



## INTRODUCTION TO **ANATOMY AND PHYSIOLOGY**

**T**he human body is a complex organism that functions at many different levels. This module provides a broad prospective on what the rest of this text will cover in detail. It is important that you achieve a complete understanding of each module before you move on to the next.

**Anatomy** is the study of the structure of the body and its parts, while **physiology** is the study of how those parts function and work together to make the human body the wonder that it is. There are many different ways that anatomy can be studied.

**Developmental anatomy** is the study of the changes that begin in the human body at conception and proceed into adulthood. **Embryology** is the subdivision of developmental anatomy that covers the first eight weeks following conception. This time period is filled with amazing moment-to-moment changes.

**Surface anatomy** is used for diagnosis. When a physician feels your skin to determine whether your glands are swollen or if there are any suspicious lumps or bumps on your body, the physician is using surface anatomy.

**Regional anatomy** means analysis of specific parts of the body. Have you ever been to a podiatrist (foot doctor)? Podiatrists treat diseases of the feet, including warts, infected toenails, and aches and pains of the many joints within the feet. Podiatry is a good example of an application of regional anatomy. The podiatrist needs to know the precise location of blood vessels, nerves, muscles, tendons, ligaments, and bones. How

### *heart of the matter*

Each of your cells is its own incredible world, containing basic knowledge of how to survive. Instead of living for itself, however, each cell cooperates with other cells to form and sustain the anatomy and physiology of your body. You are probably not even aware of your cells' individual presences. As you read through this chapter, take a few moments to contemplate how complex your body is and how no part functions entirely on its own.

else could the podiatrist, for example, safely inject an anti-inflammatory medication into a patient's painful foot?

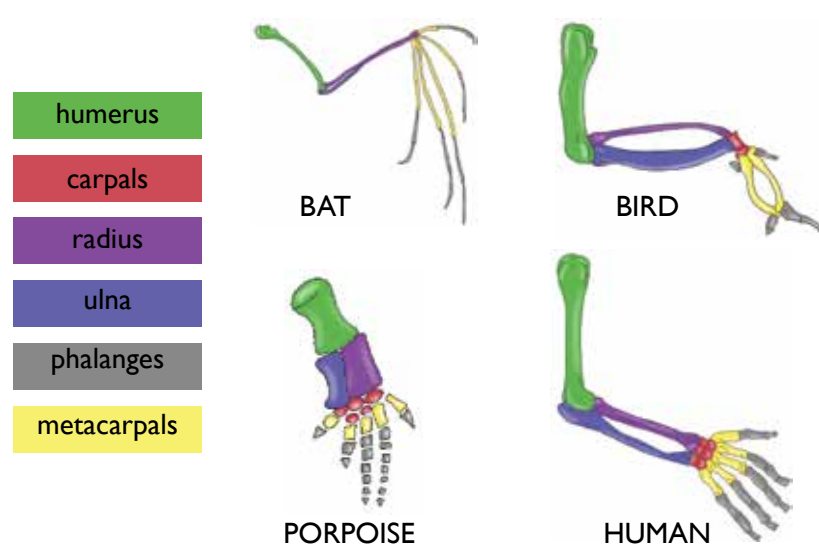
In this course, the majority of study will focus on **gross anatomy**. *Gross* in this context means large, so you will be studying systems that you can see. The term **macroscopic anatomy** is also used to mean gross anatomy. To understand how an organism functions, however, you sometimes have to see it up close. **Microscopic anatomy** is the study of structures so small that you will be required to use a microscope to see them. As necessary, we will cover microscopic anatomy.

This text concentrates on **systemic anatomy**, which means anatomy of the **organ systems**—groups of organs related by shared functions. One example of systemic anatomy is the digestive system. The organs—teeth, tongue, esophagus, stomach, intestines, liver, pancreas, and others—all cooperate as a system to provide a common function, which is digesting food. Systemic anatomy is the best approach when both anatomy and physiology are being studied at the same time.

**Comparative anatomy** refers to the anatomy of nonhuman species, and it can be used to assist in the study of the human body. Your dissection labs are a comparative anatomy study. For example, the bones of some animals are homologous (huh mol' uh gus), which means that they are similar.

As demonstrated by figure 1.1, comparative anatomy is truly a fascinating study. The human forearm is made of two bones called the radius and the ulna. A porpoise's flipper also has a radius and ulna, and the bones that form a bird's wing include a radius and ulna. Thus, we could say that a porpoise swims with its "arms" and a bird flies with its "arms." A bat's "arm" also contains a radius and an ulna, but they are small. Bones that are similar to human finger bones (phalanges) form the bat's wings. Thus, we can say that the bat flies with its "fingers."

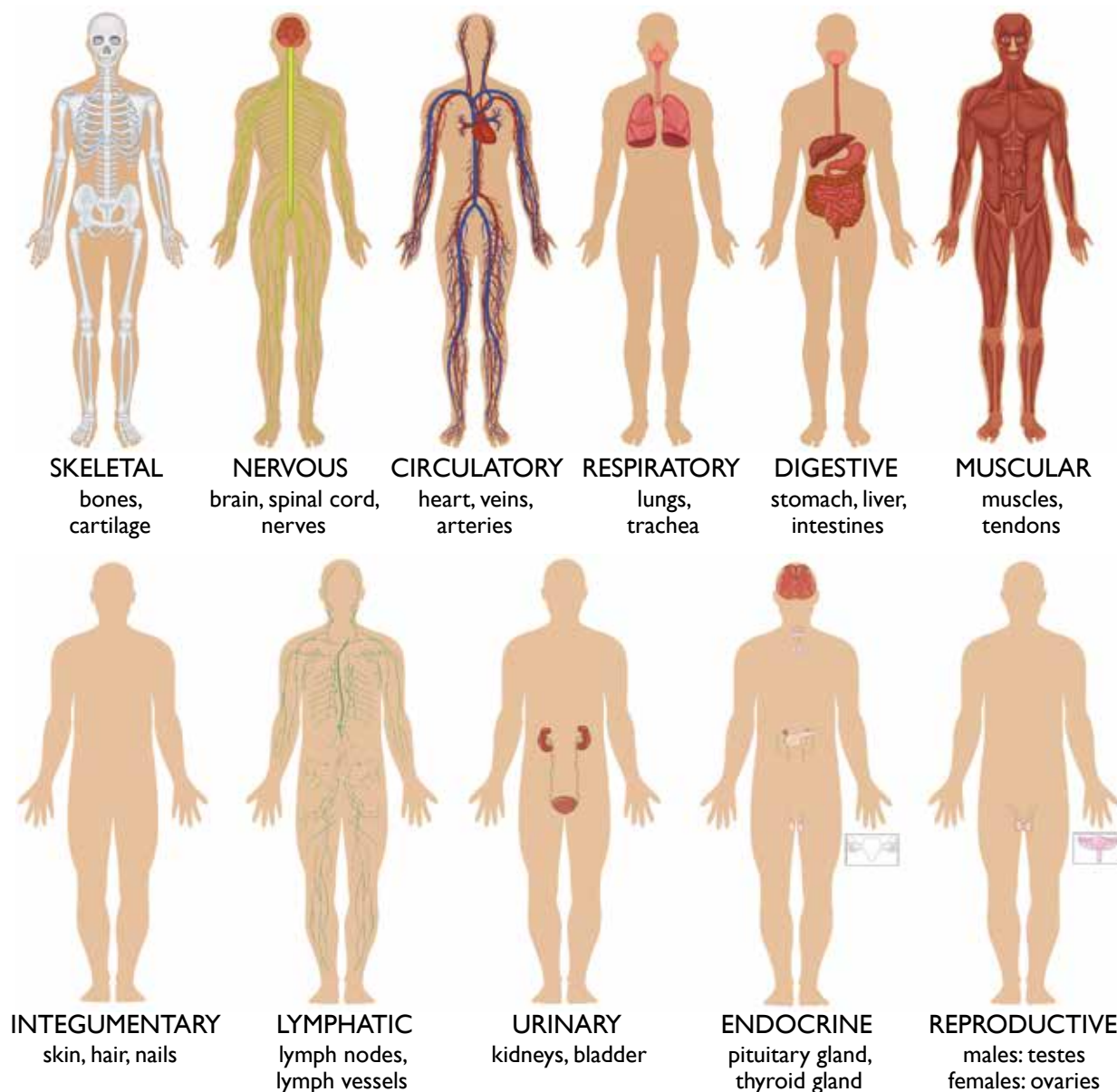
Do not worry about memorizing the bones in this figure. For right now, just notice that even though bats, birds, porpoises, and people are quite different from one another, they have similar bones. In other words, these bones are homologous.



**FIGURE 1.1**  
Comparative Anatomy of Upper (Fore) Limbs  
Illustration by Megan Fruchte

## ORGANIZATIONAL LEVELS OF THE HUMAN BODY

The first thing you need to be familiar with is that the human body is organized on several different levels. The highest level of organization is the entire person, or whole **organism**. The entire person, of course, is made up of a single human body. When we look at that human body from a scientific point of view, what do we see? First, *we can divide the entire body into eleven different organ systems*.



**FIGURE 1.2**

The Eleven Organ Systems in the Human Body with Examples of Organs

Illustrations: first eight © Matthew Cole, last three by Megan Fruchte

An **organ system** is a group of organs that work together to perform related functions. As you will learn, some organs belong to more than one organ system.

The **skeletal system** is made up of the bones in your body and their associated

cartilages, ligaments, and joints. It provides support, as in the leg bones, and protection, as in the skull and ribs. It gives shape to the body, and its joints allow the body to move. It also produces blood cells.

The **nervous system** is composed of the brain, spinal cord, nerves, and all of your body's sensory receptors, including vision, hearing, smell, taste, and touch receptors. It detects sensations and controls movement, and it controls intellectual function. It regulates the other organ systems, and so is "in charge" of many physiological processes, both conscious and unconscious. It is capable of very rapid responses.

The **circulatory system** is composed of the heart, blood vessels, and blood. It transports gases, nutrients, waste products, hormones, and many other molecules throughout your body. It has an active role in your immune system and also aids in the regulation of your body temperature.

The **respiratory system** contains your lungs, respiratory passages, and diaphragm. It enables the exchange of oxygen and carbon dioxide between your blood and the air. It also has a role in regulating your blood pH.

The **digestive system** is perhaps the most familiar of all the organ systems. Your mouth, esophagus, stomach, intestines, liver, gallbladder, pancreas, appendix, and rectum are all part of it. It breaks down the foods you eat so that they can be absorbed out of the intestines into the blood, and it eliminates waste products.

The **muscular system** consists of the muscles of your body. It powers the movements of your skeleton and maintains your posture when you stand still. It enables internal organs such as the heart, diaphragm, stomach, and intestines to move. It is also used to generate heat, as when you shiver.

The **integumentary system** consists of skin, hair, sweat glands, oil glands, and nails. Its purpose is to protect your body, regulate your body temperature, prevent water loss, and aid in the production of vitamin D.

The **lymphatic system** consists of a multitude of organs, including your spleen, thymus gland, lymphatic vessels, and lymph nodes. It is sometimes called the **immune system**, because it gets rid of foreign substances such as bacteria, viruses, and fungi that may invade your body. But in addition to fighting disease, its thin-walled lymphatic vessels maintain the right amount of fluid around your cells, and these vessels also absorb fat from your digestive tract.

The **urinary system** consists of your kidneys, urinary bladder, ureters, and urethra. It removes waste products from your blood, and it regulates blood pH, ion balance, and water balance.

The **endocrine system** is made up of a number of organs that secrete signal molecules called **hormones**. The hypothalamus, pineal gland, pituitary gland, thyroid gland, parathyroids, thymus, adrenals, pancreas, ovaries (female), and testes (male) are all typical hormone glands.

