The digestive system and the excretory system help the body to absorb nutrients and remove waste.

32.1 Nutrients and Homeostasis  
32.2 Digestive System  
32.3 Absorption of Nutrients  
32.4 Excretory System  

Data Analysis  
IDENTIFYING OUTLIERS  

ONLINE Labs  
- Testing a Digestive Enzyme  
- QuickLab Villi in the Small Intestine  
- Antacid Effectiveness  
- Digesting Milk  
- Factors Affecting Digestion  
- Video Lab Lactose Digestion  

HMDScience.com
What is that gut feeling inside you?

A lot is going on in your stomach when you eat. For instance, epithelial cells, shown in this close-up, secrete four types of substances: stomach acid; a protective mucus that keeps the stomach from digesting itself; enzymes that break down many types of food; and hormones that control the process.

USING LANGUAGE

Classification Organizing things into groups will show their relationships to each other and to other things. Grouping is called classification, and another word for group is class. For example, a hammer is a tool. A hammer is not the only type of tool. Saws, drills, and screwdrivers are also tools. Tool is the class and saw, drill, screwdriver, and hammer are members of that class.

YOUR TURN

1. Pizza, hamburger, and salad are members of the class food. List three additional members that could belong in this class.

2. The class nutrient includes the members vitamin, mineral, carbohydrate, protein, and lipid. Think of another class to which the members carbohydrate, protein, and lipid could belong.
Cells require many different nutrients.

Six types of nutrients help to maintain homeostasis.

Meeting nutritional needs supports good health.

Nowadays, many foods are enriched with essential vitamins, and you have been taught about nutrients that your body needs. Until the 1740s, British sailors on long voyages were crippled by scurvy, an illness that produced weakness, bruising, bleeding gums, and painful joints. Meanwhile, Dutch sailors who ate oranges at sea never got scurvy. British physician James Lind hypothesized that citrus fruits might not only cure the illness but prevent it as well. Lind divided the crew of one ship into six groups and gave each different foods. Sailors eating oranges and lemons remained healthy. Simply adding vitamin C eliminated scurvy at sea.

Six types of nutrients help to maintain homeostasis.

Today, scientists and health experts know a great deal more about how important nutrients are to maintain homeostasis in your body. You need to consume six types of nutrients every day to keep your body in good health: water, carbohydrates, proteins, fats, minerals, and vitamins. If any one of these nutrients is missing for too long, your body’s cells will stop working properly, which also affects your organs.

Water

Your body is made up of 55 to 60 percent water. As a natural solvent, water is involved in nearly every chemical reaction in every cell of your body. It also helps you to digest food and eliminate waste products, maintain your blood volume, regulate your body temperature, and keep your skin moist. To maintain your fluid balance, you need to drink about 2 liters (8.4 cups) of water a day to replace the amount you lose through sweat, urine, and respiration.

Carbohydrates

Carbohydrates, shown in Figure 1.1, are the main source of energy for your body. Simple carbohydrates are sugars found in sugar cane, honey, and fruits. Complex carbohydrates are starches found in vegetables, grains, and potatoes. To be absorbed by your body, starches must be broken down during digestion into simple sugars, such as glucose. Excess supplies of glucose are converted to glycogen and are stored in the liver and muscle tissues for future use. Many grains, fruits, and vegetables also contain cellulose, a dietary fiber. Fiber cannot be digested, but it helps move food through your digestive system.
Proteins
Proteins, such as those shown in Figure 1.2, are the raw materials used for the growth and repair of the body’s cells and tissues. Proteins also make up all enzymes and many hormones that are vital for cell metabolism. Proteins are composed of chains of amino acids. Your body can make only 12 of the 20 amino acids it needs to build proteins. The other 8, called essential amino acids, must come from the foods you eat. Foods such as meat, cheese, and eggs contain all eight essential amino acids. Most plant proteins lack at least one essential amino acid. People who do not eat meat, dairy products, or eggs must eat certain combinations of foods to obtain all the amino acids they need. For example, red beans and rice together contain all 20 amino acids.

Fats
Fats provide energy and key components in cell membranes, myelin sheaths for neurons, and certain hormones. Fats consist of long chains of fatty acids hooked to glycerol molecules. Your body can make some fatty acids, but you must obtain all of the essential fatty acids from the foods you eat. Fats are classified as either saturated or unsaturated, depending on the structure of their fatty acid chains. Saturated fats are solid at room temperature and are found in animal products. Most unsaturated fats are liquid at room temperature and are found in plant oils, such as corn or olive oils, and in some fish, such as cod or salmon. In general, unsaturated fats are considered more beneficial to people’s health than are saturated fats.

Minerals
Small amounts of minerals and vitamins are also needed to maintain homeostasis. Minerals are inorganic materials the body uses to carry out processes in cells and to build or repair tissues. Some of the more common minerals are listed in Figure 1.3. Calcium, for example, is essential for bone and tooth formation, muscle contraction, and nerve transmission. Sodium and potassium help to maintain the body’s fluid homeostasis. You are constantly losing minerals in sweat, urine, and other waste products. You can replace them by eating a variety of plant foods or by combining plant and animal foods.

