Module #1: An Organizational Overview and Some Review

Introduction

Are you ready to be astounded? You had better get ready! In this course, you are going to learn about the human body. As you learn more and more about the structures in the body and how they work, you will become more and more amazed at the mighty power of God! The human body is the Lord's ultimate design achievement. Indeed, the organic machine which we call the human body makes all of humanity's technological wonders simply pale in comparison.

The human body is the most incredible chemical manufacturing plant in the world! It makes a wider variety of chemicals than the sum total of all chemists in the world, and it does this job more efficiently than human science can *ever hope to*! It converts fuel to energy more efficiently than the *best* engine that human science can design, and it processes information hundreds of thousands of times faster than the best computer in the world! Clearly, the human body is the most elegantly-designed "machine" imaginable!

Of course, in order to appreciate the depth of design that we see in the body, you need to be familiar with a lot of science already. That is why we require that you have taken at least a year of biology *and* a year of chemistry before you take this course. There are some things from those subjects that we will just assume you know. Also, there are several terms that you need to know in order to learn about the human body. That's where we'll start.

Some Terminology

What is **anatomy** and **physiology**? First, anatomy underlies physiology. You have to understand the structure of the body (anatomy) before you can understand the way that it functions (physiology). We can separate structural anatomy into **gross anatomy** and **microscopic anatomy**. Gross anatomy doesn't mean disgusting anatomy - it means macroscopic anatomy, the parts of the body which we can see with the unaided eye. Microscopic anatomy, on the other hand, refers to the anatomy that we cannot see without the aid of a microscope.

Gross anatomy - The study of the macroscopic structures of an organism

Microscopic anatomy - The study of the microscopic structures of an organism

We will be working mainly with gross anatomy, which can be divided into **human anatomy** and **comparative anatomy**. Human anatomy is wonderful. It allows us to see how well-designed our bodies are. Human anatomy is an incredible testimony to the awesome power of God!

Comparative anatomy is also a very interesting topic. For example, the bones of mammals and some animals are homologous (huh mol' uh gus), which means that they are similar. Humans have two bones called the radius and the ulna in their forearms. Horses have a radius and ulna as well. The bone that forms a bird's wing has a radius and ulna, too. Thus, we could say that a bird flies with its arms. The bones that make a bat's wing, however, *do not* resemble the radius or ulna. Instead, they are similar to human finger bones. Thus, we can say that the bat flies with its fingers. Comparative anatomy is truly a fascinating study.

There are some other anatomy terms you need to learn as well. **Surface anatomy**, for example, is anatomy by Braille. It 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 anatomy of various parts of the body. Someone specializing in hand surgery, for example, needs to know the precise location of everything in a hand. That way, when the specialist cuts into the hand for surgery, he or she knows what blood vessels are there, what nerves are there, what muscles are there, etc. This will insure that the specialist knows just where to cut and where not to cut!

In this course, we will concentrate on **systemic anatomy**. Systemic anatomy means anatomy by organ systems. We will define organs shortly, so don't worry about the precise definition. For right now, we will just give you an example. The digestive system (mouth, teeth, tongue, esophagus, stomach, small and large intestine, and so forth) is an organ system. The organs all cooperate to provide a common function - digesting food. Systemic anatomy is important to us because we also want to study **physiology**, which is a study of the *functions* of an organism.

Physiology - The study of the functions of an organism and its parts

Microscopic anatomy is also an incredibly fascinating field of study. You will get a glimpse of this interesting field in some of the laboratory exercises you will perform. The microscopic anatomy that you will study in this course will concentrate on **histology**, which is the study of tissues.

Histology - The study of tissues

Tissues are the building materials of the body. We will define them more precisely in a little bit. For right now, think about tissues this way. Look around the room you are in. If there is a rug or carpet in the room, you can see that it is made of synthetic material. If you look at the door, you can see that it is made of wood, and that there is metal on the door handle and so forth. Just as easily, if you look under a microscope for any length of time, you can see what the body is made of - tissues.

Organization of the Human Body

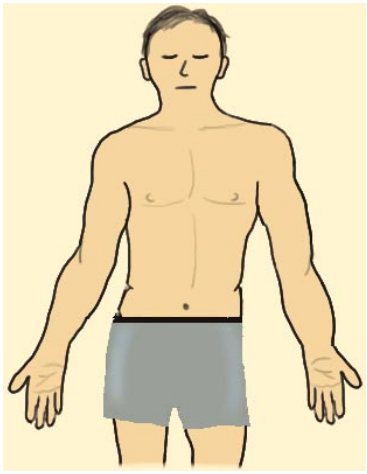
Now that we have some basic terms defined, let's look at the organization of the body as a whole. The first thing you need to know is that the human body is organized on several different levels. For example, when you look at the muscles of the human body, you see organization in the way that the muscles are arranged. However, if you look at muscle tissue under a microscope, you will find a completely *different* kind of organization. Thus, the human body's organization has several levels to it, and we must address each level.