However, the heart, stomach, small intestine, and kidneys also secrete hormones, even though we usually classify them with other organs systems. Along with the nervous system, the endocrine system regulates other organ systems. This system influences metabolism, growth, reproduction, and many other unconscious internal functions of your body. It generally acts more slowly than does the nervous system.

The **reproductive systems** are made up of the female ovaries, vagina, uterus, and mammary glands; or the male testes, penis, prostate gland, and other internal organs.

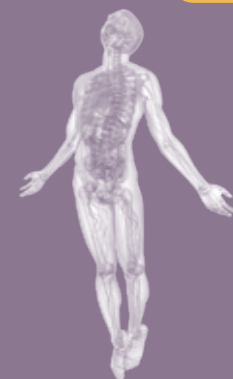
The female reproductive system produces oocytes for fertilization, provides a place for fetal development, and produces milk for the newborn. The male reproductive system produces and transfers sperm for fertilization. Both the female ovaries and male testes produce important reproductive hormones.

This is the big picture of what you will study throughout this course. By the time you are done, you will have greater knowledge of each of these organ systems.

We've mentioned the term *organ* a few times, but we really have not defined it yet.

## COLORING BOOK EXERCISE 1.1

In the laboratory supplies for this course, we have included *The Anatomy Coloring Book* by Kaplan. This is an excellent tool for remembering anatomy. We recommend reviewing what you have just learned by coloring in the organ systems found on pages 9-13 in this coloring book.



### Organ—A group of tissues specialized for a particular function

Examples of organs include the liver, lungs, kidneys, heart, skin, and many others that you could list. Of course, the definition of an organ does not do much good without a definition of *tissues*. Tissues are like building materials that can be assembled in multiple ways to build the structures of your body.

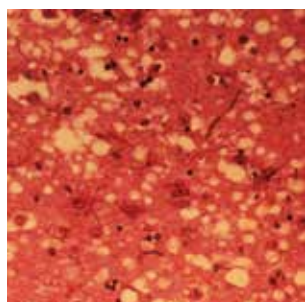
### Tissues—Groups of cells forming various building materials of the body

Now, here is an amazing thing. There are eleven organ systems in your body, and each of those systems is made up of many different organs. Thus, there are a *lot* of organs in your body, and some organs are members of more than one organ system. You would, therefore, expect there to be a multitude of tissues in the body; however, *there are only four basic kinds of tissue in the entire human body!*

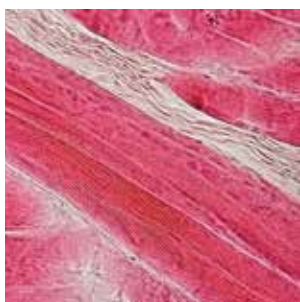
The first basic kind of tissue is *nervous tissue*. It makes up the brain, spinal cord, and nerves. Nervous tissue has the ability to conduct electrical signals.

*Muscular tissue* comprises the muscles that enable your skeleton to move, your heart to beat, and your other internal organs to push food or fluid along.

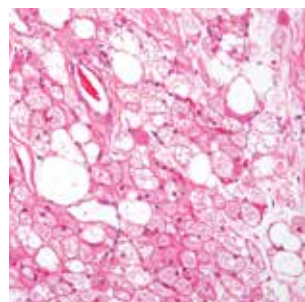
The third type of tissue is *connective tissue*, which makes up bone, cartilage, the deeper layer of the skin, and the bindings or connectors around and between organs. The bridge of your nose and the flexible part of your ears are



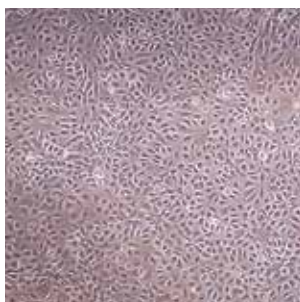
NERVOUS TISSUE



MUSCULAR TISSUE



CONNECTIVE TISSUE



EPITHELIAL TISSUE

**FIGURE 1.3**

Four Types of Tissue

Photos (clockwise from top left): Public Health Image Library, APHIS, PD; Department of Histology, Jagiellonian University Medical College, cc-by-sa 3; Nephron cc-by-sa 3; Subclavian, PD

cartilage. Even your body fat and your blood are connective tissues.

The last of the four basic kinds of tissue is **epithelial** (ep uh theel' ee uhl) **tissue**. The surface of your skin is epithelial tissue, as is the inner lining of your respiratory passages, digestive tract, urinary tract, and reproductive tract. Glands, including your thyroid gland, liver, and many others, are also made of epithelial tissue.

Are you beginning to see a pattern here? The human body is organized into organ systems. Each organ system is composed of specific organs, which do one or more jobs to achieve common goals. Each organ is composed of tissues. Notice, then, that we have already discussed four levels of organization in the human body: whole body, organ system, organ, and tissue. The first three levels are part of the study of gross anatomy.

Tissues are best studied at the level of microscopic anatomy because each tissue is composed of specific **cells**. The cell is the basic unit of life. The trillions of living cells that make up your body are themselves composed of membrane-bound **organelles**, which means little organs. Thus, even your cells are composed of smaller units! Beyond this level is biochemistry. Organelles are formed from incredibly complex molecules, such as proteins, fatty acids, and carbohydrates. Finally, these **molecules** are a combination of atoms; see figure 1.4.

## COLORING BOOK EXERCISE 1.2

The levels of organization are illustrated and discussed on page 5 of your coloring book. Use this as a review for what you have just learned. Note that the coloring book refers to these levels as the hierarchy of the body.

## ON YOUR OWN

**1.1** Certain muscles are attached to your skeleton by tendons. Of the four tissue types, which kind makes up tendons?

**1.2** Which three levels of organization in the human body are studied in gross anatomy?

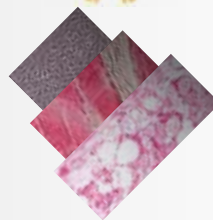
1. The **Whole Organism** is made up of eleven organ systems.



2. **Organ Systems** consist of groups of organs that work together to perform related functions.



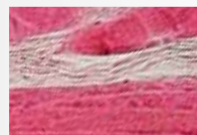
3. **Organs** consist of different types of tissues.



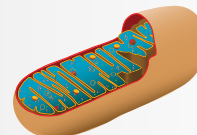
4. **Tissues** consist of similar types of cells and the materials around them.



5. **Cells** are made up of organelles.



6. **Organelles** are the "little organs" of the cell. They are made of molecules.



7. **Molecules** that cells make include DNA, RNA, proteins, fatty acids, and carbohydrates. Molecules consist of complex arrangements of atoms.



**FIGURE 1.4**

Seven Levels of Organization

Photos (top to bottom): Dreamstime; composite of illustrations by Matthew Cole; Department of Histology, Jagiellonian University Medical College, cc-by-sa 3; Nephron cc-by-sa 3; Subclavian, PD; Mariana Ruiz Villarreal LadyofHats; Inc ru, cc-by-sa 3.0

## think about this

When you were growing up, you found stability and security in having boundaries. Your parents set the boundaries for you because they knew what was required to help you grow and learn about God's purpose for your life. Your physical body also requires boundaries. Homeostasis keeps your body functioning within the boundaries necessary for maintaining your life.

### HOMEOSTASIS

We have briefly introduced to you the anatomy (structure) of the body, which underlies the physiology (function) of the human body. What is the goal of physiology? *The goal is to maintain life and health in spite of the many changes, inside and out, that are always occurring.*

Energy must be expended constantly to maintain life, so energy must be acquired from outside the body in the form of

food. That food must be processed, delivered to each cell, and then used by those cells as building materials or as an energy source. For example, the molecules that make up your organelles deteriorate and must be replaced, a process that requires both materials and energy. In thousands of ways, moment by moment, the organ systems maintain the body so that it can continue to live and be healthy. We could say that the goal is to keep the body working “normally” or “with stability” despite constant external and internal changes. The scientific term for this ongoing stability despite ongoing change is **homeostasis** (ho' me oh stay' sis).

**Homeostasis**—A state of dynamic equilibrium in the body with respect to its internal environment and functions

Let's analyze that definition for a minute. Equilibrium means balance or stability, and dynamic refers to energy. The “internal environment” in this usage means the surroundings of the cells that make up the body. “Functions” might be defined as the tasks the cells perform. So, homeostasis means the ability of your body to maintain itself in a stable balance despite the fact that energy must be used to do so. That healthy stability is maintained internally around the cells. That environment is far different from the external environment, outside the body.

Homeostasis is *the* big idea of physiology, and we will help you to gradually develop your understanding of it. Yes, we need to have a stable environment within our bodies, and there are many different **variables** within, such as temperature, acid-base balance, nutrient levels, blood pressure levels, oxygen levels, and waste levels, that must be controlled. What keeps us alive is the ability to maintain these variables and many more around some normal level, which we call a **set point**. These variables can change somewhat, but only within certain limits. If they would change too much, serious problems, illness, or death would result. Each of the organ systems illustrated in Figure 1.2 is responsible for maintaining some aspect of homeostasis for the entire person.

**Set point**—Ideal normal value of a variable around which homeostasis is maintained through a normal range of values that are acceptable to the body

Blood pressure is a variable that offers a good example of how homeostasis is maintained. Your blood pressure can go up under certain conditions (such as when you exercise), and it can go down under other conditions (such as when you are asleep), but it is controlled within a normal range. Thus, your body is constantly working to ensure that your blood pressure stays in equilibrium around the set point. That is a practical application of the concept of homeostasis.

Your body temperature is another variable that must be controlled. Whether your external environment is really cold or really hot, the temperature of your internal environment does not vary much. Even when you have a fever, your body temperature is still not out of control. Your body has merely increased the set point for body temperature to deal with an infection. There are many variables within the body that must be controlled in order for the body to work properly. When those variables are within the normal range of acceptable values, the body is in a state of homeostasis. It is healthy!

Your body requires mechanisms to maintain homeostasis because the outside world (the external environment) and the needs of the body itself subject your body to stress. Now when you hear the term stress, you probably have a specific idea in mind. For example, studying for a hard test might cause you stress. In this course, however, we use the term in a much broader sense. **Stress** is an imbalance in the internal or external environment that causes one or more variables to move away from its set point. This causes your body to react to return the variable to an acceptable value. If the variables are not corrected, your health will be affected. In other words, stress is an imbalance that must be corrected to maintain homeostasis.

**Stress**—A factor that causes one or more physiological variables to move away from its homeostatic set point

The common cold is an example of a stress. Colds are caused by viruses that have invaded your body. You might not think that a cold is very bad but that's because you have an organ system (the lymphatic system) which creates uncomfortable symptoms as it combats the virus and rids it from your body, restoring homeostasis. Without your lymphatic system, the common cold probably would be called *the fatal cold*.

The organ systems in the body, each in their own ways, contribute to homeostasis. The urinary system maintains acid-base balance; the respiratory system maintains oxygen and carbon dioxide balance, and so on, as you will learn throughout this course. Each organ system counteracts particular stresses so as to maintain the body's normal balance. Some physiologists propose that there is one exception among the eleven organ systems, however. Can you guess which one? It is the reproductive system, which is designed to propagate the human race. We will discuss this in a later chapter.



**FIGURE 1.5**  
Homeostasis

Your body constantly monitors its temperature and adjusts to maintain homeostasis. This child is sweating (integumentary system) because he is too hot. If this child were to get too cold, he would start to shiver (muscular system). The motion of the muscles would produce heat, warming the body.  
Photo © iStockphoto/Terryj

## CONTROL OF HOMEOSTASIS: FEEDBACK SYSTEMS

Let's look for a moment at the **control mechanisms** of homeostasis. You will see that the issue of control will come up again and again throughout this course. It is one of the most fundamental aspects of physiology. Two organ systems, the nervous system and the endocrine system, are responsible for “deciding” if a variable is moving away from a state of homeostasis. They then initiate a message to correct the imbalance. The brain and spinal cord, together called the **central nervous system**, act as the nervous system's **control center**. **Endocrine glands** also serve as control centers. They secrete chemical messengers called **hormones** that signal the proper organs to respond in such a way as to maintain homeostasis.

