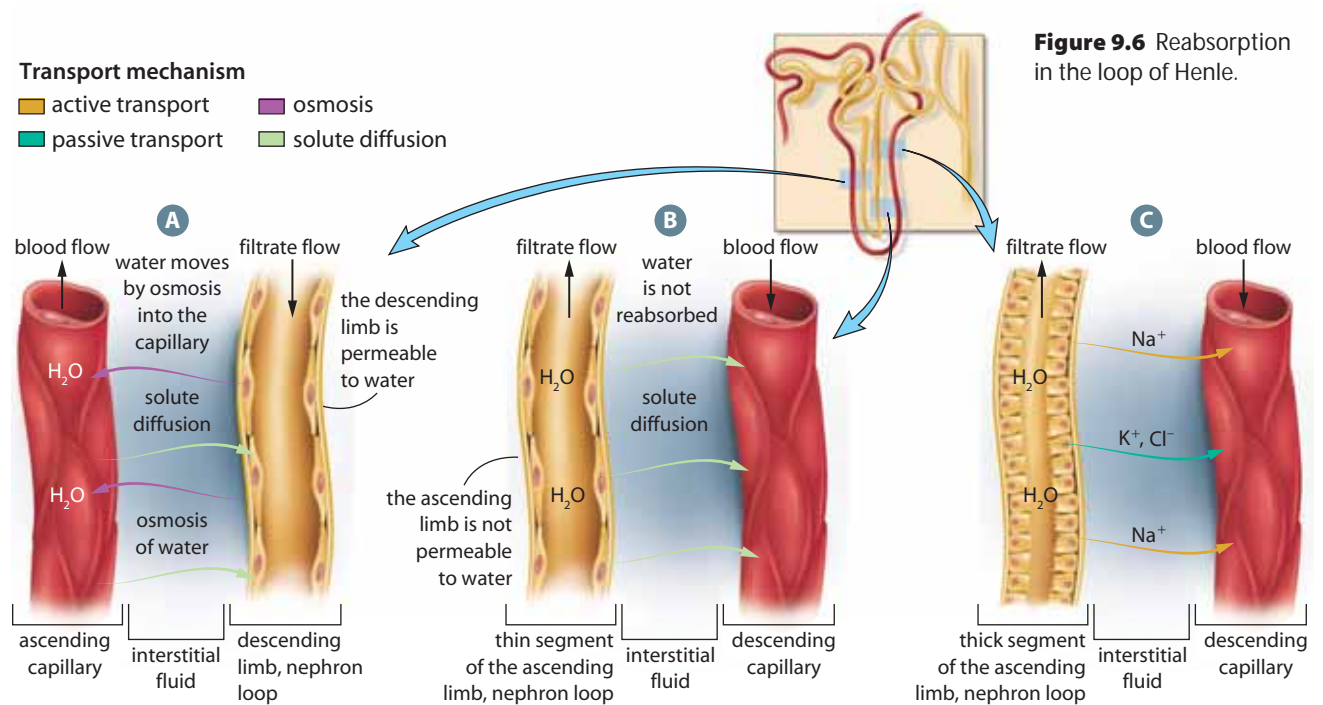
**10** What role does ATP play in the processes occurring in the proximal tubule?

### Focussing on the Loop of Henle in the Proximal Tubule

The function of the **loop of Henle** is to reabsorb water and ions from the glomerular filtrate. As the descending

limb of the loop of Henle plunges deeper into the medulla region, it encounters an increasingly salty environment. The cells of the descending limb are permeable to water and only slightly permeable to ions. As a result of the salty environment of the medulla and permeability of the descending limb, water diffuses from the filtrate to the capillaries by osmosis (see Figure 9.6A). As water moving through the descending limb leaves the filtrate, the concentration of sodium ion ( $\text{Na}^+$ ) inside the tubule increases, reaching its maximum concentration at the bottom of the loop.

As the filtrate continues around the bend of the loop of Henle and into the ascending limb, the permeability of the nephron tubule changes. Near the bend, the thin portion of the ascending tubule is now impermeable to water and slightly permeable to solutes. Sodium ions diffuse from the filtrate along their concentration gradient and pass into nearby blood vessels (see Figure 9.6B).



**Figure 9.6** Reabsorption in the loop of Henle.

## BiologyFile

### FYI

Tubular secretion also occurs in the proximal tubule, as well as in the distal tubule. In fact, reabsorption and secretion take place continuously throughout the nephron. For purposes of simplicity, the two processes are often treated separately in many high school and introductory-level biology resources.

At the thick-walled portion of the ascending limb of the loop of Henle, sodium ions are moved out of the filtrate by active transport (see Figure 9.6C). This transport of  $\text{Na}^+$  out of the filtrate has two consequences. First, it helps replenish the salty environment of the medulla, which aids in the absorption of water from filtrate in the descending limb. Second, the removal of sodium ions from the filtrate in the thick-walled portion of the tubule makes the filtrate less concentrated than the tissues and blood in the surrounding cortex tissue. By now, about two thirds of the  $\text{Na}^+$  and water from the filtrate has been reabsorbed.

11 Describe the composition of the filtrate as it moves up the ascending limb of the loop of Henle toward the distal tubule.

### Tubular Reabsorption and Secretion in the Distal Tubule

The active reabsorption of sodium ions from the filtrate into the capillaries (see

Figure 9.7) depends on the needs of the body. Passive reabsorption of negative ions such as chloride occurs by electrical attraction. The reabsorption of ions decreases the concentration of the filtrate, which causes water to be reabsorbed by osmosis.

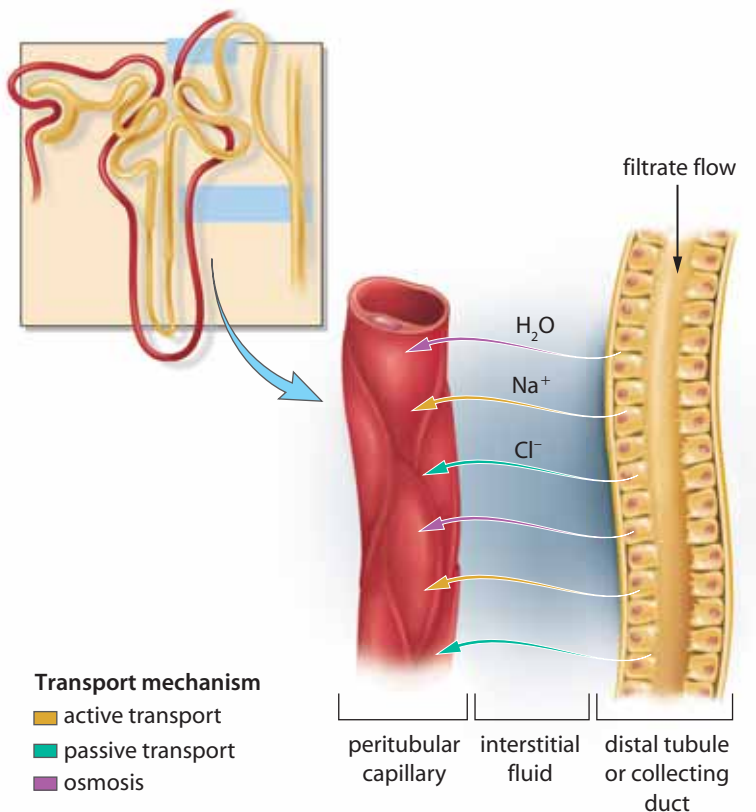
Potassium ions ( $\text{K}^+$ ) are actively secreted into the **distal tubule** from the bloodstream in the capillaries. Hydrogen ions ( $\text{H}^+$ ) are also actively secreted as necessary in order to maintain the pH of the blood. Other substances that are not normally part of the body, such as penicillin and other drugs, are secreted into the distal tubule. (Reabsorption and secretion in the distal tubule are under the control of hormones, as you will see in Section 9.3.)