Okay, let's start at the top and say, "Who are we?" We are the whole thing, the organism. In this course, then, we are talking about the whole person. When we look at the human body on that level, what do we see? First, we can divide the body into its organ systems. The organ systems are organs which cooperate to perform a common function. For example, consider the respiratory system. This system contains the nose, the trachea (airway), the lungs, and several other components. These organs all cooperate to perform a function. They get oxygen into your bloodstream and also remove carbon dioxide from it. There are 11 such organ systems, as illustrated in Figure 1.1.

Illus. By Megan Whitaker

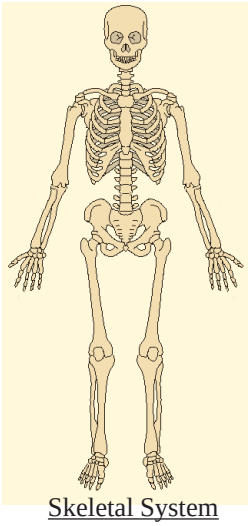
FIGURE 1.1

The 11 Organ Systems in the Human Body



Integumentary System

Skin, hair, etc.

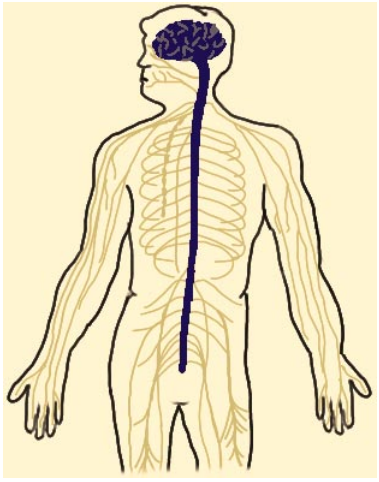


Skeletal System

Bones, cartilage, etc.

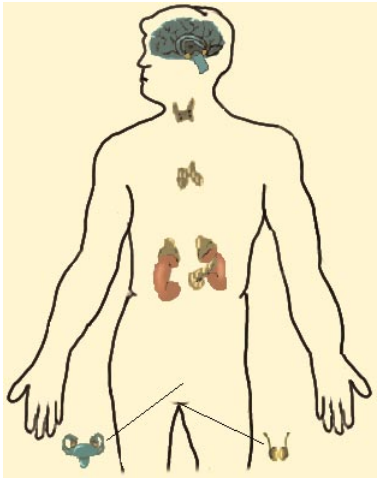
Muscle System

Muscles, tendons, etc.



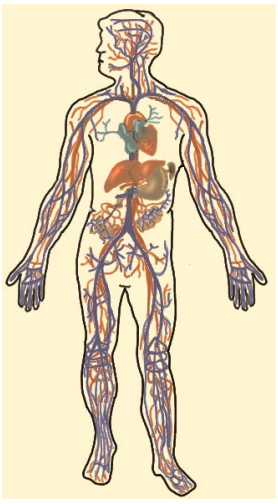
Nervous System

Brain, spinal cord, nerves, etc.



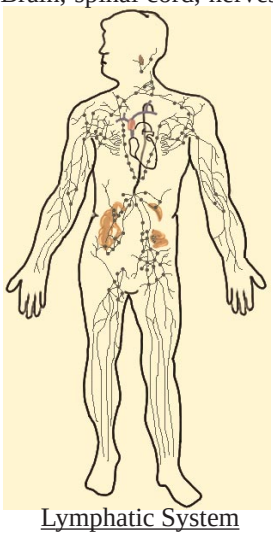
Endocrine System

Pituitary gland, thyroid gland etc.



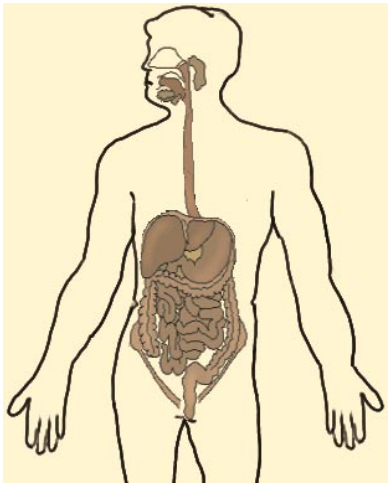
Circulatory System

Heart, veins, arteries, etc.



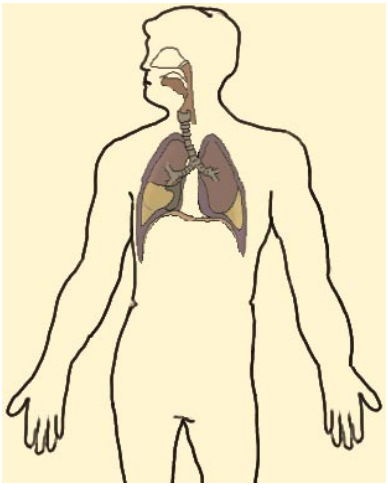
Lymphatic System

Lymph nodes, lymph vessels, spleen, etc.