## *think about this*

Did you know that the simple act of standing up after lying down is actually a major change for your body? When you stand up after you have been lying down, your blood pressure drops as gravity pulls your blood away from your head. Your body quickly compensates for this change through a negative feedback mechanism. Otherwise, if you stood up suddenly, you would faint, because your blood pressure would be too low. Have you ever gotten light-headed after standing up too quickly? That happened because your negative feedback system took a little too long to raise your blood pressure.

**Control center**—The part of the body, either central nervous system or endocrine gland, that receives information about a variable, determines the set point, and signals a response to correct imbalances

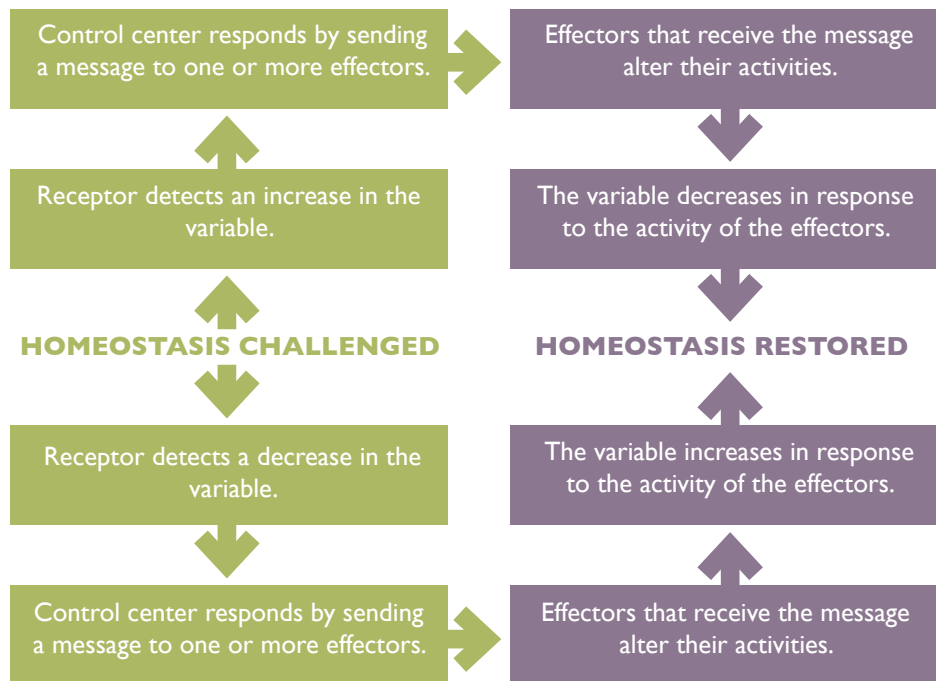
Here's an example of how homeostasis works. Earlier, we told you that blood pressure must not get too high or too low. A “happy medium” keeps you healthy. Your body's blood pressure is detected by sensory **receptors** located in arteries near the heart and in the neck. When these receptors sense high blood pressure, nerves associated with them send a message to your brain, the control center, indicating that your blood pressure is too high.

**Receptor**—A structure in the body that monitors the values of your body's variables

Your brain, however, can't directly lower blood pressure. In order to get the job done, it sends a message via nerves to an **effector**. The effector makes the change. In this example, the effector is the heart, which slows down in order to lower your blood pressure.

**Effector**—A structure in the body that can change the value of a variable in response to a signal from the control center

As the definition indicates, the effector can change the blood pressure. In this example, the brain sends a message via nerves to the effector, and the effector then lowers the blood pressure. The effect, called the “response,” is that your blood pressure drops. This, then, is an example of how your body detects and counteracts stress. What we have here is a really useful process called a **negative-feedback system**, which is illustrated in figure 1.6.



**FIGURE 1.6**  
The Body's Negative-Feedback System

**Negative-Feedback System**—A control mechanism consisting of receptors, control center, and effectors through which homeostasis in the body is maintained by regulation of the body's organ systems. It is called negative feedback because the control system *opposes or reverses* the original stress.

Now think of the blood pressure example we just gave you in terms of the upper part of figure 1.6. An increase in blood pressure is detected by the receptors in your arteries. Those receptors send signals about the blood pressure that your brain (the control center) monitors. If the brain senses that your blood pressure is getting too high, it sends a message via nerves to one or more effectors. In our example, we used only one effector, the heart. Your heart changes its activity (it slows down), and the result is that your blood pressure decreases. Thus, an *increase* in blood pressure detected by the control center produced a reaction that caused a *decrease* in the blood pressure.

The opposite can happen as well. Look at the lower portion of figure 1.6. Remember, blood pressure that is too low is also a stressor. If the receptors in your arteries detect a decrease in blood pressure, they will relay that information to the brain. As the control center, the brain will recognize that your blood pressure is getting too low, and it will send a message to your heart (the effector). The message will be for your heart to speed up, and the result will be that your blood pressure increases. So, in this case, a *decrease* in blood pressure produces a reaction that will *increase* blood pressure. That's what negative feedback means—the feedback system detects a change and initiates the *opposite* effect. *Negative* in this usage means “opposite.”

Let's go through one more example. As you know, the level of glucose in your blood is closely regulated, whether you have just eaten a big meal or whether you have not eaten

for many hours. Blood glucose is sensed by receptors in your pancreas. If your pancreas (the control center in this case) receives information from its receptors that blood glucose levels are too high, it releases the hormone **insulin** (in' suh lin) into your blood. Insulin affects most of the cells in your body. They respond to the insulin by taking in glucose. This removes glucose from your blood, which results in a decrease in the blood glucose level. This is negative-feedback because the response *reverses* the stress.

What body system is the control center in this negative feedback mechanism? The *endocrine* system. Hormones are secreted by the endocrine system. Thus, *if a hormone is involved, the endocrine system must be involved.*

In summary, homeostasis is controlled by negative-feedback mechanisms. Both the nervous system and the endocrine system are used as control centers to maintain homeostasis within the body. This is no small feat given that these systems coordinate homeostasis for trillions of cells!

Before we end this discussion, we should mention positive-feedback systems. That sounds great, does not it? *Positive* means “good,” right? Well, not when it comes to feedback mechanisms! Positive-feedback systems are naturally unstable and *escalate* the imbalance, moving the body farther and farther away from homeostasis. They can lead to disease or death unless they are interrupted.

Nevertheless, there are certain times when positive-feedback systems are important in human physiology. When we study the reproductive process toward the end of this course, you will see an example of a positive-feedback system that is necessary for childbirth. However, that positive-feedback system is *eventually* interrupted by the birth of the baby, and a negative-feedback system takes its place. Thus, even the positive-feedback systems that are necessary in the body (there are not many of them) must eventually be interrupted.

### ON YOUR OWN

We already have discussed shivering as a response to the body being cold. Here's how it works. Receptors in the skin send temperature information to the hypothalamus (hi poh thal' uh mus), a structure in the brain. If the hypothalamus “decides” that the temperature is too low, it can send signals via the nerves to the muscles. These signals cause the muscles to start moving rapidly, which we observe as shivering. This increased movement produces heat, which warms the body.

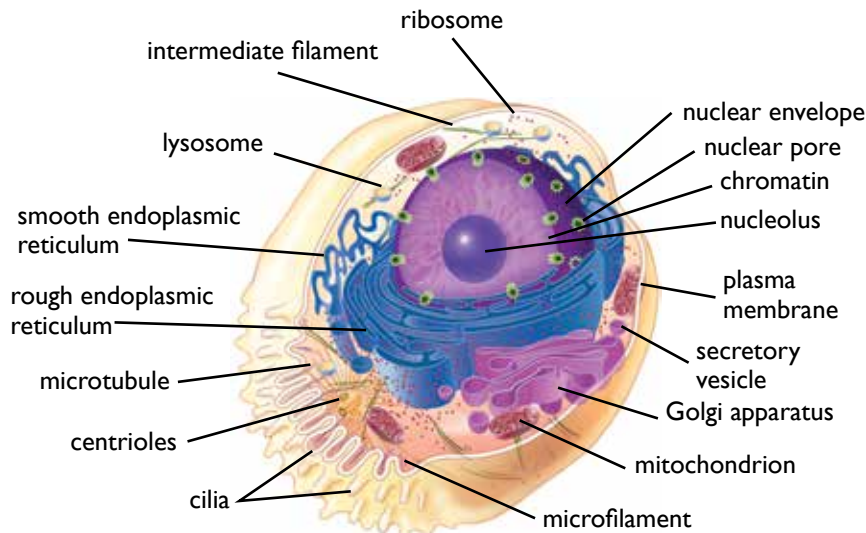
- 1.3** Is this a negative- or positive-feedback system? Why?
- 1.4** What is the control center for the system?
- 1.5** What is the effector?
- 1.6** Based on this description, is the endocrine system involved in this process?



### A REVIEW OF CELL STRUCTURE AND ORGANELLE FUNCTION

So far, in terms of organization in the human body, we have talked about the organism, the organ systems, and the organs. In the next module, we will discuss tissues, so we will not talk about that level of organization here. Instead, we will jump down to the next levels of organization: the cell and its organelles. We will not spend too much time on this subject. The majority of your anatomy and physiology study will occur at the tissue level and above.

Figure 1.7 is a drawing of an idealized animal cell. All members of kingdom Animalia, including human beings, have this basic kind of cell. You have to realize, however, that there is probably no cell in the human body that looks exactly like the illustration in the figure. Indeed, some cells (such as neurons) look quite different from what you see here. Nevertheless, the features that you find in various cells throughout the body are woven together into this idealized representation of a typical animal cell.



**FIGURE 1.7**  
An Idealized Animal Cell  
Illustration: Jennifer Fairman

Of course, not every cell will have all of the features pointed out here. The key is that all of the features pointed out exist in at least some cells. For example, mature red blood cells do not have a nucleus. Nevertheless, most of your other cells do. Cells that line your trachea (the airway to your lungs) are an example of cells with cilia, but most of your cells do not have cilia.

Remember, tissues are composed of cells, and cells are composed of organelles. In order to understand cells, you need to know the major organelles and their functions. Let's start with the **plasma membrane**. The plasma membrane is the boundary of the cell. It holds the cell together and controls entry and exit of substances. It has many receptors on it, allowing it to determine what substances are transported into the cell and what substances are allowed out of the cell.

The next organelle to consider is the **nucleus**. It's wrapped in a nuclear membrane called the **nuclear envelope**. It is actually a double membrane, which is quite porous. The nucleus contains the genetic material, which is DNA (deoxyribonucleic acid). Except during cellular reproduction, the DNA is "spread out" in the nucleus. We usually use the term **chromatin** (kro' muh tin) to identify it. During cellular reproduction, the DNA forms **chromosomes** (krom' uh sohms). We will go over that in a later section of this module. The nucleus can be thought of as the control center of the cell because the DNA is there. The DNA codes for all the proteins that the cell produces.

Between the nucleus and the cell membrane, **cytoplasm** (sigh' toh plaz uhm) is found. The fluid part of the cytoplasm, called **cytosol**, contains many dissolved chemicals,

## think about this

Although the cells in your body are all chemically similar, they are as diverse as flowers in a florist shop. Some journey through your body to bring oxygen to other cells; others enable your body to move. Bone cells provide rigid structure for your body, and soft skin cells contribute to your physical appearance. No matter how small and odd your cells may seem, they all work together to create the wonder of your life.

including ions, proteins, and other molecules. These chemicals are used for various processes, including the breakdown of sugars and fats, as well as for the production of other chemicals that the cell needs.