### Reabsorption from the Collecting Duct

The filtrate entering the collecting duct still contains a lot of water. Because the collecting duct extends deep into the medulla, the concentration of ions along its length increases. (This concentration of ions is the result of the active transport of ions from the ascending limb of the loop of Henle.) This causes the passive reabsorption of water from the filtrate in the collecting duct by osmosis. If blood plasma is too concentrated (for example, if a person is dehydrated), the permeability to water in the distal tubule and the collecting duct is increased. This causes more water to be reabsorbed into the surrounding capillaries in order to conserve water in the body. (In the collecting duct, as in the distal tubule, hormones control reabsorption and secretion.)

The reabsorption of water in the collecting duct causes the filtrate to become about four times as concentrated by the time it exits the duct. This filtrate—which is approximately 1 percent of the original filtrate volume—is now called **urine**. Table 9.2 summarizes the main functions of the nephron and where they occur.

**Figure 9.7** Reabsorption in the distal tubule and collecting duct





**Table 9.2** A Summary of Nephron Functions

Part of the Nephron	Function
Glomerulus	<b>Filtration</b> <ul style="list-style-type: none"> <li>• Glomerular blood pressure forces some of the water and dissolved substances from the blood plasma through the pores of the glomerular walls</li> </ul>
Bowman's capsule	Receives filtrate from glomerulus
Proximal tubule	<b>Reabsorption</b> <ul style="list-style-type: none"> <li>• Active reabsorption of all nutrients, including glucose and amino acids</li> <li>• Active reabsorption of positively charged ions such as sodium, potassium, calcium</li> <li>• Passive reabsorption of water by osmosis</li> <li>• Passive reabsorption of negatively charged ions such as chloride and bicarbonate by electrical attraction to positively charged ions</li> </ul> <b>Secretion</b> <ul style="list-style-type: none"> <li>• Active secretion of hydrogen ions</li> </ul>
Descending loop of Henle	<b>Reabsorption</b> <ul style="list-style-type: none"> <li>• Passive reabsorption of water by osmosis</li> </ul>
Ascending loop of Henle	<b>Reabsorption</b> <ul style="list-style-type: none"> <li>• Active reabsorption of sodium ions</li> <li>• Passive reabsorption of chloride and potassium ions</li> </ul>
Distal tube	<b>Reabsorption</b> <ul style="list-style-type: none"> <li>• Active reabsorption of sodium ions</li> <li>• Passive reabsorption of negatively charged ions such as chloride and bicarbonate</li> </ul> <b>Secretion</b> <ul style="list-style-type: none"> <li>• Active secretion of hydrogen ions</li> <li>• Passive secretion of potassium ions by electrical attraction to chloride ions</li> </ul>
Collecting tube	<b>Reabsorption</b> <ul style="list-style-type: none"> <li>• Passive reabsorption of water by osmosis</li> </ul>

## Section 9.2 Summary

- Filtrate moves through the nephron, and the processes of glomerular filtration, tubular reabsorption, tubular secretion, and water reabsorption modify the filtrate so that cleansed plasma and substances such as glucose, amino acids, and  $\text{Na}^+$  return to the blood.

- In the glomerulus, filtration moves water and solutes (except for protein) from blood plasma into the nephron.
- Solutes are actively transported from the filtrate in the proximal tubule back into the blood.
- Approximately 65 percent of the filtrate that passes through the entire length of the proximal tubule is reabsorbed and returned to the body, while the urine becomes concentrated.

### Section 9.2

### Review

1. Use word processing or spreadsheet software to create a chart that identifies the major parts of the nephron and summarizes the function of each part. **ICT**
2. Use graphics software to draw a sketch of a simplified nephron. Include a series of captions on your diagram that identify the part(s) of the nephron responsible for each of the following:
  - a) movement of sodium ions from the nephron to the surrounding capillaries
  - b) movement of water from the nephron to the surrounding capillaries
  - c) movement of glucose out of the nephron
  - d) movement of penicillin and potassium ions into the nephron **ICT**
3. Compare and contrast blood entering the kidney to urine leaving the kidney.
4. Explain the difference between reabsorption and secretion in the nephron.
5. Based on what you have learned so far in this chapter, predict how perspiring heavily on a hot day would affect the composition and production of a person's urine. (Assume that the person has not yet consumed water to replenish body fluids.)

# Maintaining the Excretory System

## Section Outcomes

In this section, you will

- **describe** how the kidneys contribute to homeostasis with respect to water and ions
- **perform** a urinalysis using simulated urine samples
- **relate** the design of dialysis technologies to the design of the kidney

## Key Terms

antidiuretic hormone  
aldosterone  
renal insufficiency  
dialysis  
hemodialysis  
peritoneal dialysis

The amount of water reabsorbed from the filtrate influences two important characteristics of blood: its volume and the concentration of plasma solutes. The force generated as water moves by osmosis is called osmotic pressure. The greater the concentration gradient, the greater the osmotic pressure becomes. Osmotic pressure affects many cellular activities, especially the exchange of materials between cells and blood. Blood volume influences blood pressure and, thus, affects the health of the cardiovascular system.

The solute concentration of the blood remains constant despite variations in the amount of water people consume in food and liquids. If we drink too much, the kidneys allow more water to pass into the urine. If water is scarce, the kidneys conserve water by producing concentrated urine. How do the kidneys “know” when to conserve (reabsorb) water and when not to?

## Regulating Reabsorption of Water

*Osmoreceptors* are cells that are sensitive to osmotic pressure. Most osmoreceptors are located in the hypothalamus, which is a part of the brain that regulates hunger, thirst, blood pressure, body temperature, fluid balance, and salt balance. In other words, the hypothalamus regulates mechanisms that enable the body to maintain homeostasis. When blood plasma becomes too concentrated (for example, if you are dehydrated), osmotic pressure increases. In response, osmoreceptors in the hypothalamus send impulses to the adjacent pituitary gland in the brain that causes the release of **antidiuretic hormone** (ADH). (Diuresis means “increased excretion of urine.” Since the “anti-” prefix means “against” or “opposed to,” antidiuresis means “decreased excretion of urine.”) ADH

travels through the blood to the kidneys, where it increases the permeability of the distal tubule and the collecting duct, allowing more water to be reabsorbed into the blood. This dilutes the blood and lowers osmotic pressure to normal.