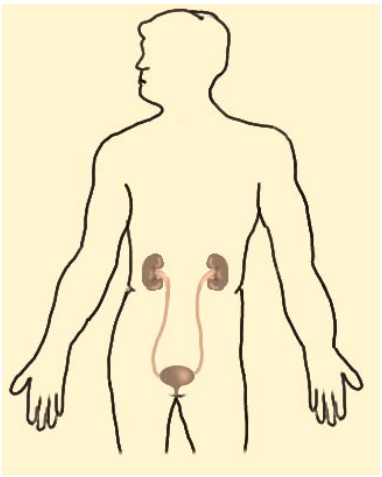
Digestive System

Stomach, liver, intestines, etc.

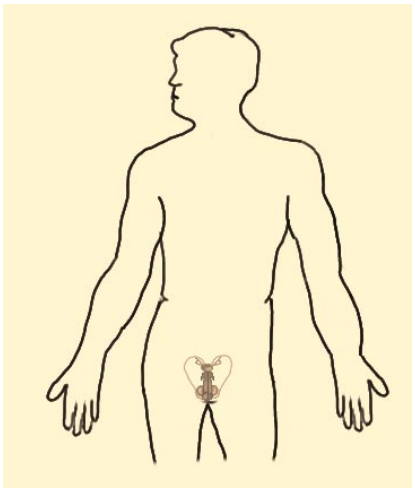


Respiratory System

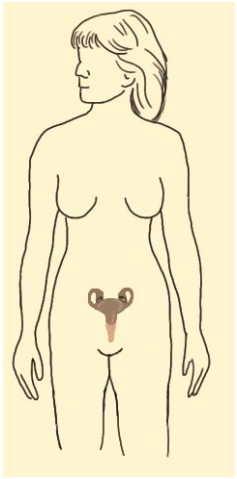
Lungs, trachea, etc.



Urinary System
Kidneys, bladder, etc.



Reproductive System
Male: testes, seminal vesicles, etc.



Female: ovaries, uterus, etc.

Now don't try to memorize this figure! As time goes on, we will eventually talk about each of these systems, and you will become familiar with each of them. We just wanted to show you the "big picture" right now to give you some idea of what's going on.

We've mentioned the term **organ** a few times, but we really haven't defined it yet. Of course, when we say "organ," we are *not* referring to the instrument played on Sunday morning; instead, we are referring to a group of tissues specialized for a particular function.

Organ - A group of tissues specialized for a particular function

Examples of organs include the liver, lungs, kidneys, and so forth. Of course, the definition of organ doesn't do much good without a definition of **tissues**.

Tissues - Groups of cells specialized for a particular function

To really appreciate tissues, you have to use a microscope. The majority of the microscope labs in this course will focus on the study of tissues. Now, here is the amazing thing. Remember, there are 11 organ systems in the body, and each of those systems is made up of two or more organs. Thus, there are a *lot* of organs in the body. Well, as our definition of organ clearly states, organs are made up of tissues. Thus, you would expect that there are a multitude of tissues in the body, right? Wrong! In fact, there are only four basic kinds of tissue in the whole body!

The first basic kind of tissue is **nervous tissue**. It makes up the brain, spinal cord, the eye, etc. Then there is **muscular tissue**, which (obviously) makes up the muscles on your skeleton, the heart, and the muscles which operate your organs. The third type of tissue is **connective tissue**, which makes up bone, cartilage, and so forth. Since this kind of tissue might not be as easy to understand as the first two, let's give you a couple of examples. If you feel the bridge of your nose, that's cartilage. The flexible part of your ear is also cartilage. That's all connective tissue. If you pull on your skin, you find that it's attached to something. It's attached by connective tissue. The last basic kind of tissue is easy to identify. It just has a longer name—**epithelial** (ep uh theel' ee uhl) **tissue**. Epithelial tissue makes up the lining of many organs, as well as glands, which will be

discussed in more detail later. For example, the surface of your skin is epithelial tissue. The lining of your mouth is also made of epithelial tissue.

Are you beginning to see a pattern here? The human body as a whole is organized into organ systems. Each organ system is composed of specific organs which do one or more jobs to achieve a common goal. Each organ is further composed of tissues. Notice, then, that we have already discussed four levels of organization in the human body. We can go at least three steps further. Tissue itself is composed of specific cells. Remember from your first year of biology that all members of kingdom Animalia (which, of course, includes humans) are made up of **eukaryotic** cells. You should also remember from that course that eukaryotic cells are composed of membrane-bound **organelles**. Thus, even the cells are composed of smaller units! Finally, even those organelles are composed of **molecules** like proteins, salts, fats, acids, etc. That's what we meant when we said that the organization of the human body has several levels to it.

ON YOUR OWN

1.1 Certain muscles are attached to your skeleton by tendons. What kind of tissue makes up tendons?

1.2 Although we did not explicitly list them, we discussed seven levels of organization in the human body. List each level.

Steady as She Goes!

Now remember, we said that anatomy underlies physiology. We just briefly introduced to you the organization of the body, which is an anatomical concept. The body is organized into organ systems, which are composed of organs, etc., etc. That anatomy underlies the physiology of the human body, which describes the way in which the body works. Okay, let's think about physiology for a moment. What is the big idea behind physiology? If you think about it, the goal of the body's functions are to keep the body working "normally." What does the word "normal" mean? That's a *hard* word to define, so we will instead use the word **homeostasis** (ho' me oh stay' sis).