If we think of the nucleus as the control center of the cell, the **ribosomes** (rye' buh sohms) can be thought of as tiny kitchens within the cell. Proteins are synthesized in the cell's ribosomes.

The proteins that a cell produces

are a major part of determining what the cell does for the body. So, the ribosomes are an essential part of the cell. Because they are so tiny, they are represented by dots in the figure. Sometimes, the ribosomes stand alone. If so, they are called **free ribosomes**. You may also find ribosomes attached to the next organelle that we will discuss, the **endoplasmic** (en' doh plaz' mik) **reticulum** (re tik' you luhm).

The prefix *endo* means “within,” and *plasmic* refers to the cell's cytoplasm. The word *reticulum*, from the Latin, means “network.” Thus, the endoplasmic reticulum is the network within the cell's cytoplasm. There are two types of endoplasmic reticulum: **smooth endoplasmic reticulum** and **rough endoplasmic reticulum**. The smooth endoplasmic reticulum is a series of tubes that are used in intracellular transport (transport within the cell) as well as in the production of lipids and carbohydrates. Rough endoplasmic reticulum is also used for intracellular transport, but it is rough in appearance because it has ribosomes on it. Because of these ribosomes, rough endoplasmic reticulum is used in protein synthesis as well as intracellular transport of proteins. The amount of smooth and rough endoplasmic reticulum can give you a clue as to the function of the cell. Cells with large amounts of smooth endoplasmic reticulum usually specialize in the production of lipids and carbohydrates. Cells with large amounts of rough endoplasmic reticulum specialize in protein synthesis.

The **Golgi** (gol' jee) **apparatuses** can be thought of as the cell's packaging plants. They take various chemicals and package them for many purposes, especially secretion. This packing may involve chemical modification. Nervous system cells, called neurons, have many Golgi apparatuses. That should tell you something about what they do. They secrete chemicals. When you eat, your salivary glands secrete saliva. This is done by the Golgi apparatuses within the salivary glands' cells.

The **secretory** (sec' ruh tor ee) **vesicle** in figure 1.7 came from the Golgi apparatus. When the Golgi apparatus has packaged a chemical for secretion, it puts the chemical into a secretory vesicle, which is a tiny membrane-bound sac. The vesicle then pinches off the Golgi apparatus and travels through the cytoplasm to the plasma membrane, where its contents can be released outside the cell. Often, a cell will build up secretory vesicles, but those vesicles will not release their chemicals until the cell gets a signal. For example, in our earlier discussion of blood glucose level, we mentioned that the pancreas releases insulin when the blood glucose level increases. That is done by cells in the pancreas whose Golgi apparatuses produce secretory vesicles full of insulin. However, those cells do not release their insulin

## science and creation

Mitochondrial DNA is ideal for determining your maternal heritage because all of your mitochondrial DNA comes from your mother, as you will understand better when you study reproduction. However, since there is much less mitochondrial DNA compared to nuclear DNA, scientists must be careful about drawing too many conclusions when studying it. In 2008, for example, a study was done comparing mitochondrial DNA found in the skeletons of Neanderthals to that of the mitochondrial DNA from people living today. It was concluded that Neanderthals were a completely different species from humans! However, in 2010, a study was done comparing the nuclear DNA of Neanderthals and people living today, and that study concluded that Neanderthals and humans are both members of the same species. The conclusions of the latter study confirm what creationists have been saying about Neanderthals since they were first discovered. It is the more reliable of the two studies, since nuclear DNA is a more complete data set from which to draw such conclusions.

sometimes actually a *good* thing. When we need to get rid of diseased or damaged tissues, the lysosomes provide a way for these cells to, in effect, self-digest. White blood cells, for example, are full of lysosomes. Have you ever had a cut that got infected? Typically, an infected cut produces white pus. That white pus is from white blood cells (we will talk about these cells in more depth in a later module) that burst their lysosomes. This kills the white blood cell, but it also kills the foreign invader. Isn't that amazing?

**Centrioles** (sen' tree olz) are found in the **centrosome** (sen' truh sohm), which is the center of **microtubule** formation for the cell. Microtubules are spiral strands of proteins that form a rope-like structure. They influence the movement and shape of the cell. Centrioles are important in cellular reproduction.

**Cilia** are like tiny hairs formed from an intricate arrangement of microtubules. In your first-year biology course, you studied paramecia and perhaps other ciliates. They are examples of microscopic organisms with cilia. What you might not realize, however, is that there are cells in your body with cilia. For example, ciliated cells are in the back of your nose, down your trachea, and all the way down your larger airways. Their cilia beat upward, pushing mucus toward your throat. The mucus typically has dust and other foreign particles that it traps. Once the cilia-containing cells push the mucus far enough upward, it can be swallowed or blown out your nose.

**Microfilaments** also contribute to movement. They enable certain cells to contract. Muscle cells, for example, do their job by contracting and relaxing. The microfilaments in the muscle cells take care of this function. Your cells also have **intermediate filaments**, which are responsible for strengthening and supporting the cells. This allows them to maintain their normal shape.

until they get a signal to do so. So, the vesicles tend to build up until the cells get the signal to release the insulin.

The **lysosome** (lie' so sohm) is a kind of vesicle, and its main function is to break down lipids, proteins, polysaccharides, carbohydrates, and nucleic acids. What makes the lysosome interesting is that, in order to do its job, it must contain certain enzymes. These enzymes are very damaging to other parts of the cell and can easily kill the entire cell if released from the lysosome.

Have you ever heard that you can only live four to eight minutes without oxygen? Do you know why? After four to eight minutes without oxygen, the lysosomes of the neurons can't hold themselves together. They then burst, dumping their lethal contents into the cell. This kills the neurons.

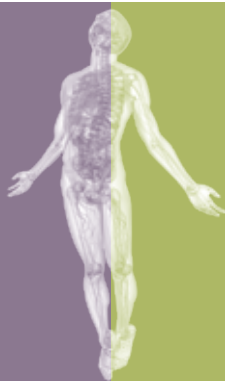
The rupturing of lysosomes is

**Mitochondria** (my tuh kahn' dree uh) are the major site of **ATP** synthesis in the cell. ATP (adenosine triphosphate) is the “currency” in which cellular energy is stored. As a result, we call the mitochondria the powerhouses of the cell. It is important to remember that not all ATP (and therefore not all cellular energy) is produced in the mitochondria. The first stage of cellular respiration (called glycolysis) actually occurs in the cytoplasm, so some ATP is made there. However, the vast majority of cellular energy is produced in the mitochondria.

Although most of the DNA in a cell is stored in its nucleus, there is actually some DNA in the mitochondria. This DNA, called **mitochondrial DNA**, codes for the production of certain proteins necessary for the mitochondrion (singular of mitochondria) to do its job. Not only is DNA present in the mitochondria, but ribosomes are as well. With both DNA and ribosomes, a mitochondrion can produce its own proteins. Interestingly enough, however, a mitochondrion cannot produce all of the proteins it needs. Some proteins vital for the mitochondria are still produced by DNA in the nucleus, and the ribosomes in the cytoplasm. Those proteins are then transported to the mitochondria.

### COLORING BOOK EXERCISE 1.3

An overview of the cell and its organelles can be found on page 21 of your coloring book. Color and label sections a-p.



### ON YOUR OWN

**1.7** A microbiologist is looking at a cell under a microscope. It has a large number of Golgi apparatuses in it. What, most likely, is the cell's major function?

**1.8** Substances regularly are transported into and out of cells. If a substance is transported into a cell, what is the first structure it must pass through?

## A REVIEW OF PROTEIN SYNTHESIS

**Proteins** are large molecules formed by the joining of amino acids. The type and number of amino acids joined together, along with the order in which they join, determine the properties of the protein. For example, some proteins, called enzymes, act as **catalysts**. Catalysts are molecules that speed up chemical reactions without being either reactants or products. Other proteins act as hormones. Some act as **antibodies**, which fight infections. There are thousands and thousands of proteins involved in the processes of life.

Protein synthesis in the cell takes place in two steps, **transcription** and **translation**. A transcription is a written representation of something. Historically, scribes were the persons who copied documents—keep that in mind. Translation is the process of rendering the meaning of one thing (transcription) into something else (protein).

For all of its complexity, understanding DNA is rather simple. DNA is similar to the alphabet, except that it has only four letters, not twenty-six. These letters, called bases, are adenine (A), thymine (T), cytosine (C), and guanine (G). Just as the twenty-six letters of the alphabet are combined to form words of communication, these four bases, in groups of three, form “words” that make up genes. Genes are like sentences in that they state complete thoughts. Simply put, a cell can transcribe a gene and then translate that copy into a complete protein.

Here is an analogy to explain transcription and translation: Imagine that you would like a recipe for an old-fashioned johnny cake. You go to the library to a set of encyclopedias and look up “johnny cake.” There you find a recipe, but of course, you cannot take the encyclopedia set out of the library. On the other hand, you do not need the whole set, and you do not even need the whole book. You just need the recipe. What do you do? You jot the recipe down on a piece of paper and take the information home. Once you get to your kitchen, you use the recipe to get the right amounts of the correct ingredients together, and then you use them to make the johnny cake.

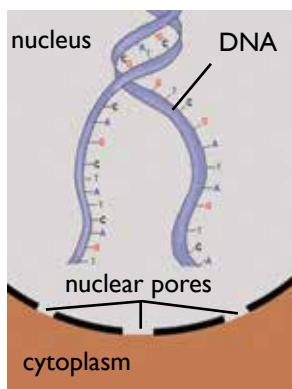
The library with its encyclopedias is like the nucleus of a cell. You can think of the library as having two sets of encyclopedias, each with twenty-three volumes. They are from different publishers, but they cover the same material, though perhaps with a different perspective. Those two sets represent the twenty-three pairs of chromosomes in your cells, one set of each pair inherited from each parent. They contain *all* the information for *everything* every cell in the body can do.

Of course, no one cell needs anywhere near all that information, and it is enclosed in the cell nucleus anyway. When you opened up one volume to the correct page and made a copy on paper, that was **transcription**. Some of the DNA from one DNA molecule “unwound,” so that a copy could be made of just that part. Your paper with the correct information copied from the book is **messenger RNA** (mRNA).

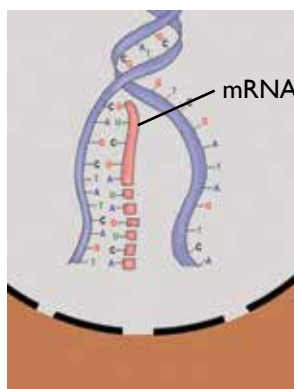
The mRNA, like a recipe, has the information you need, and it is small enough to leave the nucleus. The ribosomes where proteins are made are like the kitchen. When the mRNA is used to call up the right amino acids in the right order to make a protein, that process is called **translation**. Transfer RNA (**tRNA**) brings the correct amino acids to the ribosome to make the protein. Figure 1.8 illustrates this process.