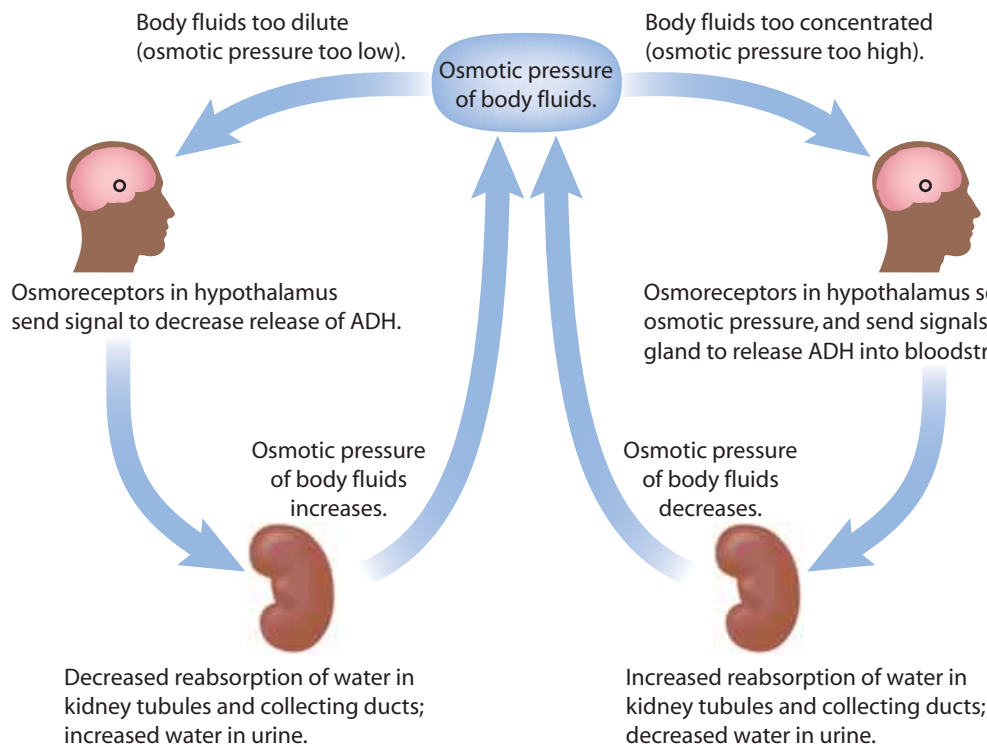
Conversely, if blood plasma is too dilute (that is, if the osmotic pressure is too low), osmoreceptors stop or prevent the release of ADH. As a result, the distal tubule and the collecting duct become less permeable to water. This allows more water to be excreted in the urine, concentrating the solutes in the blood. The osmotic pressure of the plasma and tissue fluids rises to normal. Figure 9.8 outlines the control mechanisms that lead to the release or inhibition of ADH.

In a condition called *diabetes insipidus*, ADH activity is insufficient, so a person urinates excessively—perhaps as much as 4 L to 8 L per day. Thirst is intense, but water is excreted more quickly than it is consumed, leading to severe dehydration and ion imbalances. People who have diabetes insipidus may take synthetic ADH to restore the balance of water reabsorption.

The ethanol in alcoholic beverages is a diuretic, so it increases the volume of urine. Alcohol stimulates urine production partly by decreasing ADH release, which decreases the permeability of the tubules and collecting ducts. Because it increases water loss to urine, drinking an alcoholic beverage actually *intensifies* thirst and leads to dehydration. Caffeine, a common substance in coffee, black tea, and many carbonated drinks, is also a diuretic.

12 Describe the role of osmoreceptors in regulating water reabsorption.

13 What is the role of ADH in maintaining the volume of water in the body?



**Figure 9.8** The release of ADH controls the amount of water reabsorbed or excreted in urine.

## Reabsorption of Salts

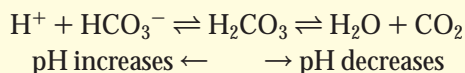
The kidneys regulate salt balance in the blood by controlling the excretion and reabsorption of various ions. Sodium ion ( $\text{Na}^+$ ) is the most abundant ion in blood plasma, but its concentration can fluctuate dramatically depending on diet and the consumption of beverages with diuretic effects. A drop in blood  $\text{Na}^+$  concentration is normally compensated by the kidneys under the influence of the hormone **aldosterone**. This hormone stimulates the distal tubules and collecting ducts to reabsorb  $\text{Na}^+$ . Because the reabsorption of  $\text{Na}^+$  is followed passively by chloride ions and water, aldosterone has the net effect of retaining both salt and water. Aldosterone also stimulates the secretion of potassium ions ( $\text{K}^+$ ) into the distal tubes and collecting ducts if  $\text{K}^+$  concentration in the blood is too high.

## Maintaining Blood pH

The pH of body fluids stays at about 7.4 via three main mechanisms. The acid-base buffer system buffers the blood—prevents changes in pH by adding or removing hydrogen ions ( $\text{H}^+$ ). One of the key buffering reactions in the blood

involves carbonic acid ( $\text{H}_2\text{CO}_3$ ) and bicarbonate ions ( $\text{HCO}_3^-$ ); see the chemical equation below. An increase in  $\text{H}^+$  pushes the reaction to the right. This reaction, and others, helps prevent major changes in blood pH. It is aided by a second mechanism that involves changes to breathing rate. An increased breathing (respiration) rate pulls the reaction to the right to generate  $\text{CO}_2$  more quickly.

These mechanisms to control acid-base balance are aided by the more powerful actions of the kidneys. Think of the kidneys as excreting  $\text{H}^+$  and reabsorbing  $\text{HCO}_3^-$  as needed to maintain normal blood pH. If the blood is too acidic,  $\text{H}^+$  is excreted and  $\text{HCO}_3^-$  is reabsorbed. If the blood is too basic,  $\text{H}^+$  is not excreted and  $\text{HCO}_3^-$  is not reabsorbed. Since urine is usually acidic, it follows that  $\text{H}^+$  is usually excreted. The ability of the kidneys to control blood pH is crucial to maintaining an internal environment in which cell enzymes continue to function properly.



## BiologyFile

### Try This

The release of aldosterone is stimulated directly by a rise or fall in  $\text{Na}^+$  and  $\text{K}^+$  concentrations in the blood. Aldosterone may also be stimulated indirectly through a drop in blood pressure. Do research to discover the main steps involved in the renin-angiotensin-aldosterone system of hormone control. Sketch a flowchart similar to Figure 9.8 to show how this system responds to a rise or fall in blood pressure and blood volume.



## BiologyFile

### FYI

The chemical reactions that act to maintain a constant blood pH are linked to the respiratory system, because  $\text{H}_2\text{CO}_3$  reacts in solution to form carbon dioxide ( $\text{CO}_2$ ) and water ( $\text{H}_2\text{O}$ ). Therefore, levels of  $\text{H}_2\text{CO}_3$  are linked to levels of  $\text{CO}_2$ , which are regulated by breathing.

14 Describe how the kidneys regulate salt balance in the body.

15 How do the excretory and respiratory systems work together to regular blood pH?

## Upsetting the Balance of the Excretory System

The composition of urine reflects the amounts of water and solutes that the kidneys must remove from or retain in the body to maintain homeostasis. Analyzing the physical and chemical composition of urine, therefore, enables physicians to make reasoned inferences and hypotheses about a person's health. Table 9.3 provides values for selected tests that are performed on urine. These values are consistent with those of urine from a healthy adult. Note, however, that urine composition varies greatly over the course of a day due to factors such as dietary intake, physical activity, emotional stress, and fatigue. In addition, unhealthy constituents of urine may not necessarily indicate illness or disease. For example, the presence of glucose in urine may result from a sugary meal. Proteins may appear in urine following vigorous exercise. Ketones—acids that result from the digestion of fats when the body lacks sufficient stores of carbohydrates—may

result from a short-term fast or a specially designed low-carbohydrate diet. Because so many factors can influence the presence and amounts of substances in urine, trained professionals must consider a wide variety of variables when evaluating a sample of urine. You will have a chance to examine a much narrower range of variables and substances in Investigation 9.B.

## Disorders of the Excretory System

The excretory system is vital to maintaining homeostasis, so when it is affected by a disorder, the proper functioning of other body systems may be jeopardized. One of the most common disorders of the excretory system is a urinary tract infection. If the bladder has a bacterial or viral infection, the disorder is called cystitis; if only the urethra is involved, the condition is called urethritis. Urinary tract infections are more common in women than in men, primarily because of the differences in anatomy. In females, the urethral and anal openings are closer together, making it easier for bacteria from the bowels to enter the urinary tract and start an infection.