**FIGURE 1.3 Important Minerals**

<table>
<thead>
<tr>
<th>MINERALS</th>
<th>SOURCES</th>
<th>IMPORTANT FOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium</td>
<td>dairy products, salmon, sardines, dark leafy greens</td>
<td>blood clotting, bone/tooth formation; muscle/nerve function</td>
</tr>
<tr>
<td>Iron</td>
<td>liver, dark leafy greens, whole grains</td>
<td>component in hemoglobin</td>
</tr>
<tr>
<td>Iodine</td>
<td>iodized salt, seafoods, sea vegetables</td>
<td>component in thyroid hormones</td>
</tr>
<tr>
<td>Magnesium</td>
<td>nuts, whole grains, leafy green vegetables</td>
<td>bone/tooth formation; coenzyme in protein synthesis</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>meats, dairy products, nuts, dried peas and beans</td>
<td>bone/tooth formation; active in many metabolic processes</td>
</tr>
<tr>
<td>Potassium</td>
<td>meats, dairy products, many fruits and vegetables</td>
<td>regulation of pH, fluid balance, and muscle/nerve function</td>
</tr>
<tr>
<td>Sodium</td>
<td>table salt, seafoods, processed foods</td>
<td>regulation of pH, fluid balance, and muscle/nerve function</td>
</tr>
<tr>
<td>Zinc</td>
<td>meats, seafoods, grains</td>
<td>activation of many enzymes in metabolic processes</td>
</tr>
</tbody>
</table>
Vitamins are organic molecules that work with enzymes to regulate cell functions, growth, and development. As shown in Figure 1.4, these nutrients are divided into fat-soluble vitamins and water-soluble vitamins. Fat-soluble vitamins dissolve in fatty acids. The fat-soluble vitamins A, D, E, and K can be stored in the body’s fatty tissues for future use. For this reason, taking high doses of these vitamins can actually create harmful, or toxic, levels in the body.

Water-soluble vitamins dissolve in water. The water-soluble vitamin C and the B vitamins cannot be stored and are excreted in urine and feces. As a result, you need to eat foods rich in these nutrients to keep replenishing them. The National Academy of Sciences publishes recommended daily amounts of minerals and vitamins based on your age, gender, and level of activity.

Apply Would a diet higher in protein or in complex carbohydrates give you more energy? Explain your answer. TEKS 9A

**FIGURE 1.4 Essential Vitamins**

<table>
<thead>
<tr>
<th>VITAMIN</th>
<th>SOURCES</th>
<th>IMPORTANT FOR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fat-Soluble (Dissolves in Fat)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A (retinol)</td>
<td>dark green, yellow, and orange vegetables, fortified milk, fish and liver oils</td>
<td>healthy skin, mucous membranes, vision</td>
</tr>
<tr>
<td>D (calciferol)</td>
<td>fortified dairy and whole grain products, egg yolks, fish and liver oils</td>
<td>bone and tooth formation, increase in calcium and phosphorus absorption</td>
</tr>
<tr>
<td>E (tocopherol)</td>
<td>vegetable oils, nuts, fish oils, meats, leafy green vegetables</td>
<td>prevention of cell damage</td>
</tr>
<tr>
<td>K</td>
<td>leafy green vegetables, egg yolks, liver; also made by intestinal bacteria</td>
<td>blood clotting and synthesis of clotting factors</td>
</tr>
<tr>
<td><strong>Water-Soluble (Dissolves in Water)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B₁ (thiamine)</td>
<td>pork and red meats, whole grains, dried beans and peas, eggs</td>
<td>metabolism of carbohydrates</td>
</tr>
<tr>
<td>B₂ (riboflavin)</td>
<td>dairy products, liver and organ meats, enriched whole grains</td>
<td>metabolism of carbohydrates and proteins, normal growth in skin, lips, and mucous membranes</td>
</tr>
<tr>
<td>B₃ (niacin)</td>
<td>meats, dried peas and beans, whole grains</td>
<td>metabolism of glucose, fats, and proteins</td>
</tr>
<tr>
<td>B₆ (pyridoxine)</td>
<td>meats, fish, peanuts, eggs, bran cereal</td>
<td>metabolism of amino acids</td>
</tr>
<tr>
<td>B₁₂</td>
<td>liver, meats, eggs, dairy products</td>
<td>protein synthesis and red blood cell production</td>
</tr>
<tr>
<td>C (ascorbic acid)</td>
<td>citrus fruits, berries, tomatoes, broccoli, cabbage, potatoes, melons</td>
<td>antioxidant, maintenance of cartilage and bone, iron absorption, tissue repair, wound healing, healthy gums</td>
</tr>
<tr>
<td>Pantothenic acid</td>
<td>meats, dairy products, whole grains</td>
<td>metabolism of glucose, fats, and proteins</td>
</tr>
<tr>
<td>Folic acid</td>
<td>leafy green vegetables, liver, nuts, oranges, broccoli, peas, fortified cereals</td>
<td>amino acid synthesis and metabolism, prevention of neural tube defects in fetuses</td>
</tr>
<tr>
<td>Biotin</td>
<td>egg yolks, liver, soybeans</td>
<td>metabolism of carbohydrates, proteins, and fats</td>
</tr>
<tr>
<td>Choline</td>
<td>egg yolks, liver, whole grains</td>
<td>production of phospholipids and neurotransmitters</td>
</tr>
</tbody>
</table>
Meeting nutritional needs supports good health.

A balanced diet is important throughout your life, but particularly during pre-teen and early teen years. During these years, you are growing and developing faster than at any other time since the first two years of your life. Your bone mass is increasing nearly 40 percent, you are gaining most of your adult body mass, and you are developing sexual characteristics.

To fuel this growth spurt, your body requires considerably more nutrients and more energy in the form of Calories consumed, as shown in Figure 1.5. A calorie, with a small c, is the amount of energy required to raise one gram of water one degree Celsius. One calorie (capital C) from food equals one kilocalorie, or 1000 calories. One gram of protein or carbohydrate yields four Calories, while one gram of fat yields nine Calories.

Calories are not the whole story, however. The rapid changes in your body require adequate amounts of all six nutrients. Dietary experts recommend that most of your Calories come from eating whole grains, fruits, and vegetables, like those shown in Figure 1.6, which are rich in fiber, vitamins, and minerals. Also, experts suggest drinking more low-fat milk or soy drinks and water, and fewer high-sugar soft drinks and juices. High-sugar foods provide Calories but little nutritional value. Dietary recommendations include eating more lean meats and fish, while cutting down on foods high in saturated fat.

It is also important to find a balance between food and physical activity so that you use about as many Calories as you consume. The U.S. Department of Agriculture (USDA) website provides information on how to develop a balanced diet.

**FIGURE 1.5 Growth and Energy Needs**

During rapid growth, the body requires significantly more energy.

**MALES**

- Height gain (cm/year)
- Required Calories/day

**FEMALES**

- Height gain (cm/year)
- Required Calories/day

**Contrast** What differences do you notice between the two charts?

All cells need ATP to power their metabolic processes. Explain why eating carbohydrates is so important to the process of cellular respiration.