Homeostasis - A state of equilibrium in the body with respect to its functions, chemical levels, and tissues

What does this definition mean? Well, what keeps us alive is the maintenance of many, many variables in our body around some norm, which we can call a "set point." You see, we need to have a stable environment within our bodies. Thus, the variables can change a little, but they can only vary within strictly defined limits.

What are these variables? Think about blood pressure, for example. It can go up under certain conditions (like when we are agitated), and it can go down under other conditions (like when we sleep), but it is controlled within a range. The blood pressure should not get too high, nor should it get too low. It should vary around a certain value, the "set point." That's homeostasis. Another

example of a variable in the human body is oxygen in the blood. The amount of oxygen in the blood is tightly controlled. There must not be too little oxygen in the blood, and there must not be too much oxygen, either. In homeostasis, the amount of oxygen in the blood varies only slightly around its set point. Your body temperature is another variable that must be controlled. We know that even if it's really cold or really hot, your internal body temperature doesn't vary much. Even when you have a fever, your body temperature is still not out of control. It's simply higher than the ideal set point. There are, literally, thousands of variables within the body that must be controlled in order for the body to work properly. When those variables are being controlled, the body is in a state of homeostasis. That's the body's ultimate goal, at least from a physiological point of view.

Homeostasis is a constant battle in the body. You see, the outside world (our environment) subjects our bodies 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 something in the environment that causes one or more variables to move too far from their set point. This makes our bodies react to correct them. If the variable or variables are not corrected, our health will be affected. In other words, stress is an imbalance that must be corrected for proper health.

There are many examples of stress. Suppose the pH of the body is too low or too high. The body must immediately correct that, or there will be disastrous consequences. Too little glucose (a term you should recognize from your first-year biology course) in the blood is another stress. It must be corrected. If it gets out of hand, it's not compatible with life. Microbiological stress is another example. Suppose you get a cold. That cold is caused by a virus which has invaded your body. Now you might not think that a cold is bad, but that's because we have a system (the lymphatic system) which combats the virus. Without our lymphatic system, the common cold would be called "the fatal cold."

The organ systems illustrated above, which we will study in depth throughout the course, counteract stress. For example, suppose you go outside without a coat, and it's very cold. What is one of the first things that happens? You start to shiver. That's actually your muscle system trying to counteract the stress of it being too cold. The increased muscle activity involved in shivering actually warms you up! What happens if it's too hot? Your skin (part of the integumentary system) responds by making you sweat. When your sweat evaporates, the evaporation cools your skin. We could cite example after example like this. In fact, as we go through the course, we will!

The organ systems in the body, then, are major players when it comes to homeostasis. They counteract stress so as to maintain the body's balance. There is one exception, however. There is one organ system that doesn't counteract stress. In fact, you can argue that this organ system actually increases your stress. Can you think of what organ system we mean? We are talking about the reproductive systems—male or female. They are not made to correct imbalances in our own body so as to keep us alive. Instead, they are made to propagate the human race. That is, of course, absolutely necessary in the long term, but it has nothing to do with homeostasis.

Let's look for a moment at the control of homeostasis. You will see that the issue of control will come up again and again throughout the course. It is one of the most fundamental aspects of physiology. It turns out that two body systems, the nervous system and the endocrine system, are

responsible for the control of homeostasis. As pointed out in Figure 1.1, the nervous system is composed of the brain, spinal cord, and nerves. The endocrine system is composed of several glands (a term we will define later on in the course) which secrete chemicals called **hormones**. These hormones control the body's chemistry. The nervous system primarily detects variables that go too far beyond their set points, and the endocrine system often secretes chemicals that will help the body bring the variables back under control.

Here's an example of how all of this works. Earlier, we told you about blood pressure. It must not get too high, and it must not get too low. A "happy medium" keeps us healthy. Your body's blood pressure is detected by receptors that are in arteries near the heart and in the neck. When these receptors sense high blood pressure, they send a message to the brain indicating that the blood pressure is too high. The brain, however, can't directly lower blood pressure. What it can do is send a message to an effector.