Symptoms of a urinary tract infection include a painful burning sensation during urination, a need to urinate frequently even if no urine is present, and bloody or brown urine. The upper abdomen or lower back may be tender, and chills, fever, nausea, and vomiting may be present. Urinary tract infections have the potential to become serious, and they can result in permanent damage to the kidneys and possible kidney failure. Treatment usually is with an antibiotic, but in serious cases of kidney infection, surgery may be needed. Preventative measures include maintaining hygienic personal behaviours, such as proper wiping from front to back after a bowel movement, and drinking lots of water.

Another fairly common disorder of the excretory system involves the

**Table 9.3** Normal Values from Selected Common Urine Tests

Urine Test	Accepted Healthy Value*
Acetone and ketones	0
Albumin (protein)	0–trace
Bilirubin (a breakdown product of hemoglobin)	0
Calcium	< 150 mg/day
Colour and clarity	Pale yellow to light amber; transparent
Glucose	0
pH	4.5–8.0
Urea	25–35 g/day
Uric acid	0.5–1.0 g/day

\*These values may vary with the type of equipment used for analysis.

development of crystalline formations called kidney stones (see Figure 9.9). Most kidney stones form due to excess calcium in the urine. In fact, about 85 percent of kidney stones are made up of calcium compounds. Recurrent urinary tract infections, insufficient water consumption, and low activity levels contribute to kidney-stone formation. Treatment varies depending on the size of the stones. Many stones pass through the urinary tract on their own. Depending on the cause of the stone formation, medications may help to break down the crystals. If the stones are less than 20 mm in diameter, ultrasound shock waves can be used to disintegrate the crystalline structure of the stones so that they can be passed naturally in the urine. For larger stones, surgery may be needed to remove them.

## Problems with Kidney Function

**Renal insufficiency** is a general term used to describe the state in which the kidneys cannot maintain homeostasis due to damage to their nephrons. Some causes of nephron damage include:

- kidney infection
- high blood pressure
- diabetes mellitus
- trauma from a blow to the lower back or constant vibration from machinery
- poisoning (either from skin contact, inhalation of fumes, or ingestion of contaminated food) by heavy metals such as mercury and lead or solvents such as paint thinners
- atherosclerosis (which reduces blood flow to the kidneys)
- blockage of the tubules

Nephrons can regenerate and restore kidney function after short-term injuries. Even when some of the nephrons are irreversibly damaged, others can compensate for their lost function. In fact, a person can survive on as little as one-third of one kidney. If 75 percent or more of the nephrons are destroyed, however, urine output is inadequate to maintain homeostasis. Under these



circumstances, a person requires a means for replacing kidney function. This is achieved either with a kidney transplanted from a donor, if one is available, or with an artificial kidney that performs a blood-cleansing process called **dialysis**.

### Hemodialysis and Peritoneal Dialysis

**Dialysis** is the diffusion of dissolved substances through a semipermeable membrane. These substances move across a membrane from the area of greater concentration to one of lower concentration. Substances more concentrated in blood diffuse into the dialysis solution, called the dialysate. Substances more concentrated in the dialysate diffuse into the blood. Other substances can be added to the blood following this same principle. For example, if the acid-base balance of the blood is off and the blood is too acidic, bicarbonate ions can be added to the dialysate where they will diffuse into the blood and reduce its acidity.

There are two main types of renal (kidney) dialysis: hemodialysis and peritoneal dialysis. **Hemodialysis** utilizes an artificial membrane in an external device—in essence, an artificial kidney—that is connected to an artery and a vein in a person's arm. **Peritoneal dialysis** utilizes the lining of the intestines, called the peritoneum, as the dialysis membrane. Dialysate is introduced to the abdominal

**Figure 9.9** Kidney stones vary in size from a grain of sand to a golf ball. The larger ones, which cause extreme pain as they pass through the excretory system, can be broken into fragments with ultrasound technology in a procedure called lithotripsy.

### BiologyFile

#### FYI

In 1946, Dr. Gordon Murray was the first Canadian scientist to develop and use kidney dialysis. To succeed, he solved the problem of getting the blood outside of the body and keeping it from clotting by pioneering the use of the anticoagulant drug heparin. (An anticoagulant hinders clotting.) Then he found a material porous enough to let wastes diffuse while retaining the larger particles and blood cells in the plasma—cellophane designed to wrap sausages.

Target Skills

Collecting and interpreting data in the analysis of simulated urine, and stating a generalization based on data analysis and interpretation

Identifying limitations of data collected

Comparing collected values to theoretical values

## Urinalysis

Urinalysis is the physical, chemical, and sometimes microscopic examination of urine. Many diseases with no obvious symptoms can be revealed during urinalysis. Long before modern techniques such as chemical dipsticks and microscopic analysis were developed, medical practitioners used the appearance, odour, and even taste of urine to help them make inferences about a person's health. In this investigation, you will test samples of simulated urine to identify an imaginary criminal. In so doing, you will perform several of the tests that are performed when health professionals do a urinalysis.

### Question

What physical and chemical tests can you use, and what data do they provide, in the analysis of urine?



### Safety Precautions

- Do not taste the simulated urine.
- If observing odour, follow safe and proper methods.
- Be careful when handling the simulated urine. Clean up spills immediately, and notify your teacher if a spill occurs.

### Materials

- 1 medicine dropper
- 1 test tube rack
- 10 mL graduated cylinder
- 5 test tubes
- 100 mL beaker
- hot water bath
- universal indicator paper with colour charts
- glucose test strips with colour charts
- simulated urine samples

### Procedure

Consider this scenario. A theft was committed in the washroom of a community building. Forensic specialists collected a urine sample at the scene of the crime. The police have four suspects in custody. Your task is to find out who committed the crime.

1. Copy the data table at the bottom of the page in your notebook.
2. You will start by doing a trial run of four tests to find out what information they provide. This will serve as the control for this investigation.
3. Perform the following tests on your simulated urine sample.

**Test 1—Colour, Odour, Clarity:** Normal urine is a clear, straw-coloured liquid. Urine may be cloudy because it contains red or white blood cells, bacteria, or pus from a bladder or kidney infection. Normal urine has a slight odour. Foul-smelling urine is a common symptom of urinary tract infection. A fruity odour is associated with diabetes mellitus. Determine the colour, odour, and clarity of your simulated urine.

- a) Use the graduated cylinder to obtain 20 mL of the Control Urine Sample.
- b) Place the Control Sample into the beaker.
- c) Examine the urine carefully. Record the colour and the clarity (clear or cloudy) in your data chart.
- d) Using the proper technique, determine the odour of the urine. Record your observations in your data chart.

**Test 2—Protein:** One sign of kidney damage is the presence of protein in urine. Find out if the sample contains protein by doing the following.

- a) Use the graduated cylinder to divide the sample equally between two test tubes (10 mL into each test tube).
- b) Put one tube into the hot water bath, and leave the other at room temperature.

Test	Control Tests	Crime Scene	Suspect 1	Suspect 2	Suspect 3	Suspect 4
1. Colour/odour/clarity						
2. Protein						
3. pH						
4. Glucose						



- c) After a few minutes, remove the test tube from the hot water bath and compare the heated and unheated urine.
- d) If the heated sample is cloudier, it contains protein. Record your observations.
- e) Dispose of the heated sample as directed by your teacher. Use the unheated sample for the next test.