## *think about this*

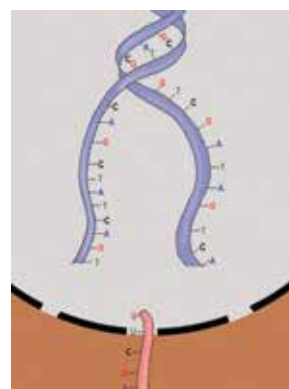
You are now a fully developed, mature person, but you started life as a single cell. At each cell division, your DNA copied itself so that each of your cells contains your entire DNA “encyclopedia.” Throughout this process, your cells specialized according to their functions. Using the encyclopedia analogy, we could say, for example, that your muscle cells may operate from “volume four,” and your nerve cells use “volume six,” but they all have a complete set of DNA instructions. Now you might wonder how your DNA protects its information from mutations, which are abrupt changes in the DNA sequence. A very common kind of mutation is produced when the chemical machinery that copies DNA makes a mistake and uses the wrong nucleotide base. This, of course, will change the codon that is formed in transcription, which could result in a change in the protein, and that might be a real problem for the cell. However, since many codons refer to the same amino acid, many mutations don’t result in a change in the protein because the new codon produced by the mutation still refers to the same amino acid to which the old codon referred. This is called **redundancy**, and it is very important in any kind of coding system. The more redundant the code, the less prone it is to random error. Interestingly enough, when two researchers (Freeland and Hurst) analyzed the genetic code of DNA in terms of how well it uses its redundancy to reduce random error, they found that it is significantly better than codes that scientists could devise. Indeed, the title of the paper by Freeland and Hurst in which they published their results is “The Genetic Code Is One in a Million.” —Freeland and Hurst, 1998



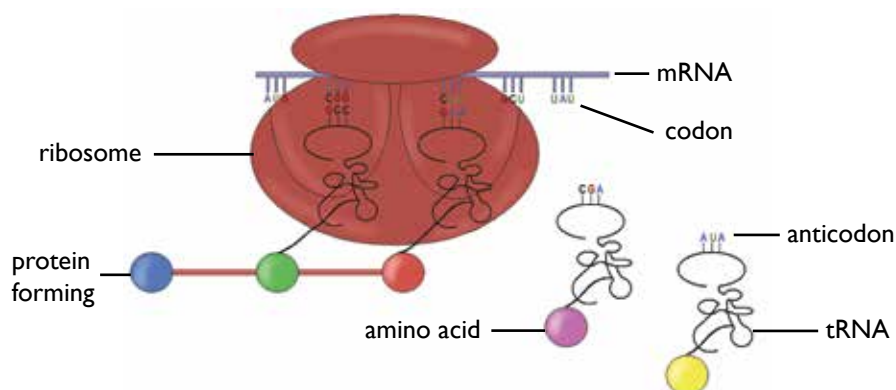
In the nucleus of the cell, DNA unwinds.



RNA nucleotides in the nucleus bind to the exposed DNA nucleotides, forming a strand of mRNA. The mRNA copies only a small part of the DNA's information.



The smaller mRNA then leaves the nucleus through a nuclear pore and goes to a ribosome, where there are plenty of tRNA molecules and the associated amino acids.



In the ribosome, tRNA strands are attracted to mRNA sections that have a codon with which their anticodon can bind. They bind to that section of the mRNA, dragging their amino acids along with them. This results in amino acids sitting next to each other. The amino acids chemically bond, and after this happens many, many times, a protein is formed.

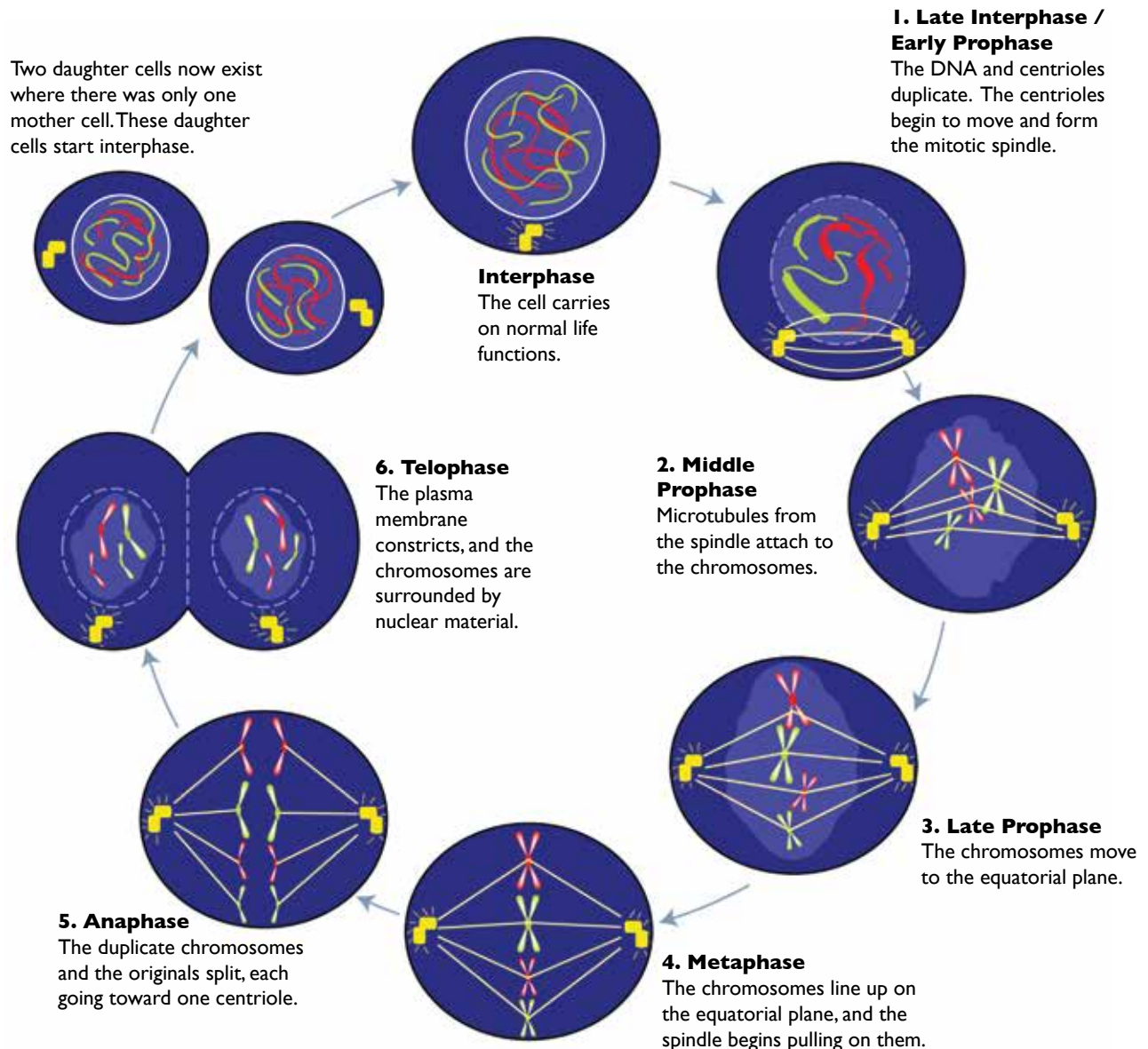
**FIGURE 1.8**

A Schematic Describing Protein Synthesis in Cells  
Illustration by Megan Fruchte

## A REVIEW OF CELLULAR MITOSIS

Before we move on to information that will be new, a review of one more thing about cells is in order. One of the most fundamental processes that a cell must undergo is reproduction. Indeed, you started your life as a single cell. In order to develop into the person you are today, that single cell and all of its *daughter cells*, as they are called, had to reproduce over and over again. In addition, most of the cells in your body must reproduce so that you can grow and repair injuries.

Cells reproduce according to a process known as **mitosis** (mye toh' sis). This process takes place in four broad steps: prophase, metaphase, anaphase, and telophase. When a cell is not undergoing mitosis, it is said to be in interphase, which is the normal state for a living cell. All of these phases of a cell's life are summarized in figure 1.9. In the figure, the only organelles shown are the nucleus and the centrioles. Those are the most important



**FIGURE 1.9**

Mitosis

Illustration: Speartoons

organelles in mitosis. The other organelles of the cell have been removed to make the illustration easy to understand.

Notice that in interphase, there are no distinguishable chromosomes. That's because the DNA is spread throughout the nucleus, and it is called chromatin. During **prophase**, four things happen. The centrioles duplicate and begin to form a spindle of microtubules between them. They also move toward opposite ends of the cell so that the spindle spreads across the cell. Also, replicated DNA forms chromosomes, which are thick and condensed and can be seen easily under a microscope. Those chromosomes move toward the center of the cell. That place in the center is the equatorial plane.

Once the chromosomes reach the equatorial plane, the cell is in **metaphase**. The spindle attaches to the chromosomes right at the point where each replicated chromosome is attached to its partner. At that point, the spindle begins to pull so that the duplicates

and originals are pulled apart, which is the beginning of anaphase. During **anaphase**, the duplicates and originals separate and are pulled to opposite ends of the cell.

In the last phase, **telophase**, one set of chromatin is on one side of the cell, and another set is on the other side. The plasma membrane constricts to pinch the cell in two. The result, then, is two daughter cells that go back to interphase.

Before moving on, note that the X shapes that you see for the chromosomes during prophase and anaphase exist because the chromosome has been replicated (duplicated). A chromosome that has not been replicated does not have the X shape that most people think of when they think of chromosomes. Instead, a normal chromosome before replication looks more like what is shown in the illustration of telophase, and it is called chromatin.

Although most of the cells in your body are able to reproduce via mitosis, there are three types of cells that cannot: *mature neurons*, *mature skeletal muscle cells*, and *mature cardiac muscle cells*. These cells lack centrioles and cannot form the spindle for mitosis. This means that if skeletal muscle or cardiac muscle cells die, you lose them forever and cannot get new ones! On the other hand, if a part of your liver gets injured, your remaining liver cells can undergo mitosis and repair that injury.

Since neurons cannot undergo mitosis, scientists thought until recently that once you were past infancy, you could never produce any more neurons. So, if some of your neurons died, you simply lost them forever. We now know that is not true in at least some regions of the brain. These special regions do produce new neurons each year; however, they are not produced via mitosis. They are produced via processes we will discuss when we cover the brain in detail.

### ON YOUR OWN

**1.9** A human cell has 46 chromosomes. If the illustration in figure 1.9 were of a human cell, how many X shapes would there be in the prophase and metaphase illustrations?

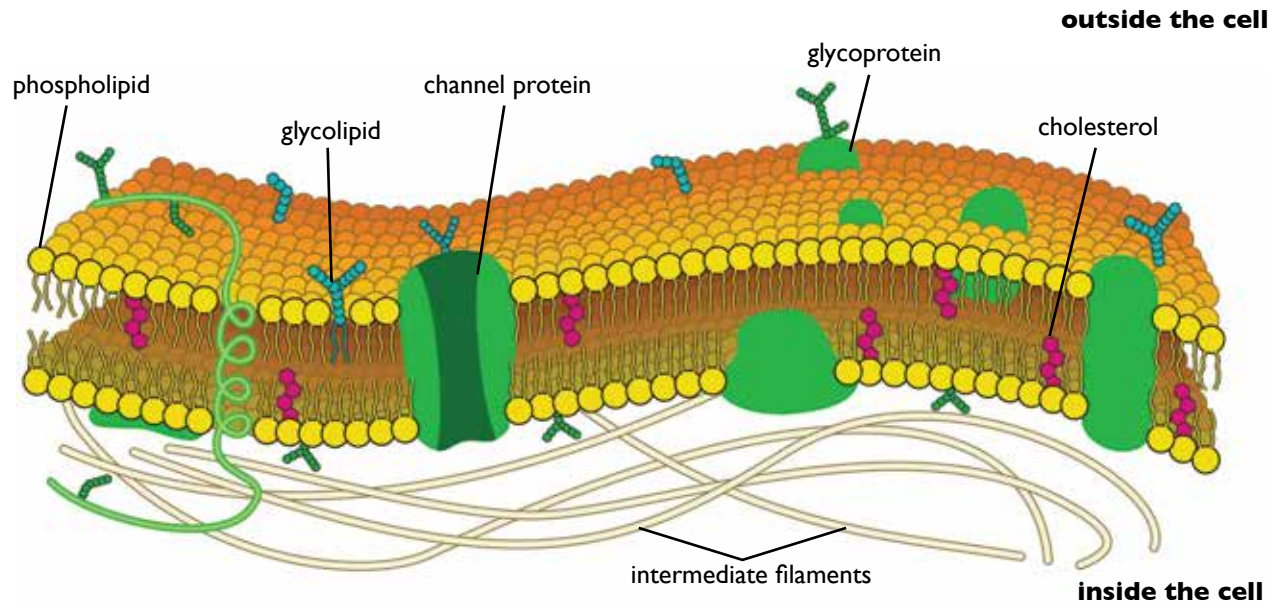


## THE PLASMA MEMBRANE

We've been reviewing a lot about the organization of the cell. Before we end this module, however, we do want to go one level deeper in organization. The best way to do this is to examine one aspect of the cell in detail. Since it has so much to do with the physiology of the human body, we have chosen to discuss the details of the plasma membrane. This will probably be new to you. When you look at the plasma membrane of the cell, you are going to find a beautiful relationship between structure and function. That is, you can look at how it is put together and what it is made of, and then you can see how it works. It is truly amazing what the cell membrane does and how well it works!