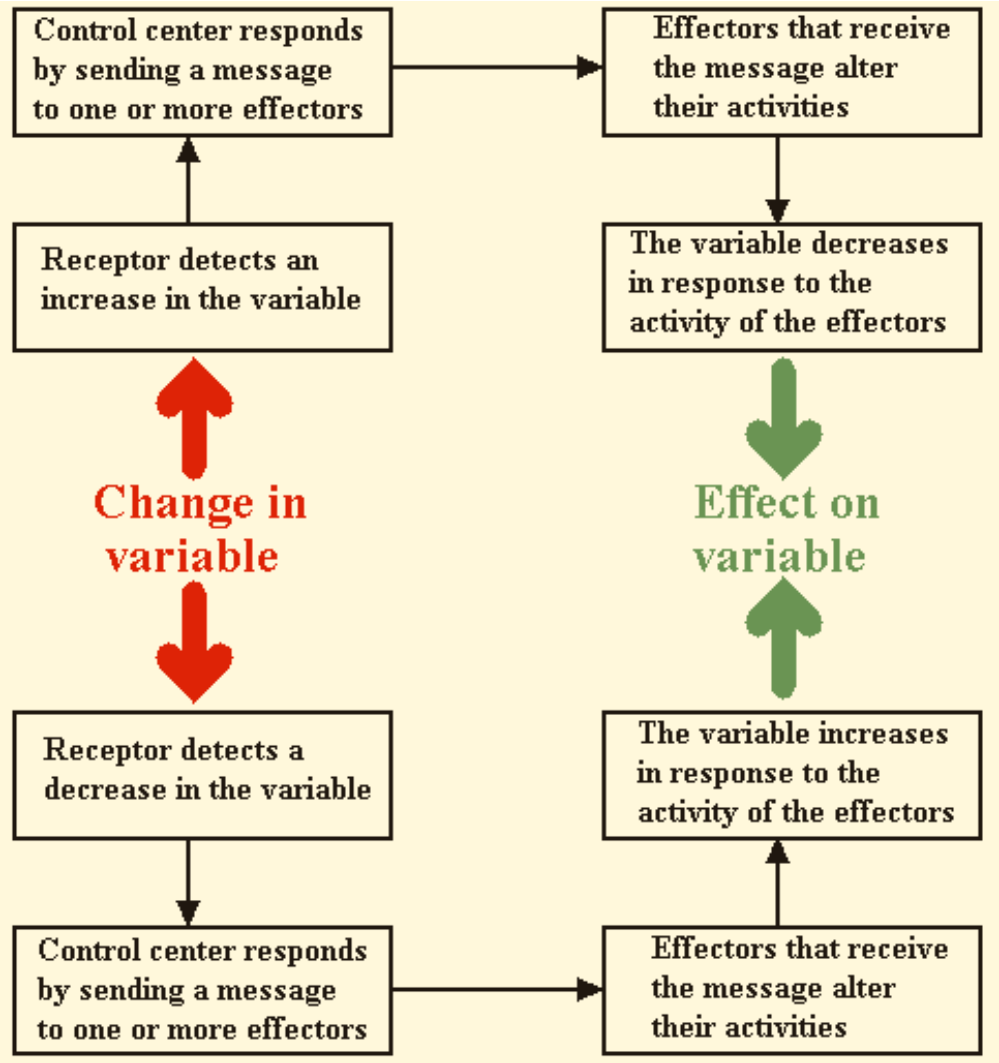
Effector - A structure in the body that can change the value of a variable

As the definition indicates, the effector *can* change the blood pressure. Thus, the brain sends a message via nerves to the effector, and the effector then lowers the blood pressure.

In the case of blood pressure, there are several effectors. One is the heart. If the heart slows down, the blood pressure goes down. Thus, the brain can send a message to the heart and tell it to slow down. The effect, usually called the "response," is that the blood pressure drops. This, then, is how your body counteracts stress. **Receptors** monitor the value of your body's variables. A **control center** (in this case, the brain) establishes the appropriate range of the variable. When the variable changes so that it is in danger of going outside of the appropriate range, the control center sends messages to one or more **effectors** to change the value of the variable so that it will stay inside the appropriate range.

What we have here is a really useful scheme called a **negative feedback system**. Figure 1.2 is a generalized illustration of the body's negative feedback systems.

FIGURE 1.2
The Body's Negative Feedback System



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

Now, of course, the opposite can happen, too. Look at the lower portion of the figure. Remember, low blood pressure is dangerous, too. Thus, the body must keep blood pressure from getting too low. If the receptors in your arteries detect a decrease in blood pressure, they will relay that information to the brain (the control center). The brain will decide whether or not the blood pressure is in danger of getting too low and, if it is, it will send a message to the heart (the effector). The heart will alter its activity (speed up), and the result will be that the blood pressure increases.

That's what "negative feedback" means - the feedback system detects a change and produces the *opposite* effect. Now we often think of "negative" as meaning "bad," but that's not the case here. Negative feedback systems are healthy, because they promote homeostasis. 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, a *major* decrease in blood pressure occurs. This change is very quickly compensated for by a negative feedback mechanism. Otherwise, if you stood up suddenly, you would just faint, because your blood pressure would be too low. Have you ever gotten light-headed after standing up quickly? That's a result of your negative feedback system not working quite quickly enough.

Let's go through one more example. As we mentioned before, the level of glucose in your blood must be tightly regulated. The level of glucose in the blood is sensed by receptors in the pancreas, an organ of the digestive system. If the pancreas (which acts as the control center in this case) determines that its receptors sense a blood glucose level that is too high, it releases a hormone, **insulin** (in' suh lin), into the blood. The insulin affects most of the cells in the body. They react to the insulin by taking in glucose. This removes glucose from the blood, which results in a *decrease* in the blood glucose level. Once again, then, this is negative feedback. What body system is the main player in this negative feedback mechanisms? The *endocrine* system. Remember, hormones are secreted by the endocrine system. Thus, if a hormone is involved, the endocrine system must be involved. In the end, then, homeostasis is controlled by negative feedback mechanisms, and that's why we have spent so much time going over how such a system works.