**Test 3—pH:** The wide range of pH values (pH 4.7 to 8.5) makes this is the least useful parameter for diagnosis of kidney disorders. Kidney stones are less likely to form and some antibiotics are more effective in alkaline urine. There may be times when acidic urine may help prevent some kinds of kidney stones. Bacterial infections also increase alkalinity, producing a urine pH in the higher 7–8 range.

- a) Use a clean medicine dropper to place a drop of the urine on a small piece of universal indicator (pH) paper.
- b) Leave the paper for about 30 seconds.
- c) Determine the pH by comparing the new colour with the colour chart provided.
- d) Record the pH of your urine sample in your data table.

**Test 4—Glucose:** One sign that a person has diabetes mellitus is the presence of glucose in urine. Find out if the sample contains glucose by doing the following.

- a) Dip a glucose test strip into the test tube of unheated urine sample and immediately take it out.
- b) Count to 10, then check the colour with the glucose colour chart.
- c) Record whether the results are negative, light, medium, or dark. (The darker the colour, the greater the amount of glucose.)

- 4. Your group will be assigned to test one of the remaining samples of simulated urine. One sample was collected at the crime scene. The others have been provided by the four suspects in police custody. Run the four urinalysis tests and record your observations on a class data sheet provided by your teacher.

### Analysis

- 1. Which suspect do you think committed the crime?
- 2. Explain how you arrived at this conclusion.

### Conclusions

- 3. Based on your urinalysis, identify the disease that Suspect 4 might have. Explain.
- 4. List at least three other characteristics of urine that you would expect to observe (or not) in a healthy urine sample.
- 5. In what ways were the data that you collected in this urinalysis limited? What additional data would provide a more comprehensive picture of a urine sample?

### Extension

- 6. Explain why you would not expect to find evidence of glucose or protein in a urine sample from someone whose kidneys are healthy. (Use details of nephron anatomy in your answer.)
- 7. The urine of athletes is routinely tested for evidence that they may have taken performance-enhancing drugs. Based on your understanding of urine formation, describe how molecules of a drug could appear in a person's urine.

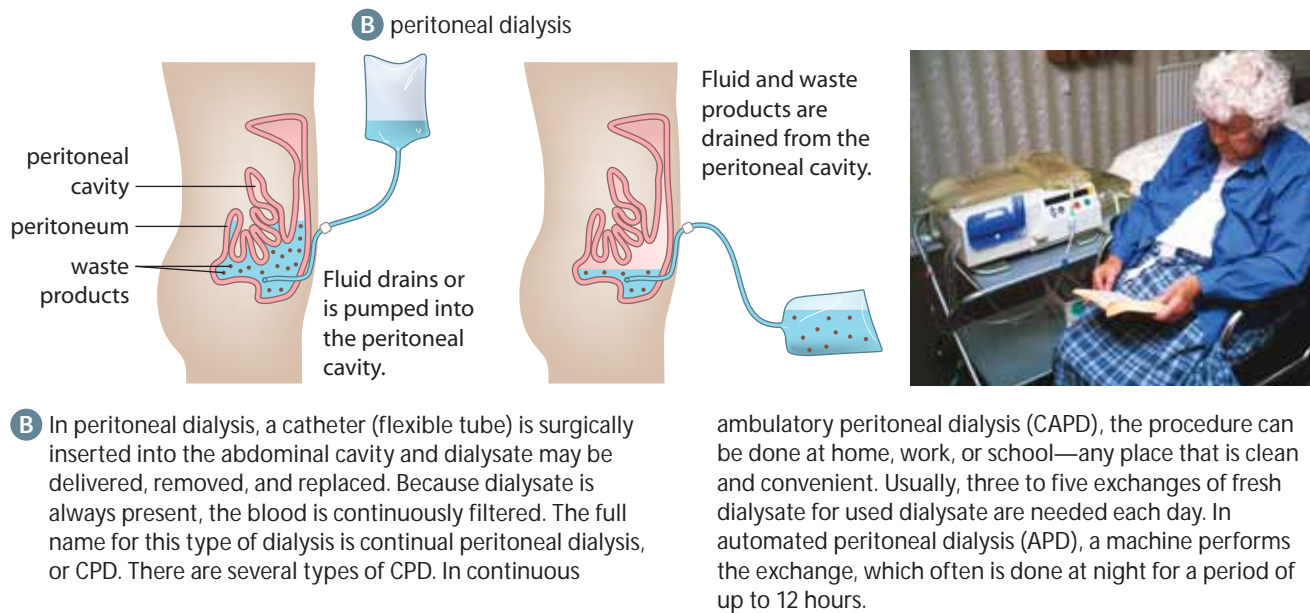
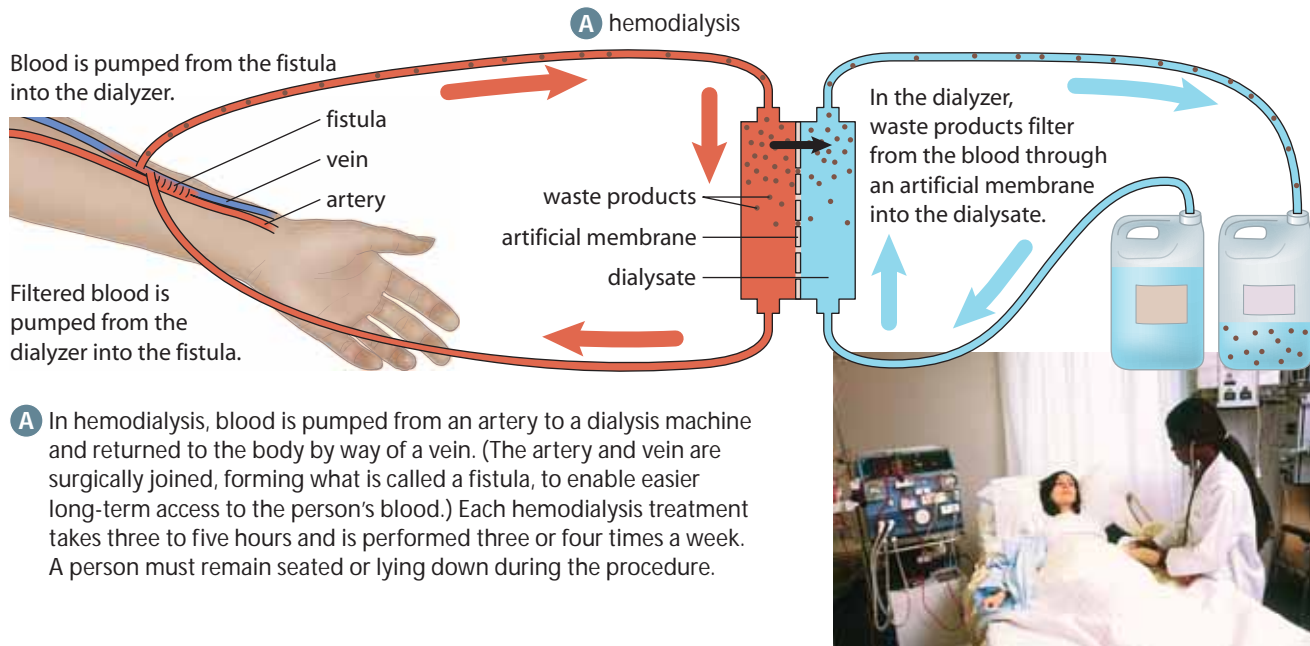
cavity, where the large surface area and rich supply of capillaries of the peritoneum slowly filter the blood. Figure 9.10 on the next page illustrates these two methods of dialysis.