The cell membrane, of course, holds the cell together. That is not all it does, however. The plasma membrane is incredibly important to the life of the cell because it restricts what goes in and out of the cell, and it lets the cell communicate with its environment. First, let's look at its structure, as illustrated in figure 1.10.

The first thing that you should notice about the figure is that the cell membrane is largely made of a **phospholipid bilayer**. What's that? A phospholipid is composed of two fatty acids and a phosphate group. The result is a molecule that is polar (water-soluble) on one side and nonpolar (lipid-soluble) on the other. In the figure, the yellow balls represent the polar region of each phospholipid. The two stems coming out of each ball represent two fatty acids, which make up the nonpolar region of the phospholipid. So, that defines the phospholipid part. Bilayer means, as you can see, two layers: a set of phospholipids on top and a set on the bottom.



**FIGURE 1.10**  
The Plasma Membrane  
Illustration: Speartoons

Phospholipids are interesting molecules. They have a head and two tails. The heads are water-soluble because they are polar. Sometimes, biologists use the word hydrophilic instead of water soluble because hydrophilic means “water loving.” The other end of the molecule (with the tails), however, is nonpolar. This means it will dissolve in oil (another nonpolar substance) but not in water. Biologists often call this hydrophobic, which means “water hating.”

Because phospholipids have this remarkable property (water-soluble on one end, lipid-soluble on the other), the plasma membrane can automatically re-form if it gets disturbed for some reason. This will happen because the nonpolar tails of each layer are attracted to one another and because the polar heads of each layer are attracted to the water outside the cell and the water of the cytoplasm inside the cell. So, the phospholipids, even if they are moved and disoriented, will reorient themselves so that the heads of the phospholipids on the bottom point in toward the cell and the heads of the phospholipids on the top point out toward the watery environment surrounding the cell. The tails of each phospholipid, then, are pointed toward each other. This results in a stable arrangement because the tails are attracted to one another.

It is important to realize that the overall nature of the plasma membrane is *lipid solubility*. It acts as a lipid barrier between two very different water-based fluids—the **intracellular fluid** within the cell and the **extracellular fluid** around the cell. The water-soluble heads of the phospholipids serve to orient the phospholipid, but again, the plasma membrane is largely a lipid-soluble barrier.

Of course, phospholipids are not the only substances we find in the plasma membrane. Floating within the phospholipid bilayer, like icebergs in a sea, are proteins. Remember, proteins are large molecules. You can see several in figure 1.10, and they have different functions. Some are **channel proteins**. They have a little channel to let water and small water-soluble molecules in and out. Some are **glycoproteins**. The prefix glyco means

“glucose.” A glycoprotein is a protein that has a carbohydrate chain attached to it. Glycoproteins typically act as markers, allowing cells to recognize each other. For example, your immune system’s cells must identify both cells that belong to you and foreign cells that must be destroyed. The glycoproteins allow for such identification. There are also **receptor proteins** that receive messages from other cells. For example, in order for a neuron to tell a skeletal muscle cell to contract, it must release a chemical that will bind to the receptor protein on the muscle cell. The chemical binds to the receptor. The muscle cell responds by contracting.

Additionally, **glycolipids** are found in the plasma membrane. Just as a glycoprotein is a protein that has a carbohydrate attached to it, a glycolipid is a lipid with a carbohydrate attached to it. These molecules help to anchor some membrane proteins in place and provide structural support to the plasma membrane.

Another molecule that is found within the plasma membrane is **cholesterol**. Fully one-third of the lipid part of the membrane is cholesterol. Now, cholesterol is lipid-soluble, which means it is nonpolar. So, cholesterol is found among the nonpolar tails of the phospholipids. It is important to realize that cholesterol is critical to the plasma membrane. Some people still have the idea that cholesterol is a toxin. It is not. It is true that your body can make cholesterol, and some people benefit by restricting their cholesterol intake, but cholesterol is a necessary substance that every cell membrane in every cell of our body uses for stabilization of the cell membrane. You see, the phospholipids by themselves just would not hold together for any reasonable length of time. Cholesterol gives the membrane the right degree of firmness.

This description of the plasma membrane is called the **fluid mosaic model**. The word fluid refers to the phospholipid bilayer. Remember, phospholipids, like all lipids, are oil-soluble molecules, so, the phospholipids form a kind of fluid. The word mosaic refers to the fact that there are many different kinds of chemicals floating within the phospholipid bilayer, especially proteins. Finally, remember that the overall nature of the plasma membrane is lipid solubility.

## FUNCTIONS OF THE PLASMA MEMBRANE

What are the functions of the plasma membrane?

First, it delimits the cell; that is, it holds the cell together. Second, it provides receptors so that the cell can sense its environment. These receptors are extremely important. You have probably heard of diabetes. There are two types of diabetes. In Type 1 (insulin-dependent) diabetes, the person lacks the ability to make the hormone **insulin**. Insulin signals the plasma membrane to allow glucose to enter the cells. In Type 2 (non-insulin-dependent) diabetes, which is much more common than Type 1, the receptors are not responding. There is more than enough insulin in the body, yet the cells do not respond to the insulin because the receptors either do not work correctly or are reduced in number. As a result, glucose cannot enter the cells. You can see from this example that the plasma membrane’s receptors are essential to cells. The example of diabetes actually leads to the third function of the plasma membrane: **selective permeability**.

**Selective permeability**—The ability to let certain materials in or out while restricting others

### ON YOUR OWN

**1.10** Suppose you placed a cell in a nonpolar fluid. Suppose furthermore that the plasma membrane was disturbed. In this kind of environment, could the plasma membrane reassemble? Why or why not?



The definition is easy if you think of the individual words. Selective means that some things will be selected; others will not. Permeability is the ability to go through. Therefore, selective permeability is the ability to let certain materials in or out of the cell while restricting others.

What gives the plasma membrane selective permeability? There are several factors. Let's start with the easiest one first. Lipids are fats, and therefore nonpolar. Polar dissolves polar, and nonpolar dissolves nonpolar, but nonpolar cannot dissolve polar. Now, when you think of the cell membrane, think of it as largely lipid (largely oily) because the majority of it is formed by the tails of the phospholipids. So, suppose a cell encounters a small fat molecule. The fat will dissolve into the oily plasma membrane because nonpolar dissolves nonpolar. So, the fat can travel through the plasma membrane and get into the cell. As a result, fatty molecules can get into the cell rather easily (unless they are quite large). This is applicable practically. Have you heard of a nicotine patch that can help people quit smoking? This patch works by putting a drug that reduces craving for nicotine into a bandage. The patch is placed on the skin, and the skin cells absorb the drug. Why? Because the drug is nonpolar! It can travel through the plasma membranes of the closely packed skin cells.

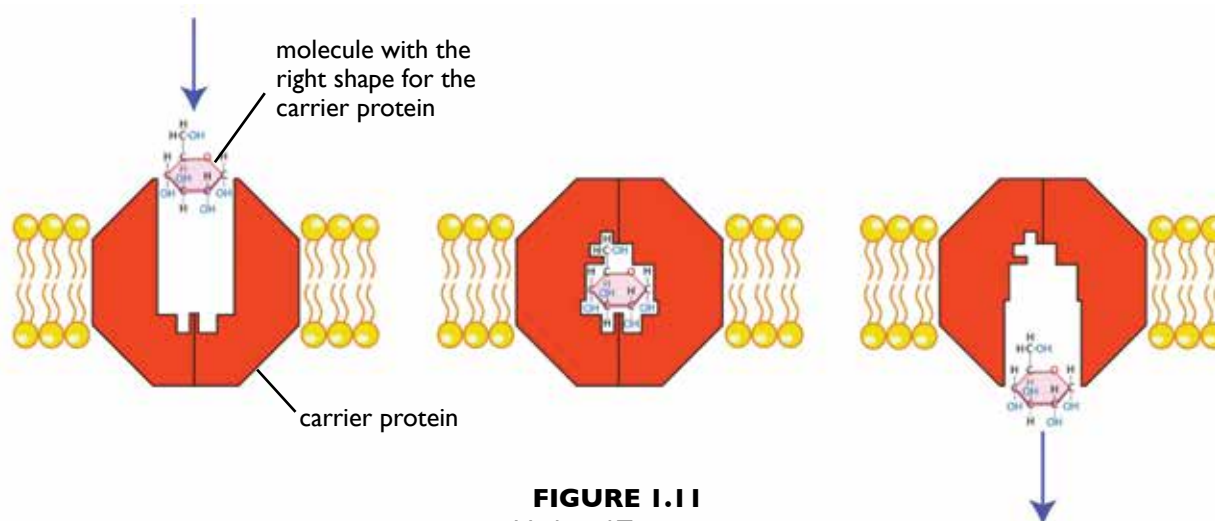
The second reason that the plasma membrane has selective permeability is also easy to understand. It has to do with the *size* of the molecule that approaches the plasma membrane. Remember, one type of protein you find in the plasma membrane is a channel protein. As the name implies (and figure 1.10 illustrates), a channel protein has a channel running through it. Small molecules can travel through that channel. Practically speaking, that means that water, which is one of the smallest of molecules, easily moves into and out of cells. If there is too much water outside the cell, water will move in. If the cell has too much water inside, water will move out. Large molecules (such as proteins) cannot get into the channel of a channel protein, so they cannot penetrate the plasma membrane easily. There are, however, other processes that allow certain proteins into the cell. We will discuss those in a moment.

Now, the third factor that affects permeability is *charge*. There are various ions (charged atoms or molecules) that cells need. There are also ions that they must release. So, ions need to move into and out of cells. Small ions can go in and out through the channel proteins, as we just discussed. However, here is an amazing design. Many channel proteins are oriented so that their amino acids form a positive or negative charge within the channel. Now think about that for a moment. If the channel inside a channel protein is negatively charged, what ions will it attract? It will attract *positive* ions. If a channel protein has a positively charged channel, however, it will attract *negative* ions. So, channel proteins not only allow small molecules into and out of the cell they also can attract certain ions. Sodium ions ( $\text{Na}^+$ ), for example, are important for neurons. These ions enter neurons through channel proteins whose channels are negatively charged.

While all of this is amazing, these three aspects of the plasma membrane's selective permeability are simply the easy ones. At this point, we need to talk about a more complicated aspect. For example, there are certain chemicals that cells have to have, which are slightly too big to fit into channel proteins. We are not talking about huge molecules like proteins. Instead, we are talking about molecules that are about the size of amino acids or glucose. Glucose is the favored fuel for most cells. It is the only fuel that brain cells normally use. However, glucose is too big to get into the cells through channel proteins. The fact that

you are conscious (we hope!) right now means that there is a mechanism for glucose to get into cells. How does this happen? It happens with the help of carrier proteins. **Carrier proteins** allow certain molecules into the cell through a process called mediated transport. The best way to explain **mediated transport** is to start with figure 1.11.