Now before we end the discussion, we should talk a little bit about positive feedback systems. That sounds great, doesn't it? "Positive" means "good," right? Well, not when it comes to feedback mechanisms! Positive feedback systems lead to disease or death, unless they are interrupted. For example, let's say someone gets an injury that causes severe bleeding. What do you think will happen to the person's blood pressure? It's going to drop. What should the heart do in this case? Speed up or slow down? A negative feedback system would cause it to speed up so as to increase the blood pressure back to its normal level. A positive feedback system, however, would cause it to slow down! What could cause such a positive feedback? Well, suppose the blood pressure dropped so much that the heart could not get enough blood to supply the nourishment it needs in order to increase its speed. In that case, the heart would slow down. What would happen to the blood pressure then? It would decrease even more. That's positive feedback - a drop in blood pressure causes another drop in blood pressure. At this point, the heart gets *even less* nourishment! As a result, it gets even weaker, causing the blood pressure to decrease even more. Can you see how this situation can spiral down into an imbalance that would ultimately lead to death?

Positive feedback systems, then, can lead to problems. They can even lead to death. Nevertheless, there are times when positive feedback systems are important in human physiology. When we study the reproductive process towards 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, and a negative feedback system takes its place. Thus, even the positive feedback systems that are necessary in the body (there are not a lot of them) eventually must be stopped.

ON YOUR OWN

We already discussed shivering as a response to the body being cold. Here's basically how it works. Receptors in the skin send temperature information to the hypothalamus (hi poh thal' uh mus), a structure in the brain. You will learn a *lot* more about that later. If the hypothalamus decides that the temperature is too low, one thing it can do is send instructions via the nervous system to the muscles. These instructions cause the muscles to start moving rapidly, which we observe as shivering. This increased movement produces a lot of heat, which warms the body.

1.3 Is this a negative or positive feedback system?

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?

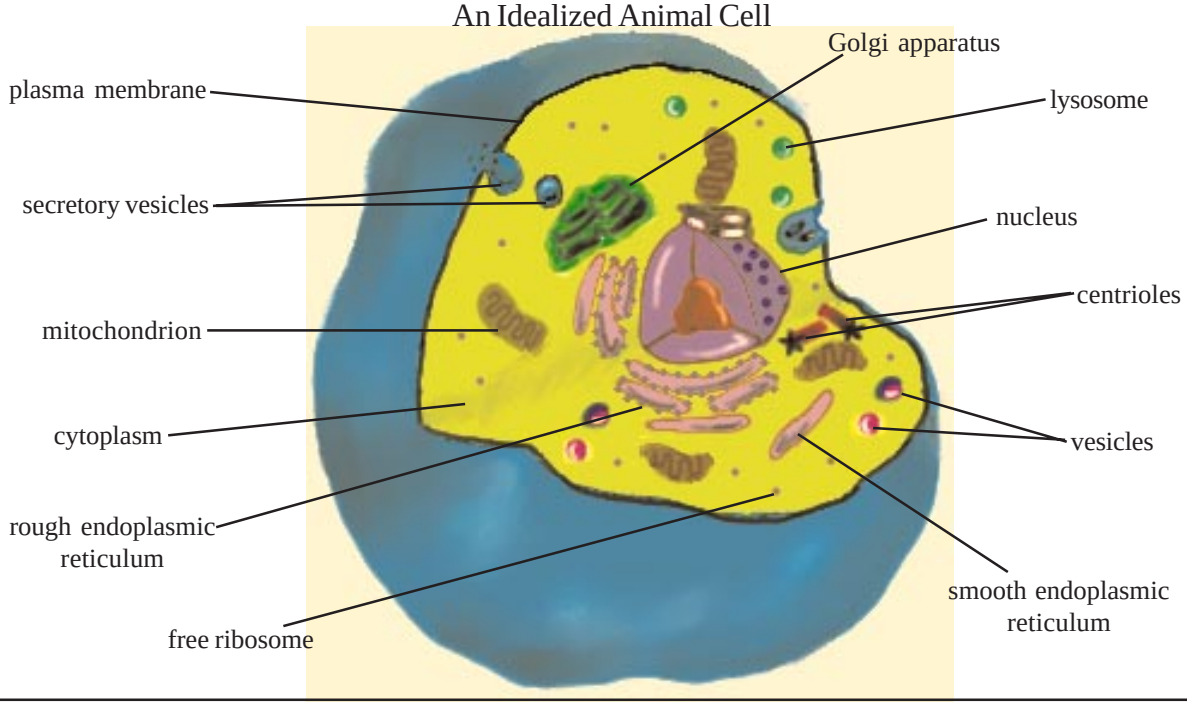
A Review of Cell Structure and Organelle Function

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. In your first-year biology course, you should have learned quite a bit about cell structure and function. We therefore will not spend an enormous amount of time on that here. However, just so that you are aware of what we expect of you, we want to do some review. If any of this does not make sense, please review your first year course, as the information is essential.