Formative Assessment

1. What six types of nutrients must you consume to stay healthy? Give two examples of how nutrients help to maintain homeostasis. **TEKS 9A**
2. What information besides the number of Calories can help you make good food choices?

Critical Thinking

3. **Apply** Explain why vegans—people who eat no animal products—must take care to include all the essential amino acids in their diet.
4. **Contrast** How do the functions of vitamins and minerals differ from the functions of proteins and carbohydrates? **TEKS 9A**

Connect to

Cellular Respiration

5. All cells need ATP to power their metabolic processes. Explain why eating carbohydrates is so important to the process of cellular respiration.
Digestive System

**KEY CONCEPT** The digestive system breaks down food into simpler molecules.

**MAIN IDEAS**
- Several digestive organs work together to break down food.
- Digestion begins in the mouth and continues in the stomach.
- Digestion is completed in part of the small intestine.

**VOCABULARY**
digestion
digestive system
sphincter
esophagus
peristalsis
stomach
chyme
small intestine
bile

**Connect to Your World**

What would you do to help advance scientific understanding? In June 1822, Alexis St. Martin was shot in the stomach and treated by William Beaumont, an Army surgeon. The 19-year-old St. Martin recovered, but the bullet wound left a small hole in his stomach. Beaumont covered the hole and persuaded St. Martin to let him observe the digestive process by tying foods to a string, dropping them into the stomach hole, and retrieving them at different times to see how quickly different foods were digested. Over ten years, the experiments yielded a wealth of information about the digestive process. St. Martin married, had children, and lived to the age of 76.

**MAIN IDEA** 

Several digestive organs work together to break down food.

*Digestion* is the process by which the large complex molecules in food are broken down into smaller molecules that can be used by the body. The *digestive system* is a collection of organs that breaks down food into energy that can be used in cells. It is like a factory that takes things apart instead of putting them together. The major organs of this “disassembly line” include the mouth, esophagus, stomach, pancreas, liver, gallbladder, large and small intestines, rectum, and anus, as shown in *FIGURE 2.1*. Rings of muscle, called *sphincters* (SFIHNGK-tuhrs), separate one section from another. The opening and closing of these sphincters and the contractions of smooth muscle in the walls of the organs keep food moving in one direction.

Digestion takes place through the interactions of enzymes, stomach acid, hormones, bile from the liver, and a network of nerves and muscles throughout the digestive system. Each organ contributes to breaking food down. For instance, in the mouth, salivary glands secrete an enzyme that helps to digest starches. The stomach releases enzymes that break down proteins.

Once digestion is complete, nutrients are absorbed by the body and transported by the circulatory system and lymphatic system to all the cells. Finally, undigested materials are eliminated as liquid and solid wastes. The entire process—from food entering the mouth to wastes leaving the body—takes about 24 to 33 hours per meal.

*Predict* What might happen if the digestive sections were not divided by sphincters?
Digestion begins in the mouth and continues in the stomach.

You may have heard someone telling their children, “Chew your food—don’t just gulp it!” This is actually good advice, because the first step in breaking down food is mechanical and chemical digestion in the mouth.

**Digestion in the Mouth**

You unwrap the sandwich you brought for lunch and bring it up to your mouth. Mechanical digestion begins the moment you bite into the sandwich and start chewing. Your teeth shred and grind the food into smaller pieces. Your tongue keeps the pieces positioned between your teeth. Chemical digestion, on the other hand, involves the action of enzymes. As you chew your food, the salivary glands release saliva that moistens the food and contains an enzyme called amylase (AM-uh-LAYS). Amylase begins the breakdown of complex starch molecules into sugars.

Once food has been chewed and mixed with saliva, the tongue pushes it to the back of the mouth. As you swallow, the food moves into the esophagus (ih-SAHF-uh-guhs), a tube that connects the mouth to the stomach. Food is kept moving down the esophagus by the action of peristalsis, as [FIGURE 2.2](#) shows. Peristalsis (PEHR-ih-STAWL-sis) is the rhythmic, involuntary contraction of the smooth muscles in the walls of digestive organs.

**Digestion in the Stomach**

The next stop for your thoroughly chewed sandwich is the stomach. The stomach is a muscular sac that can stretch to nearly twice its original size and holds up to 2 liters (2 qt) of food. The stomach continues the digestion that began in the mouth. Proteins are digested in the stomach and small intestine, but fats and sugars are digested only in the small intestine. Major enzymes and their functions in the digestive system are listed in [FIGURE 2.3](#).

The walls of the stomach contain three layers of smooth muscle that contract about every 20 seconds. This churning action breaks food into even smaller pieces and mixes the food with the stomach’s digestive juices.

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**FIGURE 2.2** As food enters the esophagus, muscles behind the food contract, pushing it forward, while the muscles in front of the food relax. This rhythmic squeezing, called peristalsis, keeps food moving in one direction.

**FIGURE 2.3** Major Digestive Enzymes

<table>
<thead>
<tr>
<th>ENZYME</th>
<th>DIGESTIVE ORGAN</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salivary amylase</td>
<td>mouth</td>
<td>breaks down starches into simpler sugars</td>
</tr>
<tr>
<td>Pepsin</td>
<td>stomach</td>
<td>breaks down proteins</td>
</tr>
<tr>
<td>Maltase, lactase, sucrose</td>
<td>small intestine</td>
<td>breaks down sugars into simpler molecules</td>
</tr>
<tr>
<td>Peptidase</td>
<td>small intestine</td>
<td>breaks down proteins into amino acids</td>
</tr>
<tr>
<td>Trypsin</td>
<td>small intestine, pancreas</td>
<td>continues breakdown of proteins</td>
</tr>
<tr>
<td>Amylase</td>
<td></td>
<td>continues breakdown of starches</td>
</tr>
<tr>
<td>Lipase</td>
<td></td>
<td>aids in breaking down fats</td>
</tr>
</tbody>
</table>
As **Figure 2.4** summarizes, chemical digestion occurs along with the churning of mechanical digestion. The stomach lining secretes gastric juice containing hydrochloric acid (HCl) and the digestive enzyme pepsin. Gastric juice is acidic enough to kill most bacteria found on food and to break the bonds between protein molecules. Pepsin also breaks some chemical bonds between the amino acids in proteins. Digestive juices and enzymes turn your partly digested sandwich into a semi-liquid mixture called **chyme** (kym).