In mediated transport, a carrier protein is designed to accept a molecule with a specific shape. More than one molecule might have that general shape, so the carrier protein may work with more than one type of molecule. In order to work, however,



**FIGURE 1.11**  
Mediated Transport  
Illustration: Speartoons

the molecule must have the shape for which the carrier protein is designed. Because the molecule fits into the carrier protein, the carrier protein accepts it. In chemical terms, we say that the carrier binds to the molecule. Then, the carrier protein changes its shape so as to release the molecule on the other side of the plasma membrane. In the end, then, a molecule that could not get through the plasma membrane via a channel protein or by dissolving into the membrane can get through with the help of a carrier protein.

Although the process of mediated transport works very well, there are three conditions that must be considered: **specificity**, **competition**, and **saturation**. First, let's discuss specificity. The carrier protein is made for a *specifically shaped molecule*. For every molecule that must get into the cell via mediated transport, you need carrier proteins into which the molecule can fit. In other words, you need a carrier that is designed for that molecule's shape. Let's give an analogy. Suppose you needed to go to church. You might be able to walk there, but most likely, you would ride in a car. Suppose you had a pet giraffe and wanted him to come along. Could he? Of course not! A car is designed specifically to carry people, not giraffes. You can therefore think of a car as a carrier, but a carrier for people. If your church wants to attract giraffes, it would have to have carriers designed for giraffes in order to get them to church. It is the same way with carrier proteins. If the cell wants glucose, it needs carrier proteins designed to accept glucose. That is specificity.

The next consideration is competition. Suppose your neighbor's car is broken down and he asks you to take his family to church. Let's say that there are five persons

in your family and three persons in his, and let's say that the car can hold six persons. If, in a very unChristian manner, everyone starts to run for the car at once, the car will fill up after six persons get into it. That will leave two persons with no way to church. That is competition. Eight persons competed for six spaces. Now, consider this. Which family will, most likely, have the best representation at church? Your family will, most likely, since it had more members. Your family had a better chance at getting into the car simply because there were more of you. The same thing happens in mediated transport. Similarly shaped molecules can compete for the same carrier protein. Remember, it is the shape that determines whether or not the carrier will bind to the molecule. If two different molecules have very similar shapes, they will be able to compete for the same carrier. Similar amino acids, for example, compete for the same carrier proteins. This is why you must eat foods that have the proper proportions of amino acids. Otherwise, competition can cause problems! Typically, whichever molecule has a high concentration will tend to win the competition because more molecules means more chances to meet up with the carrier.

Finally, let's discuss saturation. Remember, in our car analogy there is room for only six persons. If you could walk to church, all of your family and all of your neighbor's family could go. However, after six persons, the car is saturated (full). Thus, having a carrier (the car) limits the number of individuals who can be transported. In the same way, if a molecule must enter the cell through mediated transport, there is a limit to how many molecules can get into the cell within a certain period of time. When the carrier is constantly busy transporting molecules through the membrane, we say that it is saturated, because there is no way to get more molecules in any faster. On the other hand, if a carrier protein meets few molecules that can bind to it, it is not saturated and if more molecules suddenly become available, they can get inside quickly.

In the end, then, there are several factors that lead to the selective permeability of the plasma membrane. First, there is its lipid-soluble nature, which allows fat-soluble molecules to travel into the cell. Second, there are channel proteins that allow small molecules to travel through the cell membrane. Third, those channel proteins can have an overall electrical charge in their channels. That leads to channeling of specifically charged, small ions. Finally, there are carrier proteins that can transport slightly larger molecules through the membrane.

### ON YOUR OWN

**1.11** In each of the cases below, indicate which path (dissolving through the phospholipids, channel proteins, charged channel proteins, or carrier proteins) the molecules will take to enter the cell.

- Chloride ions
- Simple sugars
- Fatty acids
- Water molecules

Now you should have noticed something. We have not yet told you how the cell allows in *proteins*. We have talked about carbohydrates and ions, but not proteins. Cells make their own proteins, according to the protein synthesis process discussed earlier. However, sometimes they must bring proteins in from the outside. They can certainly do that, and the plasma membrane is certainly involved, but the transport of proteins into and out of the cell involves more than just the properties of the plasma membrane. We will discuss this in the next section.

## MEMBRANE TRANSPORT PROCESSES

In the previous section, we noted the path by which certain molecules can get into and out of cells, but we did not discuss what causes this kind of transport to occur. That is what we will cover now. Along the way, we will also discuss how huge molecules like proteins are transported through the plasma membrane.

There are two basic kinds of transport through the membrane: **passive transport** and **active transport**. Let's talk about passive transport first. There are two basic passive processes: **diffusion** and **facilitated diffusion**. Diffusion is the movement of ions or molecules from an area of higher concentration to an area of lower concentration. The best example of diffusion in cells is probably  $\text{Na}^+$ . When we discuss the nervous system, you will see that cells are in an environment that has a greater concentration of  $\text{Na}^+$  than what is found inside the cell. Recall that  $\text{Na}^+$  can travel through channel proteins, typically ones with negatively charged channels. Since molecules and ions diffuse from areas of higher concentration to lower concentration, the  $\text{Na}^+$  can travel through the channel proteins and into the cell. That is how diffusion works. In the case of another important cellular ion, potassium ions ( $\text{K}^+$ ), there is a higher concentration of  $\text{K}^+$  *inside* the cell than outside.  $\text{K}^+$  will diffuse through channel proteins in the other direction, leaving the cell.

Now remember, this is a passive process. What does that mean? It means that the process does not require cellular energy. It simply happens as a matter of course. As mentioned previously, cells store energy as ATP. ATP is the abbreviation for **adenosine** (uh den' uh seen) **triphosphate** (try fahs' fate). Cells make ATP by taking **ADP**, **adenosine diphosphate**, and adding a phosphate. This stores energy, much like a compressed spring stores energy. When the cell needs energy, it breaks an ATP molecule back into ADP and a phosphate. That breakup releases energy, which the cell can then use for any number of tasks. Of course, that uses up an ATP molecule, and the cell will have to make another ATP molecule to replace the broken-down one. So, we often use the term ATP instead of energy when we talk about the cell. In the case of diffusion, then, we can say that the cell does not need to use any ATP.

It is not difficult to see that diffusion can work through a channel protein. You can probably even imagine how it can work if fatty molecules are simply dissolving through the membrane. What you might not realize is that diffusion will also occur with mediated transport as well. When that happens, we call it **facilitated diffusion**. Now think about this for a moment. Look back to figure 1.11. It is easy to see how the molecule in question gets through the membrane, but wait. Why did the molecule go into the cell? If the carrier protein can transport through the membrane, it can transport either way. Molecules can *enter or leave* the cell through mediated transport. If the direction of transport occurs according to the dictates of diffusion (the molecules are moving from a higher concentration to a lower concentration) and a carrier is required, that is facilitated diffusion.

What is so special about facilitated diffusion? Well, if the carrier protein is sending the molecules from an area of high concentration to an area of low concentration, no energy is required. It happens as a matter of course. *So, facilitated diffusion is mediated transport that requires no ATP.* In general, when glucose enters a cell, it does so via facilitated diffusion. There is almost always a higher concentration of glucose outside

of the cell than inside because the cell constantly uses glucose as a fuel. The glucose molecules travel into the cell via a carrier because they are too big to enter any other way. However, since they are doing so according to the dictates of diffusion, the cell spends no ATP on the process.

**Active transport** is transport that requires cellular energy. The cell must break down ATP in order to get the transport to work. One of the more common modes of active transport uses a carrier, but the carrier transports substances *against* the concentration gradient; that is, from lower concentration to higher concentration. Remember, diffusion happens naturally. However, if the cell needs to move a substance from an area of lower concentration to an area of higher concentration (against the dictates of diffusion), it can do so, but that costs ATP!

Consider the following example. Remember,  $\text{Na}^+$  travel through channel proteins and that the concentration of  $\text{Na}^+$  is higher outside the cell than inside. As a result, the  $\text{Na}^+$  can diffuse into the cell. This creates a problem. Cells cannot stand a high concentration of  $\text{Na}^+$ ; it kills them. Therefore, even though  $\text{Na}^+$  are constantly moving into the cells by diffusing through channel proteins, cells often need to get the  $\text{Na}^+$  right back out again. Of course, the outside of the cell is exactly where the  $\text{Na}^+$  do not “want” to go. After all, they diffused into the cell because molecules or ions tend to move from areas of higher concentration to areas of lower concentration. The cell must get rid of the  $\text{Na}^+$ , even though they do not “want” to leave. The only way to force the  $\text{Na}^+$  out is to expend energy by breaking down some ATP molecules. That energy will force the  $\text{Na}^+$  out, even though they “want” to diffuse in.

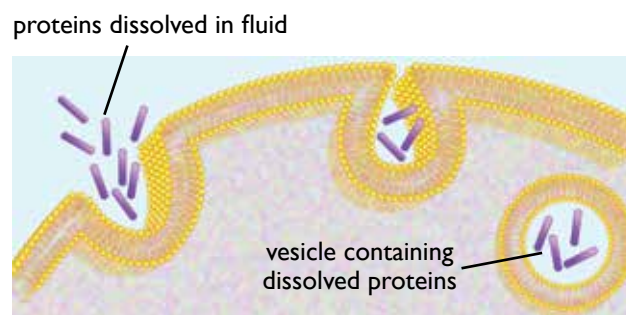
Biologists often refer to this kind of active transport as **pumping**. When you pump water, you are typically trying to send it the opposite way that gravity will take it. You need to spend energy pumping the water. In this kind of active transport, the cell is forcing the ions to travel opposite of the way diffusion demands, so the cell must pump the  $\text{Na}^+$  out. This requires a carrier. The carrier binds the  $\text{Na}^+$  and pushes them out of the cell. That takes energy, so the cell expends ATP in the process. However, it has to or the cell will die.

Let’s look at the opposite situation. Cells like to have  $\text{K}^+$  within them; in other words, they like a high concentration of  $\text{K}^+$  inside. The concentration of  $\text{K}^+$  outside cells is quite low. Because of this,  $\text{K}^+$  tend to diffuse out of the cell. To counteract this, cells are constantly pumping in  $\text{K}^+$ . This requires ATP because the  $\text{K}^+$  are going the opposite way that they would normally go. This, then, is another example of active transport. Interestingly, as you will learn when we study the nervous system, in the case of  $\text{Na}^+$  and  $\text{K}^+$ , a single carrier, powered by ATP, pushes  $\text{Na}^+$  out of the cell while simultaneously pulling  $\text{K}^+$  inside, a remarkably efficient design!

There are still two more types of active transport processes to discuss. The first is called **endocytosis** (en’ doh sigh toh’ sis). Endo means “within,” and cytos is means “cell.” So, the definition is straightforward.

**Endocytosis**—The process by which large molecules are taken into the cell

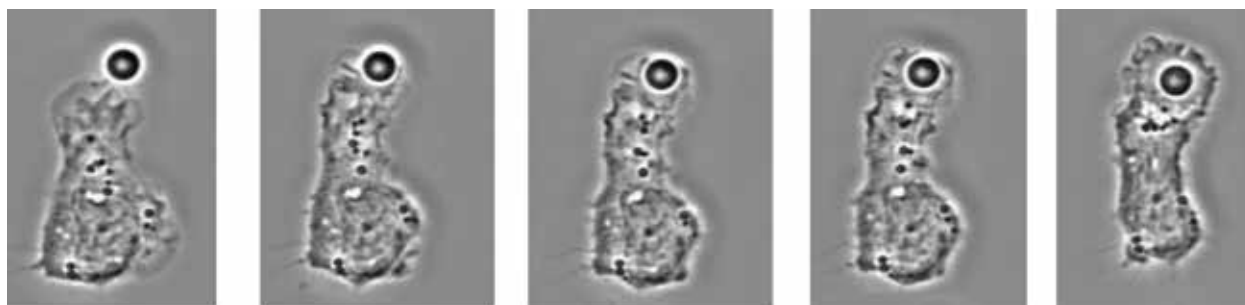
We can divide endocytosis into **pinocytosis** (pin' oh sigh toh' sis) and **phagocytosis** (pha' goh sigh toh' sis). Pinocytosis, which means “cell drinking,” is the process that allows proteins to enter into the cell. The proteins are dissolved in fluid around the cell. If a cell needs to take in a protein, the plasma membrane folds inward until it pinches off a vesicle. The vesicle, with the protein inside, can then travel in the cell to where the protein is needed. Pinocytosis is illustrated in figure 1.12.