16 What is renal insufficiency?

17 Identify the two types of renal dialysis and briefly describe their similarities and differences.

## Kidney Transplants

Dialysis enables people with kidney disease to live their lives in a relatively unchanged way. However, dialysis is not a cure, and it is not intended to be a long-term solution to the problem of kidney disease. Individuals with 10 percent or less kidney function will eventually have to replace their kidneys. The need for kidneys is much greater than the available supply. In Canada, the overall rate of organ donation is low compared to other developed countries, with about 14 donors



**Figure 9.10**  
Hemodialysis (A) and peritoneal dialysis (B)

per million people. There are thousands of people in Canada waiting for organs, and the vast majority of them—over 75 percent—are waiting for kidneys.

Transplant organs can come from one of two sources. The first source is cadaveric donors. These are people who have died suddenly and who had previously discussed their desire to donate their organs with their families. The second source is live donors—individuals who wish to donate their organs while they are still alive. Organs suitable for live donations include the kidney, part of a

liver, or part of a lung, and the genetic makeup of the donor must be similar to the person who will be receiving the organ. A minimally invasive surgical technique used to remove a kidney from a living donor is called laparoscopy (see Figure 9.11). Instruments are used to locate, dissect, and remove the kidney from the donor through three small incisions in the abdomen.

The success rate of organ transplantation, particularly of kidneys, is fairly high. Generally, the success rate for kidney transplants from living



**Figure 9.11** Laparoscopic surgery allows a kidney to be removed from a living donor. The location of the kidney, behind the abdominal organs, made it difficult to access using traditional laparoscopic instruments. Specially designed hand-assisted laparoscopes are being used with great success.

donors is higher than the success rate for transplants from cadaveric donors. A kidney from a living donor is usually a better genetic match, so rejection of the organ is less likely to occur. The success rate for living-donor transplants is about 98 percent, compared with up to 95 percent success with cadaveric-donor transplants.

In the future, these results likely will improve. Surgical techniques are constantly being improved, and new medicines to prevent rejection of the new organ are constantly being developed and improved. Recall from Chapter 8 that the immune system will react to destroy any cells that are considered foreign to the body. Some of the most common anti-rejection drugs cannot be used for kidney transplant recipients because these drugs, while revolutionizing the field of transplant surgery, cause kidney damage. For example, most heart transplant recipients have reduced kidney function as a result of their immune-suppression drugs, and a small percentage experience kidney failure, requiring dialysis and ultimately a kidney transplant.

Several medications have been developed for anti-rejection, but the treatment is given before the transplant takes place. Certain antibodies cause a temporary depletion of T cells (recall

the function of T cells from Chapter 8). When these antibodies are used as a pre-treatment, the body may accept rather than reject the incoming new organ.

- 18 Why is a kidney transplant considered a cure for a serious kidney disorder, while renal dialysis is not?
- 19 What factors could affect the short-term and long-term success of a kidney transplant?

### The Kidney-Coronary Connection

High blood pressure is one of the main reasons that kidneys begin to fail. Recall from Chapter 8 how blood flows through your body. When blood pressure is high for a prolonged period of time, the heart must pump a greater volume of blood, and blood vessels can be damaged. The blood vessels in the kidneys are very sensitive to changes in blood pressure, and if they become damaged by high blood pressure, the amount of waste and extra fluid that can be filtered from blood will be reduced. As the extra fluid accumulates in the body, it will increase the blood volume even more and cause

### BiologyFile

#### Try This

Have you thought about organ donation? Would you want your organs given to someone else if you were to die unexpectedly? You may feel strongly for or against donating your organs, and there is no correct way to feel. If you are uncertain about what you feel, do some research on the process of organ donation. It is important that you make a decision about what you would like to happen, and that you let your family and close friends know your wishes.



## Metabonomics

What happens inside your body after you swallow an Aspirin®? Although you may take this drug only to relieve a headache, the chemical ingredients in the Aspirin® can affect almost every part of your metabolism, producing a range of by-products called metabolites. Levels of these molecules rise or fall in response to the drug, and they are eventually excreted from your body in the urine. If you could obtain a measure of all these changes, you would have a “metabolic profile” that gives you a big picture of your body’s overall health. That metabolic profile is one goal of a new approach to medical research called metabonomics.

### What is a Metabolic Profile?

Just as genomics is the study of an organism’s entire genetic makeup, metabonomics is the study of the complete metabolic response of an organism to various environmental or genetic stimuli. Almost everything that happens in your body produces metabolites. Changes in the levels of metabolites can be measured in body fluids such as blood or urine, and these changes give clues that can help diagnose diseases, identify genetic mutations, or measure the body’s reaction to pharmaceutical drugs or other chemicals.

One technology used by researchers to analyze body fluids is nuclear magnetic resonance (NMR) spectroscopy. This technique measures chemical changes due to nuclear interactions and produces patterns that show many different biochemicals simultaneously.

### Applying Metabonomics

Pharmaceutical companies develop and test thousands of new drugs every year at a cost of many billions of dollars. Many of these experimental drugs turn out to be ineffective or even toxic during testing. A major advantage of metabonomics is that it allows researchers to measure multiple effects of a drug in test animals simply by analyzing samples of their blood or urine. This is much quicker and cheaper than traditional methods, which often involve taking samples of tissues and cells from many animals for microscopic examination.

Rather than focus only on the metabolism of a drug compound itself, metabonomics research measures patterns of change in hundreds of different compounds. This holistic approach is made possible only by new technologies. For example, mass spectrometry combined with sophisticated data analysis and pattern recognition programs allow the German state of Bavaria to screen newborn infants for 30 metabolic disorders simultaneously, for a relatively low cost.

...

1. Why is urine such a valuable source of information about the body’s metabolism?
2. How could metabonomics help a physician diagnose a metabolic disease before a person shows any symptoms?



A pharmaceutical technician, working to develop drugs obtained from plants used in traditional healing, places a plant sample into an NMR spectrometer to identify the molecules in the plant extract.



the blood pressure to rise further. This cycle can continue until the kidney function is so reduced that symptoms become obvious. Unfortunately, both high blood pressure and kidney impairment do not have obvious symptoms until the damage is well underway.

Maintaining a healthy lifestyle supports the overall health of all of your body's systems. Remember that none of these systems functions in isolation, so any activity that affects one of your systems will affect other systems as well. Ensuring that you have adequate physical exercise, for example, can help to make your heart and circulatory system stronger and healthier (see Figure 9.12). One reason that exercise is effective at lowering blood pressure is that it stimulates the release of a substance called nitric oxide that is produced by cells on the inside of our blood vessels. Reduction in the amount of nitric oxide in the blood is one of the first signs that plaque is building up inside the blood vessels. High blood pressure has such an impact on kidney function that exercise to reduce blood pressure ultimately reduces the likelihood of kidney damage.

### Section 9.3 Summary

- The kidneys maintain the water-salt balance in the body.
- The kidneys maintain blood pH within narrow limits by excreting excess hydrogen ions and reabsorbing bicarbonate ions.
- The kidneys excrete more concentrated urine when the body needs to conserve water and more dilute urine when the body has excess water.
- ADH regulates the amount of water in the body by reabsorbing water in the distal convoluted tubule and the collecting duct.
- Aldosterone regulates the amount of salt in the body by reabsorbing sodium ions in the distal convoluted tubule.
- Dialysis is a treatment for kidney failure where the blood is filtered using principles of diffusion. It can be internal (peritoneal dialysis) or external (hemodialysis).
- Kidney transplants are the only way to cure chronic kidney failure.
- The health of the excretory system affects the health of other body systems. Maintaining healthy blood pressure is a key way to protect both the kidneys and the excretory system.

**Figure 9.12** People do not have to be athletes or play sports to experience the benefits of physical exercise. Activities such as walking, bicycle riding, and canoeing are simple ways to promote personal health.