The stomach empties as peristaltic actions push the chyme against the sphincter that separates the stomach from the small intestine. With each contraction, the sphincter opens slightly, and chyme squirts into the small intestine, where digestion continues. It takes from two to six hours to empty the stomach after a meal.

Once the stomach is empty, the production of gastric juice stops. What keeps the stomach from digesting itself? First, pepsin is active only when there is food to digest. Second, the stomach secretes a layer of mucus to protect itself from its own acidic environment. Even so, cells in the stomach lining are replaced every few days to maintain the protective layer of mucus.

**Apply**  If you ate a meal of spaghetti and meatballs, where would chemical digestion of the pasta and meat begin?

**FIGURE 2.4** Mechanical and Chemical Digestion

The digestive organs use mechanical and chemical digestion to break food down into simple molecules.

**CRITICAL VIEWING**  Do you think a high-carbohydrate or a high-protein meal would be digested more quickly? Explain.

**CONNECT TO**  
**CHEMISTRY**

Hydrochloric acid (HCl) is so strong that it can dissolve an iron nail in a matter of hours. To protect your stomach lining, specialized epithelial cells secrete bicarbonate, a base substance. Bicarbonate neutralizes the acid to keep it from burning through your stomach lining.
The remaining carbohydrates, proteins, and fats from your sandwich are digested in the duodenum (doo-uh-DEE-nuhm), the section of small intestine closest to the stomach. The small intestine is a long, narrow tube in which most digestion takes place. Smooth muscle contractions churn the food, and chemical digestion further breaks down the complex molecules. As shown in Figure 2.5, enzymes and hormones from the pancreas, liver, and gallbladder flow through ducts into the duodenum to help complete the digestive process.

The pancreas is a small gland located behind the stomach. When chyme first enters the small intestine, the pancreas releases an alkaline fluid to help neutralize the acid and stop the action of pepsin. The pancreas also releases enzymes to break down starches further into simple sugars. For example, lactase is an intestinal enzyme that breaks down lactose, a sugar found in milk. The pancreas also produces an enzyme called lipase that splits fat into fatty acids and smaller molecules.

The liver, which filters blood, is also a digestive organ. It produces a chemical substance called bile that helps to digest fats. Bile is stored in a smaller organ, the gallbladder. When bile is needed to digest fats, it is released through ducts that empty into the duodenum. The bile breaks down large globules of fat into smaller droplets for further digestion.

Proteins entering the small intestine have already been broken down by the action of pepsin and gastric juice into smaller chains of amino acids. In the duodenum, enzymes finish the process by breaking these chains into individual amino acids. By the time chyme has passed through the duodenum, food has been broken down into small molecules. Section 3 describes how these molecules are absorbed by the body.

**Apply** How would the pancreas and liver help to digest ice cream?
Kidney Structure

The nephron is the functional unit of the kidney. Explore how blood is filtered as it passes through the long and winding renal tubes of the nephron.

Obesity

Obesity is on the rise, but is the answer as simple as “eat less and exercise more”? Examine the causes and health risks of obesity, and learn how people can take control of their weight.

Run the Digestive System

Move a snack from the mouth through the large intestine and get as much nourishment out of the food as possible.
Absorption of Nutrients

**KEY CONCEPT** Nutrients are absorbed and solid wastes are eliminated after digestion.

**MAIN IDEAS**
- Most absorption of nutrients occurs in the small intestine.
- Water is absorbed and solid wastes are eliminated from the large intestine.

**Connect to Your World**

Suppose you tried to wipe up spilled water with a “sponge” made of solid plastic. Without the ability to absorb water, your sponge is useless. People with celiac disease face a similar, but more life-threatening, problem. Celiac disease is an autoimmune disorder that makes people unable to tolerate the protein gluten found in wheat, rye, and barley. Their immune systems produce antibodies to destroy it. The antibodies also damage the surfaces of cells lining the small intestine. This means that no matter how much a person eats, the body cannot absorb the food and as a result, becomes malnourished. The only treatment is to eliminate all gluten from the diet to protect the lining of the small intestine.

**MAIN IDEA**

Most absorption of nutrients occurs in the small intestine.

Food moving through the “disassembly line” of the digestive system is only part of the process. Your body must absorb the nutrients in order for the food you digest to do you any good. **Absorption** is the process by which nutrients move out of the digestive organs into the circulatory and lymphatic systems. As shown in **FIGURE 3.1**, the small intestine has three main structures—the lining, villi, and microvilli—that absorb most of the nutrients from chyme.

**FIGURE 3.1 Small Intestine Structures**

Specialized structures in the small intestine increase surface area and absorption.

- Small intestine
- Villi cover the folds
- Lining of the small intestine
- Capillaries
- Blood vessels
- Lymph vessel
- Microvilli cover villi (SEM; magnification 12,500×)

**Analyze** How would the total surface area change if the lining were smooth instead of folded?
Specialized Structures for Absorption

As you look over the diagram in FIGURE 3.1, notice that the lining of the small intestine is ridged and folded. These structures increase the surface area and slow the passage of material through the intestine. Slower motion allows more time for nutrients to be absorbed. The folds of the lining are covered with villi. Villi (VIHL-eye) are small fingerlike projections, covered with epithelial cells, that absorb nutrients.

In turn, every epithelial cell on the villi has thousands of tiny projections called microvilli that add even more surface area to absorb nutrients. Each microvillus is smaller than the period at the end of this sentence. The photograph in the diagram shows microvilli covering the epithelial cells like a dense carpet.

Absorption of Different Nutrients

As digestion is completed, nutrients are absorbed in each of the three parts of the small intestine: the duodenum, the jejunum, and the ileum. Together, these parts measure about 6 meters (about 20 ft) long. Villi in each of the three sections absorb different nutrients.