**FIGURE 1.12**

Pinocytosis  
Illustration: Speartoons

Phagocytosis means “cell eating.” Compared to pinocytosis (cell drinking), then, you can see that phagocytosis is used to ingest particles rather than fluids containing dissolved proteins. In phagocytosis, the cell engulfs what it is trying to take in. Not all cells can perform phagocytosis. White blood cells are probably the cells that use phagocytosis the most. They do this in order to kill foreign cells or to get rid of dead cells in our bodies. Figure 1.13 is a series of photomicrographs showing a white blood cell engulfing a yeast cell.



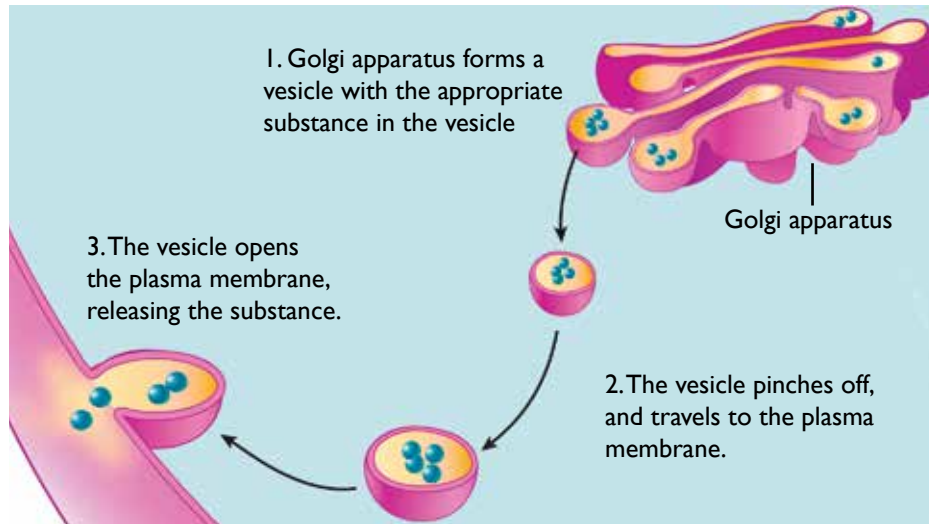
**FIGURE 1.13**

A White Blood Cell Ingesting a Yeast Cell  
Photos © James A. Sullivan, CELLS Alive!

The last active transport process that we will discuss is **exocytosis**. This, as its name implies, is the opposite of endocytosis.

**Exocytosis**—Transportation of material from inside the cell  
to outside the cell using vesicles: also called secretion

The Golgi apparatus often plays a role in exocytosis. Remember, we already mentioned that the Golgi apparatus packages chemicals so they can be sent outside the cell. Well, if a cell must secrete something, this is usually started in the Golgi apparatus, as illustrated in figure 1.14.



**FIGURE 1.14**

## Exocytosis

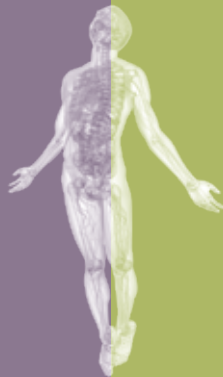
Illustration by Fairman Studios

Many cells use exocytosis to secrete important chemicals for the body's use. We already discussed cells in the pancreas that secrete insulin, which controls the facilitated diffusion of glucose by most body cells. Insulin-secreting cells use exocytosis to release their insulin.

Endocytosis (pinocytosis and phagocytosis) and exocytosis require ATP, but not because of movement from lower concentrations to higher, as in active transport of  $\text{Na}^+$  or  $\text{K}^+$ . It is the size of the molecules that causes the cell to need ATP energy. Think of it by analogy: If someone tries to move a grand piano into or out of your living room, extra effort will need to be expended because of the sheer size of it. That extra effort has nothing to do with how many grand pianos are already inside or outside of your home.

## COLORING BOOK EXERCISE 1.4

An illustration of the plasma membrane can be found on page 21 of your coloring book. Many of the different structures mentioned in your text are visible. It would be a good review to color sections q-w.



## ON YOUR OWN

**1.12** A chemical travels into a cell via a carrier protein. If that process required no ATP, what can you say about the relative concentration of the chemical inside and outside of the cell?

**1.13** A cell uses exocytosis to secrete a hormone. This process requires ATP. What can you say about the relative concentration of the hormone inside and outside of the cell?

There is one other thing to consider when it comes to endocytosis and exocytosis. Both of them involve a breakdown of the plasma membrane. After all, consider pinocytosis. When the folded portion of the membrane pinches off, the plasma membrane is broken. What happens then? Well, remember, the phospholipids of the plasma membrane allow it to automatically reassemble. Thus, exocytosis and endocytosis work only because the plasma membrane has been so well designed. If it were not for both the polar and nonpolar property of phospholipids, the plasma membrane could never reassemble, and exocytosis (or endocytosis) would destroy the cell!

Before we end this module, please take a moment to think about what we have just discussed. In the first module alone, we have touched on several wonderfully designed processes that occur in the human body. The plasma membrane of the cell is, by itself, a wonder of chemical engineering. The processes of endocytosis and exocytosis are both incredibly complex, requiring the concerted effort of dozens of chemical reactions. All of this works smoothly over and over again in every cell of your body! As the psalmist wrote, you are truly “fearfully and wonderfully made” (Psalm 139:14, NIV)!

### ANSWERS TO THE “ON YOUR OWN” QUESTIONS

- 1.1 Connective tissue attaches one tissue to another in your body. That’s what the tendons are doing: attaching muscles to the skeleton. So, tendons are made of **connective tissue**.
- 1.2 Gross anatomy is the anatomy we can study with the unaided eye. Cells and organelles must be studied with a microscope. Even though you can see tissues with the unaided eye, to study their structures, you need a microscope. So, gross anatomy covers the **whole organism, organ systems, and organs**.
- 1.3 This is clearly a **negative**-feedback system because the stress (temperature decrease) results in the opposite effect (temperature increase).
- 1.4 The control center is the **hypothalamus**. Please note that you do not need to know anything about the hypothalamus to answer this question. The first paragraph tells you that the hypothalamus is part of the brain and receives information from receptors and “makes a decision.” That’s what the control center does.
- 1.5 The effector is the structure that actually causes the change that is opposite of the stress. The **muscles are the effectors** because they generate the heat.
- 1.6 In this description, no hormones are mentioned. So, based on this description, **the endocrine system is not involved**.
- 1.7 The Golgi apparatuses package chemicals to send outside the cell. Cells tend to have large numbers of particular organelles that they use frequently. So, the cell **secretes chemicals**.
- 1.8 The **plasma membrane** is the boundary of the cell. Therefore, it is the first structure encountered by any substance attempting to enter the cell.
- 1.9 Remember, each X is a chromosome and its duplicate. The replication happens during interphase, and the X shape is a result of that. In the end, then, there will be only one X shape for every chromosome, so there will be **46 chromosomes**.

- 1.10 The **plasma membrane would not reassemble**. Remember, the reason the plasma membrane can reassemble is because the polar parts of the phospholipids orient toward the inside and outside of the cell because the cell's watery interior is polar, as is the watery fluid outside the cell. In this hypothetical case, the outside is nonpolar, so the phospholipids on the outer part of the membrane would not orient correctly.
- 1.11 a. The chloride ions, since they are charged, will go through **charged channel proteins**. Specifically, they will go through channel proteins carrying the *opposite* charge.
- b. Simple sugars are slightly too large to readily enter cells. Glucose is an example. Since we talked about glucose needing **carrier proteins**, it should make sense that simple sugars need carrier proteins.
- c. Fatty acid molecules are, of course, oil-soluble. So, they will **dissolve through the phospholipids**.
- d. Water molecules go through **channel proteins**.
- 1.12 If the process required no ATP, it used no energy, which means it is passive transport. That only happens if the motion is consistent with the dictates of diffusion. So, the chemical had to move from a region of *higher* concentration to one of *lower* concentration. Therefore, **the concentration of the chemical inside the cell is lower than it is outside the cell**. You also could have said that the concentration of the chemical is higher outside the cell than inside.
- 1.13 This is a trick question. Exocytosis always requires ATP, regardless of the relative concentration of the chemical inside and outside the cell. So, **you can't say anything about the concentrations**.

### STUDY GUIDE FOR MODULE I

1. Define the following terms:
  - a. Gross anatomy
  - b. Microscopic anatomy
  - c. Physiology
  - d. Histology
  - e. Organ
  - f. Tissues
  - g. Homeostasis
  - h. Effector
  - i. Selective permeability
  - j. Endocytosis
  - k. Exocytosis
2. If this course taught you only the name of each organ and where it is in the body, would this be an anatomy course or a physiology course?
3. What are the seven levels of organization in a living organism?
4. Suppose you are using a 40x, 100x, 400x, 1000x microscope to study the human body. What levels of organization would you be studying?
5. What are the four types of tissue?
6. Identify the type of tissue that makes up the following:
  - a. The lining of a blood vessel or your sinuses.
  - b. The trapezius muscle
  - c. The cartilage in your joints
  - d. The frontal lobe of the brain
7. What is the general term for the processes in the environment that threaten homeostasis?
8. Suppose your heart rate began to increase significantly. If the body initiated a negative-feedback response, would your heart rate go up or down? If the body initiated a positive-feedback response, would your heart rate go up or down?
9. What two organ systems are most involved in controlling the negative-feedback systems of the body?

10. When you exercise, your blood glucose levels tend to drop because you are using the glucose for energy. To counteract that effect, the pancreas monitors your blood glucose level. If the pancreas “decides” that the blood glucose level is too low, it can release a hormone called glucagon. This hormone stimulates the liver to release glucose into the blood.
  - a. What is the stress in this situation?
  - b. What is the control center?
  - c. What is the effector?
  - d. Is the endocrine system involved?
11. List the organelles discussed in module 1, and briefly state the main function of each.
12. List the phases of mitosis in order.
13. In which phases of mitosis do chromosomes have the X shape that most people associate with chromosomes?
14. What property of phospholipids gives the plasma membrane the ability to automatically reassemble?
15. What is the function of a glycoprotein in the plasma membrane?
16. What is the function of a receptor protein in the plasma membrane?
17. The model of the plasma membrane that we discussed is the fluid mosaic model. What is the “fluid?” To what does “mosaic” refer?
18. There are essentially four basic ways a substance can get through the plasma membrane. What are they? If you get specific, you will end up listing six. That is fine, too.
19. For each of the following substances, indicate how they will get through the plasma membrane and into the cell. In this case, consider channel proteins and charged channel proteins to be different, and use the two more precise terms for endocytosis.
  - a. water
  - b. a protein
  - c. a  $Mg^{2+}$  ion
  - d. a monosaccharide (simple sugar)
  - e. an invading bacterium
  - f. a lipid
20. A protein enters a cell. The outside of the cell has a higher concentration of that protein than the inside of the cell. Did the protein enter through active transport or a passive transport process?
21. A glucose molecule enters a cell. The concentration of glucose inside the cell is lower than the concentration of glucose outside the cell. Did the cell use ATP to get the glucose inside?