Figure 1.3 is a drawing of an idealized animal cell. All members of kingdom Animalia, including humans beings, have this basic type of cell.

Illus. By Megan Whitaker

FIGURE 1.3
An Idealized Animal Cell



There is probably no cell in the body that looks exactly like this. Nevertheless, all cells in the body have several features in common. These features are woven together into this idealized representation of a "typical" animal cell.

Now remember, tissue is composed of cells, and cells are composed of organelles. You need to know all of the major organelles and their function. Let's start with the **plasma membrane**. The plasma membrane is the boundary of the cell. It holds things together and it controls entry and exit of substances. It has many receptors on it which allow it to determine what substances can get transported into the cell and what substances can be allowed out of the cell. We will discuss this in more detail later on in this module.

The next organelle to consider is the **nucleus**. It's wrapped in a nuclear membrane which is porous. It's actually a double membrane. It's called the **nuclear envelope**. What do we need to know about the nucleus? We need to know that 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 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 chromatin is there. Remember from your first-year course that the DNA of a cell codes for the proteins that the cell produces.

Between the nucleus and the cell membrane, you will find **cytoplasm** (sigh' toh plaz uhm), which is represented by the yellow in the figure. The fluid part of the cytoplasm contains many dissolved chemicals, including ions, proteins, and other molecules. These chemicals are used for various processes, including the breakdown of sugars and fats, as well as 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. You see, proteins are synthesized by the cell in its ribosomes. As you should remember from your first-year biology course, the proteins that a cell produces are a major part of determining what the cell does for the body. Thus, the ribosomes are a very important part of the cell. They are represented by dots in the figure. Sometimes, the ribosomes are by themselves. We typically call them **free ribosomes**. You will also find ribosomes attached to the next organelle that we want to 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, which is used in intracellular transport (transport within the cell) as well as for the production of **lipids** and **carbohydrates** (chemicals you should remember from your first-year biology course). Rough endoplasmic reticulum is also used for cellular 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. When looking at a cell, 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 typically 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, including secretion. This packing may involve chemical modification. Nervous system cells, called neurons, have a lot of 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 saliva glands' cells.

The **secretory** (sec' ruh tor ee) **vesicle** in the figure came from the Golgi apparatus. When the Golgi apparatus has packaged a chemical for secretion, it puts the chemical into a little sac called a secretory vesicle. The vesicle then pinches off of the Golgi apparatus and travels through the cytoplasm to the plasma membrane, where its contents can be released outside of 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 discussion of blood glucose level earlier, 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 until they get a signal to do so. Thus, the vesicles tend to build up until the cells get the signal to release the insulin.

The next organelle we want to discuss is rather interesting. It is called the **lysosome** (lie' so sohm), and its main function is to break down lipids, proteins, polysaccharides, and nucleic acids. Once again, you should recognize these chemicals from your first-year biology course. What makes the lysosome interesting is that, in order to be able to do its job, it must contain certain enzymes. Well, 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? Well, after four to eight minutes without oxygen, the lysosomes of the nerve cells can't hold themselves together. They then burst, dumping their lethal contents into the cell. This kills the nerve cells. The rupturing of lysosomes is 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 are full of lysosomes. Have you ever had a cut that gets infected? Typically, you see a white pus form around the cut. 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 invading infecting agent. In the end, then, lysosomes can be used as "suicide packages" for cells that protect your body by running "suicide missions." Isn't that amazing?

Mitochondria (my tuh kahn' dree uh) are the major site of ATP synthesis in the cell. You should remember from your first-year biology course that ATP 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. If you recall from your first-year biology course, the first stage of cellular respiration (called "glycolysis") occurs in the cytoplasm. Thus, some ATP is made there. However, you should also recall that the vast majority of cellular energy is produced by the electron transport system, which is the third stage of cellular respiration. That stage occurs 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 that it needs. Some proteins vital for mitochondrion production are still produced by DNA in the nucleus and the ribosomes in the cytoplasm and then shipped to the mitochondria.

A lot of current research is being done on mitochondrial DNA, because it is rather different than the DNA found in the nucleus. For example, mitochondrial DNA forms a circle, which is nothing like the DNA in the nucleus. Also, while half of your nuclear DNA comes from your mother and half of it comes from your father, *all* of your mitochondrial DNA comes from your mother. Thus, your mitochondrial DNA is ideal for determining your maternal heritage.

Centrioles (sen' tree olz) are found in the **centrosome** (sen' truh zohm), which is the center of microtubule formation for the cell. As you should have learned in your first-year biology course, microtubules are spiral strands of proteins that form a rope-like structure. They tend to influence the movement and shape of the cell. You should have also learned from your first-year course that centrioles are very important in cellular reproduction, as they form the spindle that drives both **mitosis** and **meiosis**.