**Duodenum**  Most simple sugars, amino acids, and minerals such as calcium and iron are absorbed by villi in the duodenum. These nutrients diffuse into the circulatory system and are carried to the liver.

**Jejunum** The villi in the jejunum (juh-JOO-nuhm) absorb glucose along with some amino acids, vitamin C, most B vitamins, and some water. These nutrients diffuse into the circulatory system to be distributed throughout the body.

**Ileum** The villi in the ileum (IHL-ee-uhm) absorb fat-soluble vitamins and vitamin B₁₂, fatty acids, cholesterol, and some water. The nutrients empty into lymph and blood vessels and are distributed to the cells.

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**Villi in the Small Intestine**

In this lab, you will design a model of the villi in the lining of the small intestine.

**PROBLEM** How can you model the function of villi in the small intestine?

**PROCEDURE**

1. Use a paper cup, water, and paper towel to make a model of the villi in the lining of the small intestine.
2. Make three new models that are different. To do this, change one material to determine which model most effectively shows the action of the villi.
3. Determine which of your models most effectively models the villi.

**ANALYZE AND CONCLUDE**

1. **Summarize** Explain how this experiment models the action of the villi in the small intestine.
2. **Apply** Write a definition to describe how you measured each model’s effectiveness.
3. **Analyze** Which model was most effective? How do you know?

**MATERIALS**

- 4 large paper cups
- water
- 8 paper towels
- timer
5. The desert kangaroo rat in Arizona eats plants but doesn't drink water. Yet even in summer, it doesn't suffer from dehydration. How do you think the rat's digestive system helps it to obtain water to maintain homeostasis?

**Formative Assessment**

**REVIEWING MAIN IDEAS**

1. Explain the purposes of the lining, villi, and microvilli in the small intestine. **TEKS 10A**
2. What are the main functions of the large intestine? **TEKS 10A**

**CRITICAL THINKING**

3. **Contrast** Explain the difference between digestion and absorption. What role does each process play in maintaining homeostasis? **TEKS 10A**

4. **Apply** Which nutrients would take longer to digest and absorb: sugars, proteins, or fats? Explain.

**ANIMALS**

5. The desert kangaroo rat in Arizona eats plants but doesn't drink water. Yet even in summer, it doesn't suffer from dehydration. How do you think the rat's digestive system helps it to obtain water to maintain homeostasis? **TEKS 10A**
Identifying Outliers

Sometimes in a scientific investigation, one or more unusual data points are recorded. A data point that is outside of the pattern of data is called an outlier. Outliers can result because of human error in reading or recording data, equipment failure, or rare events such as a 31°C (70°F) day in Wisconsin in January.

To rule out the possibility that the outlier is a valid data point, scientists check their equipment, the laboratory set-up, and the recording process. If the outlier seems to be valid, further research may be needed. Simply ignoring or deleting outliers are not appropriate ways of handling these data.

Model

A scientist measured the body temperatures of 1 person over time. As shown in the scatterplot at the right, nearly every temperature was between 36.9°C (98.4°F) and 37.0°C (98.6°F). Notice, however, that one temperature was recorded at 36.8°C (98.2°F). This outlier could be the result of equipment failure or human error. In cases of outliers, scientists must always ask, “What other explanations could there be for the data point? Do these data warrant further investigation?” Investigating the outlier further might lead to new discoveries.

Practice Identify Outliers

Scientists investigated how the mass of an antacid affects its ability to raise the pH of gastric juices in the stomach. They recorded their data in the graph below. Examine the graph, and answer the questions that follow.

1. **Analyze** What is the trend in the data? Which points might be the outliers?

2. **Evaluate** What are some possible explanations for these outliers? How should the scientists proceed?
The excretory system eliminates nonsolid wastes from the body.

If the digestive system is like a disassembly and distribution line, the excretory system is like a group of waste treatment and disposal facilities. The **excretory system** is the body system that eliminates nonsolid wastes through sweat, urine, and exhalation to help maintain homeostasis in the body. The waste products include toxic materials, excess water, salts, CO₂, urea, minerals, and vitamins. The main organs of this system are the skin, lungs, kidneys, ureters, urinary bladder, and urethra, as shown in **FIGURE 4.1**.

The lungs remove excess CO₂ and some water vapor through exhalation. This action maintains the balance of O₂ and CO₂ in your blood. Sweat glands in the skin release excess water and salts. Sweat not only removes wastes but also cools the body to maintain a stable internal temperature.

The **kidneys** are organs that eliminate wastes by filtering and cleaning the blood to produce urine. The urine moves through the ureter, the bladder, and the urethra. The **ureter** (yu-REE-uh-tur) is a tube that carries urine from each kidney to the bladder. The **urinary bladder** is a saclike organ that can store up to half a liter (over 2 cups) of urine at one time. The urine is released through a single tube, the urethra, into the outside environment.

**Connect** When you are exercising, what organs of the excretory system are eliminating wastes? **TEKS 10C**
The kidneys help to maintain homeostasis by filtering the blood.

The kidneys are among the main organs responsible for maintaining fluid and chemical balances in your body within the limits that support life. One quarter of your blood supply passes through your kidneys every minute. Once the blood is filtered, cleaned, and chemically balanced by the kidneys, it is returned to the circulatory system.

Structure of the Kidneys
Your kidneys are a pair of bean-shaped organs, each about the size of your fist. They are located on the right and left sides of the lower back. Each kidney weighs about as much as a baseball. Most people are born with two kidneys. However, if one is damaged or must be removed, you can still live comfortably with only one kidney.

The main parts of the kidney are illustrated in FIGURE 4.2. Each kidney has an inner layer, called the medulla, and an outer layer, called the cortex. The cortex is packed with nephrons, which extend through the cortex and partly into the medulla. A nephron (NEHF-rahn) is the individual filtering unit of the kidney. Each of your kidneys contains about 1 million nephrons.