### BiologyFile

#### FYI

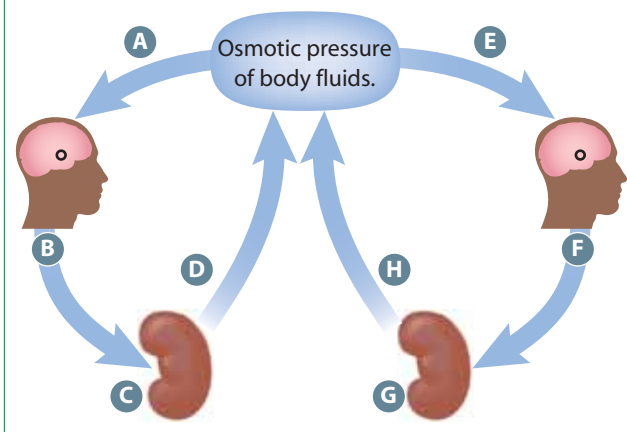
Nitric oxide is a gas that controls many functions in the body, including regulating the activity of many organs. Before 1987, nitric oxide was known only as a toxic environmental pollutant because it is a primary component of smog. However, scientists have discovered that cells on the inside of the blood vessels make nitric oxide in response to the pressure of the blood flowing through the vessels. The journal *Science* named nitric oxide its "Molecule of the Year" in 1992 because of its importance to the body's health.



1. Identify how the amount of water reabsorbed from the filtrate influences two characteristics of blood.

Use the following illustration to answer the next questions.

This diagram illustrates how the release of antidiuretic hormone (ADH) controls the amount of water reabsorbed or excreted in the urine.



2. a) Complete captions for the areas on this diagram labelled A to H.  
b) Use this diagram to explain why drinking alcoholic beverages stimulates urine production.
3. Explain why an individual with diabetes insipidus urinates as much as 4 L to 8 L per day. Why would this individual have “intense thirst?”
4. a) Illustrate, using words or a sketch, the locations of the nephron that are involved in water absorption.  
b) Explain how the excretory system would respond if you drank very little water on a hot day. Modify your answer in part (a) to include this information.
5. Explain what would happen if the body were unable to release the hormone aldosterone.
6. Based on the data in the table below, identify the substances that are secreted and those that are reabsorbed. (You do not need to know what these substances are to answer this question.) Justify your answer.

Substance	Plasma (g/L)	Filtrate (g/L)	Urine (g/L)
Creatine	0.01	0.01	1.9
Uric acid	0.05	0.05	1.0
Bicarbonate ion	1.7	1.7	0.4

7. Describe briefly how the acid-base balance of the blood is maintained.
8. Predict the effect of very low blood pressure on kidney function.
9. Imagine that you are adrift at sea and your supply of fresh water has run out. You are surrounded by water. Explain why you will become dehydrated if you drink the sea water.

Use the following information to answer the following questions.

### Urinalysis

The colour and appearance of the urine specimen is recorded. Usual colours are colourless, straw, yellow, amber; less commonly pink, red, brown. Usual appearances (opacity) are clear or hazy; less commonly turbid, cloudy and opaque, unless the specimen has remained at room or refrigerated temperatures.

The common chemical testing of urine utilizes commercial disposable test strips. Some strips can test for 10 substances: glucose, bilirubin, ketone, specific gravity, blood, pH, protein, urobilinogen, nitrite, and leukocyte esterase. The result of this testing is regarded as semi-quantitative.

10. The urine of different individuals is analyzed. Explain a possible disease or disorder that may be associated with each of the following observations:
  - a) Individual 1: protein found in their urine
  - b) Individual 2: blood found in their urine
  - c) Individual 3: glucose found in their urine
  - d) Individual 4: white blood cells (leucocytes) found in their urine
11. Use word processing or spreadsheet software to design a chart that summarizes the causes, symptoms, and treatments for the following disorders of the excretory system:
  - a) kidney stones
  - b) renal insufficiency
  - c) urinary tract infections **ICT**



The metabolic activities of cells, including energy release, maintenance, and repair, produce substances that change the balance of the volume of water and the concentration and composition of dissolved substances in the body's fluids. The excretory system removes these materials to maintain the optimal volume of water and composition of body fluids, dispose of wastes, and recycle the non-waste substances. The substances in question include carbon dioxide; water; ions of sodium ( $\text{Na}^+$ ), chloride ( $\text{Cl}^-$ ), and hydrogen ( $\text{H}^+$ ); and other compounds resulting from the breakdown of proteins and nucleic acids. The excretory system also plays a key role in maintaining the acid-base balance (pH) in the blood.

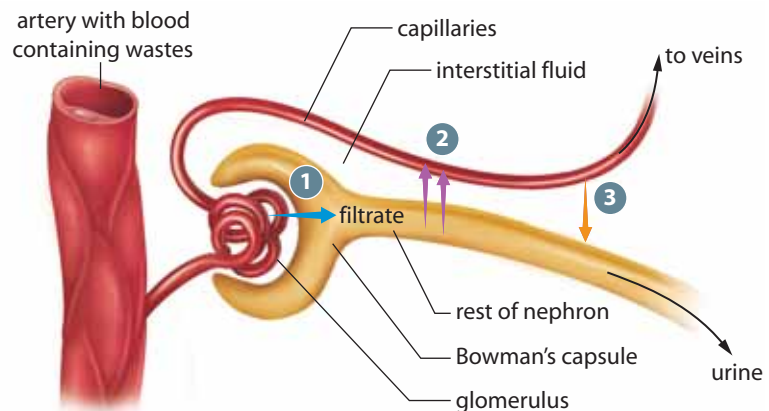
The organs of the excretory system are the kidneys, the ureters, the urinary bladder, and the urethra. The kidneys contain millions of tiny nephrons that each contain a filter, a tube, and a duct. The nephrons filter out waste and reabsorb substances such as sodium and water for reuse by the body's systems. The resulting filtrate, known as urine, is sent through the ureters to the urinary bladder for temporary storage until it is eliminated from the body through the urethra.

Disorders of the excretory system include urinary tract infections, kidney stones, and renal insufficiency. Renal insufficiency may require dialysis or a kidney transplant in order to ensure that wastes are secreted rather than building up to toxic levels in the body.

### Chapter 9 Graphic Organizer

Using the nephrons of the kidneys, the excretory system removes metabolic wastes from the body, maintains water and pH balance through filtration and secretion, and returns required solutes by reabsorption.

- 1 Filtration (blue arrow) results in the movement of fluid from glomerulus into the nephron.
- 2 Solutes are reabsorbed (purple arrow) across the wall of the nephron into the interstitial fluid by active transport and diffusion. Solute are transported back to the body for reuse.
- 3 Solutes are secreted (orange arrow) across the wall of the nephron into the filtrate for removal by excretion.

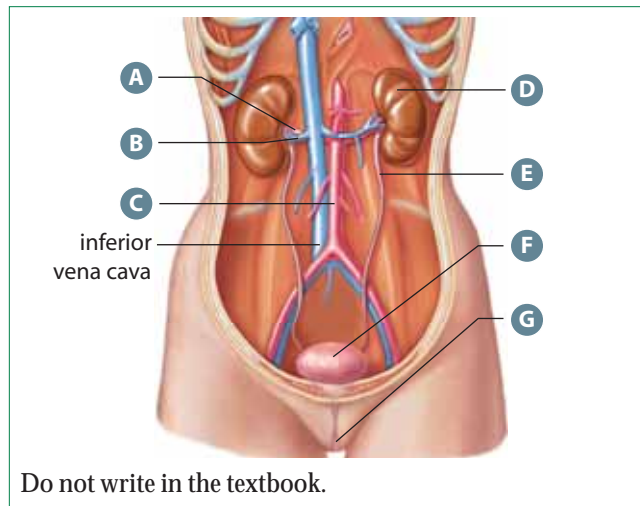


Excretory system utilizes these processes to help maintain homeostasis by regulating water-salt concentrations and pH of blood.