A large volume of blood continually enters the kidneys through the renal artery and exits through the renal vein. The word renal means “relating to the kidneys.” The function of the kidneys is largely controlled by how much water and how many salts and other materials are concentrated in the blood. Hormones released in response to these concentrations help to regulate kidney function.

Kidneys and Homeostasis
The kidneys have three basic functions in maintaining homeostasis.
- They remove waste products from the blood, such as those produced from digestion and cell respiration.
- They help to maintain electrolyte, pH, and fluid balances in the body.
- They release hormones that help to keep bones healthy, to produce red blood cells, and to regulate blood pressure.

What if the kidneys fail to work properly? Waste products quickly build up in the blood, causing serious disruptions in homeostasis in many organ systems. For example, imbalances in electrolytes such as sodium and potassium could disrupt the rhythm of the heart, causing the organ to fail. A buildup of toxic substances such as ammonium salts in the blood can impair the functioning of neurons in the brain. Someone with this condition would quickly become confused and disoriented.

Infer What might be one reason why so many nephrons are needed in the kidneys?
Nephrons clean the blood and produce urine.

The nephrons clean the blood in a three-step process: filtration, reabsorption, and excretion. First, water and other materials move out of the capillaries and into the nephron. Next, some of these materials are reabsorbed and returned to the blood. Finally, the remaining waste products are excreted in the urine.

Filtration
As shown in FIGURE 4.3, each nephron is supplied with blood through an arteriole, a venule, and a tangled ball of capillaries that is known as the glomerulus (gloh-MEHR-yuh-luhs). Each glomerulus is tucked into a cup-shaped structure called Bowman’s capsule.

When the blood enters the kidneys, it flows into the arterioles and then moves into the glomerulus of each nephron. Because the blood is under pressure, small molecules such as water, amino acids, salts, glucose, electrolytes, and urea are pushed out of the capillaries and into Bowman’s capsule. Urea is a waste product produced by the breakdown of proteins. Anything too large to move out of the capillaries—such as blood cells, plasma proteins, and platelets—stays in the blood.

Reabsorption of Materials
The materials in Bowman’s capsule are called the filtrate. The nephrons process about 180 liters (47.6 gal) of filtrate every day, yet only about 1 percent is excreted as urine. What happens to the other 99 percent?

Most of the filtrate is reabsorbed into the capillaries and returns to the blood. This process ensures that nutrients such as water, amino acids, glucose, and sodium (Na⁺) are made available to the body. The reabsorption of water and Na⁺ helps to maintain your fluid balance. For example, if you drink too much water, the nephrons will reabsorb less of the fluid and produce more urine. If you drink too little water, the nephrons will reabsorb more fluid and produce less urine.

Excretion of Materials
Finally, the waste products that are not reabsorbed are excreted in the urine. Urine is made up of water, urea, excess salts, and other materials that remain in the filtrate. These materials include ions such as potassium and hydrogen. Removal of some of these ions helps to maintain homeostasis by keeping the pH of the blood within normal limits. Filtrate moves out of Bowman’s capsule and is concentrated in the loop of Henle. The loop of Henle is where water is removed one final time to reduce the volume of urine.
FIGURE 4.3 Structures and Functions of the Nephron

The nephron filters the blood and produces urine through a three-step process.

1 **FILTRATION**
   Water, electrolytes, amino acids, glucose, urea, and other small molecules diffuse out of the blood, creating the filtrate.

2 **REABSORPTION**
   As the filtrate enters the rest of the tubule, most of the materials are reabsorbed into the blood. Materials not reabsorbed make up the urine, which flows into the loop of Henle.

3 **EXCRETION**
   In the loop of Henle, water can be reabsorbed one final time to reduce the volume of urine. The remaining urine flows into a collecting duct that leads to the ureter.

**CRITICAL VIEWING**
What might be one reason that the rest of the nephron is so long compared with the glomerulus?
The urine then moves into the collecting ducts. From there it flows through the ureter and into the urinary bladder. The adult bladder can hold about 1 liter (16 oz) of urine before it must be emptied. When the bladder is full, nerves in the walls of the bladder send signals to the brain, and you get the urge to urinate. In a healthy person, urine is a clear, pale-yellow fluid containing about 95 percent water and 5 percent waste products.

**Urine Testing**

When you go for a physical checkup, the doctor may ask you for a urine sample as part of a routine examination. The doctor is checking for normal urine content but also for materials that should not be there. For example, urine that contains sugar, protein, or blood may indicate that the nephrons have been damaged by an infection or injury. Ordinarily, these substances are too large to diffuse through the glomerulus. Also, any drugs that a person has taken are broken down in the liver, filtered by the kidneys, and excreted in the urine. A urine test is one way to determine whether a person is abusing drugs, and, if so, the types of drugs that may be involved.

**Apply** Which of the following substances would you find mainly in Bowman’s capsule: red blood cells, Na+, glucose, plasma proteins, water, or amino acids?

**MAIN IDEA**

**Injury and disease can damage kidney functions.**

You can live comfortably with one healthy kidney, but you cannot live without any kidney function. Although your kidneys can be damaged in an accident or by an infection, diabetes and high blood pressure are more often the causes of damage to nephrons. The presence of too much glucose in the blood or high blood pressure can damage the capillary walls in the glomerulus and make them more porous. As a result, too many substances pass through the walls, and the nephrons lose their ability to filter the blood. The only treatments for kidney failure are a kidney transplant or the use of dialysis.

**Kidney Transplant**

As described in **FIGURE 4.4**, a patient who needs a kidney transplant can receive a kidney from a close relative, such as a sibling, parent, or child. The tissues of both people are similar enough that the patient’s body will accept the new kidney more easily than a kidney from someone who is not related. Once the new kidney begins to function, the patient can live a fairly normal life.

Both the recipient and the donor must live with some restrictions, however. The recipient will have to take drugs that suppress the immune system for the rest of his or her life to guard against the possibility the body rejects the new organ. This also means that the person will be more vulnerable to infections from other people or from ordinary cuts and bruises. Both recipient and donor must generally avoid heavy contact sports, such as hockey, wrestling, or football. Any injury to the one kidney could be fatal.
Kidney Dialysis

If a kidney donor is not available or the patient cannot have surgery, dialysis can save the person’s life. Dialysis is a treatment in which a patient’s blood is cleaned and chemically balanced through a mechanical process. The blood is then returned to the patient’s body.

The main unit of a dialysis machine, as shown in Figure 4.5, acts like the glomerulus. Blood moves from a vein in the arm into the filtering unit. The tubing in the unit is porous, like the capillary walls, which allows waste materials to diffuse into the dialysis fluid. The fluid is continually replaced to carry wastes out of the unit. The chemical makeup of the fluid is as close to normal blood as possible. The process takes 3 to 5 hours and is done three times a week in the hospital or with a smaller dialysis machine in a patient’s home.

A few patients may prefer not to use a dialysis machine. Instead, they may be given peritoneal (per-ih-tuhn-EE-uhl) dialysis, in which the lining of the patient’s abdomen acts as a blood filter. Dialysis fluid is pumped through tubing into the abdomen. Waste products and excess fluid move from the bloodstream into the dialysis solution. The waste-filled fluid is drained from the abdomen and replaced several times until the blood is cleaned and chemically balanced.

Summarize Explain why people without kidney function would need to have dialysis at least three times a week.

**FIGURE 4.5 Dialysis Process**

The basic unit of a dialysis machine filters wastes from the blood.

- A trap prevents air bubbles from entering patient’s blood before it is returned to the body.
- Clean dialysis fluid flows in.
- A pump pushes blood through dialysis unit.
- Waste materials diffuse out of the blood, through membranes, and into the dialysis fluid.
- Used dialysis fluid flows out.
- Filter and bubble trap

Analyze Why does the dialysis fluid need to be continually replaced?

### 32.4 Formative Assessment

**REVIEWING MAIN IDEAS**

1. How do the main organs of the excretory system get rid of wastes?

2. Give two examples of how kidneys help to maintain homeostasis.

3. Describe the main structures of the nephron and their functions.

4. Explain how dialysis is similar to the way the kidneys filter the blood.

**CRITICAL THINKING**

5. **Apply** When kidney function is impaired, the pH level in the blood is disrupted. How would this loss of homeostasis affect the body’s cells?

6. **Explain** Briefly explain the following sentence: “Filtration of the blood is relatively nonselective, but reabsorption of materials is selective.”

**CONNECT TO RESPIRATION**

7. Compare the alveoli in the lungs to the nephrons in the kidneys. List the ways in which their structures and functions may be similar.
Chapter 32 Summary

**KEY CONCEPTS**

### 32.1 Nutrients and Homeostasis
Cells require many different nutrients. Six types of nutrients are important to maintain homeostasis in the body: water, carbohydrates, proteins, fats, minerals, and vitamins. These nutrients help to maintain fluid balance, cell processes, functions such as digestion and elimination, and tissue building and repair. A balanced diet and adequate Calories are especially important during puberty, a time of rapid growth and development.

### 32.2 Digestive System
The digestive system breaks down food into simpler molecules. The digestive system includes the mouth, esophagus, stomach, pancreas, liver, gallbladder, large and small intestines, rectum, and anus. Sphincters and the action of peristalsis keep food moving in one direction through the digestive system. Mechanical and chemical digestion help to break down food into simpler molecules. The process of digestion begins in the mouth, continues in the stomach, and is completed in the duodenum of the small intestine.

### 32.3 Absorption of Nutrients
Nutrients are absorbed and solid wastes are eliminated after digestion. Most absorption of nutrients occurs in the small intestine. The small intestine has specialized structures—folds, villi, and microvilli—that increase the surface area so that more nutrients can be absorbed. Nutrients diffuse into the circulatory and lymphatic systems and are carried to all the cells. The large intestine absorbs water and eliminates the solid wastes that are the byproducts of digestion.

### 32.4 Excretory System
The excretory system removes wastes and helps maintain homeostasis. The excretory system includes the skin, lungs, kidneys, ureter, bladder, and urethra. The nephrons in the kidneys filter the blood, reabsorb needed materials, and excrete waste materials in the urine. A person whose kidneys stop functioning must have a kidney transplant or dialysis treatment to maintain the body’s homeostasis.