Healthful lifestyle practices support the excretory system. Disorders of the system may be addressed through technologies such as renal dialysis and kidney transplant operations.

## Understanding Concepts

Use the following diagram to answer the next question.

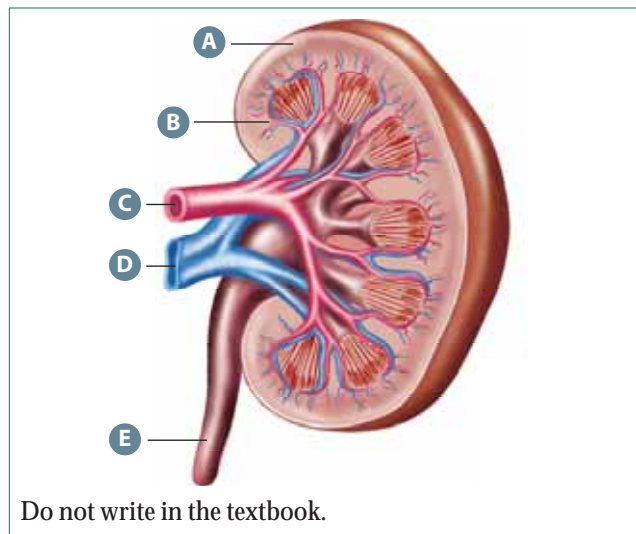


Do not write in the textbook.

1. Identify the structures labelled A to G in the diagram above, and describe their function in terms of the excretory system
2. Explain how the process of active transport within the kidney helps control the volume of urine produced during the day.
3. Explain how increased secretion of ADH affects urine concentration and urine volume. Identify a possible situation in which the hypothalamus may be stimulated to release ADH.
4. Explain why proteins and blood are not normally found in urine.
5. Identify the parts of the nephron that are most involved in regulating the pH level of the blood.
6. Identify four differences between the blood entering the kidney in the renal artery and the blood leaving the kidney in the renal vein.
7. Identify four types of dissolved substances found in the filtrate that forms in the Bowman's capsule of the nephron.
8. Describe the causes and symptoms of a urinary tract infection. Identify two ways these disorders can be prevented.
9. Use word processing software to draw a flowchart or other graphic organizer to show the response of the body after drinking several cups of water on a cool evening. **ICT**

10. Distinguish between the processes of filtration, tubular secretion, reabsorption, and osmosis as they relate to the process of urine formation.
11. How would each of the following processes in the kidney change in response to serious dehydration in the body caused by excessive sweating on a hot day?
  - a) glomerular filtration
  - b) tubular reabsorption
  - c) ADH secretion

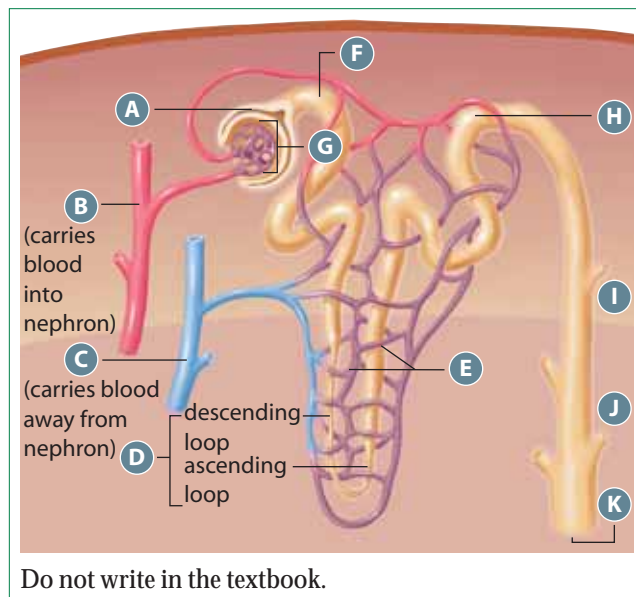
Use the following diagram to answer the next question.



Do not write in the textbook.

12. a) Identify the structures labelled A to E on this diagram.  
 b) Describe the primary functions of each of the following sections of the human kidney.
  - i) cortex
  - ii) medulla
  - iii) collecting duct
  - iv) renal pelvis

Use the following information to answer the next question.



Do not write in the textbook.

13. a) Identify each of the structures labelled A to K.  
 b) Describe the functions of the following structures  
 i) glomerulus  
 ii) Bowman's capsule  
 iii) proximal tubule  
 iv) descending loop of Henle  
 v) ascending loop of Henle  
 vi) distal tubule  
 vii) collecting duct

### Applying Concepts

Use the following information to answer the next question.

**Diuretics**

Alcohol, like caffeine, acts as a diuretic. A diuretic is a substance that removes water from the body by promoting urine formation and the loss of salt (sodium). Diuretics may be used as part of treatment for conditions that cause swelling from water retention (edema), such as heart failure, hypertension, or liver or kidney disease.

14. Explain how alcohol affects the concentration of urine produced.

Use the following information to answer the next question.

Substance	Glomerular filtrate (per day)	Urine (per day)	Reabsorption (%)
water, L	180	1.8	99.0
sodium, g	630	3.2	99.5
glucose, g	180	0.0	100.0
urea, g	54	30.0	44.0

Reabsorption from nephrons. L = litres, g = grams

15. Explain what is happening to each substance as it passes through the different regions of the nephron.  
 a) water                                      c) glucose  
 b) sodium (salts)                            d) urea
16. Explain why doctors usually prefer to use kidneys provided by living donors rather than those from deceased donors in kidney transplant cases.
17. The process of dialysis filters blood in people with reduced kidney function or kidney failure. Use word processing or spreadsheet software to create a chart or table comparing how the process is carried out by dialysis machines and the human kidney. **ICT**

18. Use word processing software to create a flowchart that illustrates how the filtrate is modified by the processes of active and passive transport as it flows through a single nephron in the human kidney. **ICT**

### Making Connections

Use the following information to answer the next question.

**Glomerulonephritis**

In diseases and conditions classified as glomerulonephritis (also called nephritis or nephritic syndrome), the glomerulus becomes inflamed and scarred. Most often, it is caused by an *autoimmune disease*, but it can also result from infection.

19. a) Explain how nephritis might affect urinary output and the removal of nitrogenous wastes from the blood.  
 b) Provide a possible explanation why the urine of a person with nephritis is usually brown instead of yellow in colour.
20. If you were to perform a urinalysis on the filtrate removed from a peritoneal dialysis machine, what would you expect to find in a chemical analysis? Assume the person is healthy other than suffering kidney failure.

Use the following information to answer the next question.

**Dialysis vs. Kidney Transplants**

Consider the following cost comparison of dialysis versus kidney transplants. Dialysis cost approximately \$50 000 per year in 2006. A kidney transplant operation at this time cost approximately \$20 000 and required \$6000 per year in followup treatments. Kidney transplants have a 98 percent success rate using kidneys from a living donor and a 95 percent success rate using kidneys from a deceased donor.

21. a) In your opinion, to what extent should cost be considered as an important variable when people make decisions about whether to choose a transplant or dialysis?  
 b) What additional information would you like to have to help you write an informed, reasoned answer to this question?