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**Reading Toolbox**

**Concept Map** Use this graphic organizer to help you recall the functions of each of the six types of nutrients.

- **protein in food** is used to help build
  - cell membranes
  - enzymes

**Flow Chart** A flow chart like the one below can help you remember the steps in digestion.

```
<table>
<thead>
<tr>
<th>carbohydrates are first broken down in the mouth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
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Reviewing Vocabulary

**Vocabulary Connections**
For each pair of words below, write a sentence to clearly show how the terms are connected. For example, for the terms *stomach* and *chyme*, you might write, “Digestive juices in your stomach turn food into a semiliquid substance called chyme.”

1. esophagus, peristalsis
2. absorption, villi
3. ureter, urinary bladder
4. digestion, bile
5. small intestine, microvilli

**Keep It Short**
For each vocabulary term below, write a short phrase that describes its meaning. For example, a short phrase to describe *sphincter* might be “ring of muscle separating digestive sections.”

6. vitamin
7. Calorie
8. nephron
9. glomerulus

**GREEK AND LATIN WORD ORIGINS**
10. The term *chyme* comes from the Greek word *khumos*, meaning “juice.” Using this meaning, explain how it relates to what chyme is.

11. The term *dialysis* is based on the Greek word *dialuein*, meaning “to break up or to dissolve.” Explain how this meaning relates to the process of dialysis.

Reviewing MAIN IDEAS

12. List the six types of nutrients the body needs to maintain homeostasis. Which nutrients are the main sources of energy for the body? **TEKS 9A**

13. Explain why meeting nutritional needs is particularly important during pre-teen and teen years.

14. Explain the main purpose of the digestive system. In which organs does the chemical digestion of carbohydrates, proteins, and fats take place? **TEKS 10C**

15. What is the difference between mechanical and chemical digestion? Give three examples of enzymes involved in chemical digestion. **TEKS 9C**

16. Describe how the digestion of food is completed in the duodenum. What digestive organs are involved in this process? **TEKS 10C**

17. How are the nutrients from digested foods transported from the small intestine to the body’s cells? **TEKS 10A**

18. What are the two main functions of the colon? How can diet affect the functions of this organ?

19. List the main organs of the excretory system. Give two examples of how this system helps the body maintain homeostasis. **TEKS 10C**

20. The main functions of the kidneys are to maintain fluid and chemical balances in the body. Explain how the structure of the kidney helps it carry out these functions.

21. The nephrons filter the blood and produce urine. Describe the steps involved in this process.

22. How does diabetes or high blood pressure affect kidney function?
Critical Thinking

23. **Analyze**  A deficiency in calcium can cause spasms in the calf muscles at night. A woman complains to her doctor about this problem, yet she gets plenty of calcium in her diet. The doctor wants to check her kidney functions. Why would he suspect a problem with her kidneys?

24. **Infer**  A gastric ulcer is a type of sore that appears in the stomach lining. The ulcer can be caused by infection or by overuse of products like aspirin or ibuprofen. How might a gastric ulcer affect a person’s ability to digest food in the stomach?

25. **Infer**  A teenager wants to build muscle so he can compete better on the wrestling team. He decides to eat a diet of mostly meat and fruit juices. Within a week, he is constipated. What probably happened, and how can the problem be corrected?

Interpreting Visuals

Molecules move across a membrane by means of active or passive transport. In active transport, molecules can be pumped across a membrane into areas of higher or lower concentration. In passive transport, molecules can move only from an area of higher concentration to an area of lower concentration. Use the following diagram to answer the next three questions.

26. **Analyze**  Look at the concentrations of Na⁺ ions and H₂O in the diagram. Can more Na⁺ ions move out of the tubule? Explain your answer.

27. **Infer**  The membrane can change to let more or less water through. If a person were dehydrated, how might the membrane change? Explain.

28. **Evaluate**  If the body contains too much fluid, which way would H₂O molecules move across the membrane? Explain your answer.

Analyzing Data Identify Outliers

To educate young people about diet and health, a local hospital offered glucose testing so teenagers could learn more about how their bodies were functioning. Testing was done one to two hours after each meal so that the food was digested and nutrients were absorbed into the body. In a healthy person, glucose levels should be 80–120 mg/dL of blood before a meal and less than 180 mg/dL after food is digested. The graph below shows the results for one teenager. Use the graph to answer the next two questions.

**GLUCOSE LEVELS**

<table>
<thead>
<tr>
<th>Glucose levels (mg/dL)</th>
<th>B</th>
<th>L</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1</td>
<td>100</td>
<td>150</td>
<td>200</td>
</tr>
<tr>
<td>Day 2</td>
<td>150</td>
<td>100</td>
<td>150</td>
</tr>
<tr>
<td>Day 3</td>
<td>200</td>
<td>150</td>
<td>100</td>
</tr>
<tr>
<td>Day 4</td>
<td>100</td>
<td>150</td>
<td>200</td>
</tr>
<tr>
<td>Day 5</td>
<td>150</td>
<td>200</td>
<td>100</td>
</tr>
</tbody>
</table>

**Testing times at meals**

B = Breakfast
L = Lunch
D = Dinner

29. **Analyze**  What is the typical glucose range for this teenager after meals? Which point is the outlier in this data set?

30. **Evaluate**  What are some possible explanations for the outlier data? How should the scientists proceed?

Making Connections

31. **Blog a Snack-Food Challenge**  More companies are offering alternative, “healthier” snack foods, such as protein bars or fruit strips. Your challenge: Use your knowledge of food labels to compare the nutritional information on these products with other snack foods such as candy bars and potato chips. Write a blog entry on your findings, including each product’s nutritional content, its cost, and where you can buy it.

32. **Synthesize**  The photo on the chapter opener shows the specialized cells in the lining of the stomach. Use what you know about the digestive process and the digestive tract to explain why the processes that occur in the stomach could not occur anywhere else.
Record your answers on a separate piece of paper.

MULTIPLE CHOICE

**TEKS 2E**

1. Scientists studying the effects of two different diets monitored three groups of people for one year. The first group was not asked to change the way they ate. The second group followed Diet A. The third group followed Diet B. The first group was asked not to change their diets in the study because —
   A. scientists knew that people would drop out
   B. scientists knew this group would lose weight
   C. the group acted as a control for the study
   D. the group acted as a model for the study

**TEKS 3E, 10C**

2. A student made a simple model to demonstrate digestion. A plastic bag and mallet were used to represent the chewing action of teeth in the mouth. A deflated balloon that could be twisted to churn food represented the stomach. Pantyhose that could be squeezed and stretched were used as a small intestine. One limitation of this model is that —
   A. it does not include chemical digestion
   B. it does not include mechanical digestion
   C. the order of the organs is incorrect
   D. model parts are each made of the same thing

**TEKS 10A, 10C**

3. In order for cells of the body to receive nutrients from the food that we eat, digestion must be followed by —
   A. excretion
   B. fluid retention
   C. respiration
   D. absorption

**TEKS 10A, 10C**

4. Chemical digestion occurs throughout the digestive tract. The stomach releases pepsin, the liver and gallbladder release bile, the salivary glands release amylase, and the pancreas releases an alkaline fluid. Together, these processes are an example of —
   A. the release of unnecessary chemicals
   B. coordinated function within an organ system
   C. a positive feedback loop between organs
   D. a negative feedback loop between organs

**TEKS 10A, 10C**

5. Lungs are part of both the respiratory system and the excretory system. In their function as excretory organs, the lungs help remove which waste products from your body?
   A. oxygen and water vapor
   B. oxygen and carbon dioxide
   C. carbon dioxide and water vapor
   D. water vapor only

**THINK THROUGH THE QUESTION**

Think about what is present in the air that is not required by the respiratory system, and therefore would be removed by the excretory system.

**TEKS 10A, 11A**

6. Which of these terms best completes the concept map below?

   ![Concept Map]

   A. nutrients
   B. water
   C. waste products
   D. red blood cells

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