A cell can also have **cilia**, which are like tiny "hairs." Although cilia are not drawn in the figure, some cells have them covering part or all of their surface. In your first-year biology course, you studied paramecia and perhaps other ciliates. Those are examples of cells with cilia. There are many cells in our body with cilia. For example, back in the nose, all the way down the trachea, and all the way down the airways, there are cells that have cilia on them. Their cilia beat upward, pushing mucus towards our throat. The mucus typically has dust and other foreign particles that it traps.

Once the mucus is pushed far enough upwards by the cilia-containing cells, it can be swallowed or blown out the nose.

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 travel into and out of cells. If a substance travels into a cell, what is the first structure it will encounter?

A Review of Protein Synthesis

In your first-year course, you should have learned how cells make proteins. It is important to get that back into your mind, since we will be discussing proteins quite a bit in the course. Thus, we want to review this very quickly. The first thing you need to remember is that **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 act as catalysts (a term you should recognize from chemistry) in chemical reactions. These proteins are typically called **enzymes**. Other proteins act as hormones. Others act as **antibodies**, which fight infections. There are thousands and thousands of proteins involved in the processes of life. In each case, the number of amino acids, the type of amino acids, and the order in which those amino acids are linked together determine the properties of that protein.

Now remember, in this course, we assume that you have already had one year of high school biology and one year of high school chemistry. Thus, we are just going to assume that you understand what DNA, mRNA, tRNA, and nucleotides are. If these terms are unfamiliar to you, then you should probably go back to your first year biology book.

Protein synthesis in the cell takes place in two steps, **translation** and **transcription**. In translation, the double helix of the DNA unwinds, exposing a sequence of **nucleotides**. Remember, there are four nucleotides in DNA (adenine, guanine, cytosine, and thymine). The nucleotides act like a "Morse code," storing the sequence of amino acids for every protein that the cell needs to make. This code for the sequence of amino acids must be copied. That is done by an mRNA molecule.

Remember, there are two big differences between RNA and DNA. DNA is a double helix, while RNA is a single strand. Also, RNA uses uracil in place of thymine. Since adenine can bind only to uracil (and vice-versa), and since guanine can bind only to cytosine (and vice versa), RNA can make a "negative image" of any DNA sequence by simply binding the appropriate RNA nucleotide to the DNA nucleotide. Thus, when the DNA sequence contains an adenine, the RNA sequence will have a uracil. When the DNA sequence contains a thymine, RNA will have an adenine. When the DNA sequence contains a guanine, RNA will have a cytosine, and when the DNA sequence contains a cytosine, RNA will have a guanine, Because the RNA used in transcription is acting as a messenger, it is called "mRNA," which is short for

"messenger RNA."

In the end, then, the sequence of nucleotides in the DNA is copied as a negative image by the mRNA. Well, it turns out that every three nucleotides on that mRNA sequence codes for a certain amino acid. Thus, a sequence of three nucleotides on an mRNA molecule is called a **codon**. For example, if an mRNA molecule has a uracil followed by a cytosine followed by a guanine, that is a codon for the amino acid serine. On the other hand, a uracil followed by another uracil followed by an adenine is a codon for the amino acid leucine. Thus, you can think of the nucleotides on mRNA in little groups of three. Each group, called a codon, codes for a specific amino acid. This list of codons must then be sent to the ribosome, where a protein with the specified amino acids can be synthesized.

When the mRNA reaches the ribosome, the next step of protein synthesis, translation, begins. In translation, the codons on the mRNA are translated into actual amino acids that are linked together to form a protein. This translation occurs with the help of tRNA, which is short for "transfer RNA."

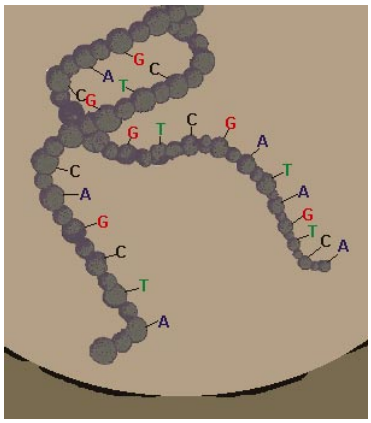
In the ribosome, the tRNA carries with it an amino acid. It has a binding site with which it can attach to the mRNA. That binding site is 3 nucleotides long. Thus, the binding site on tRNA is the same length as a codon on the mRNA. This is no coincidence. You see, the three nucleotides and the order in which they appear on the tRNA binding site determine the amino acid that the tRNA carries. For example, if the tRNA binding site contains a adenine followed by a guanine followed by a cytosine, the tRNA will carry the amino acid serine. On the other hand, a adenine followed by another adenine followed by a uracil, means the tRNA molecule will be carrying the amino acid leucine. This three-nucleotide sequence is called an **anticodon**.

In the ribosome, then, the tRNA molecules will look for an mRNA codon that can bind to its anticodon. For example, suppose the mRNA codon is a uracil followed by a cytosine followed by a guanine. The tRNA that can bind to it must have an adenine (that's the only thing which binds to a uracil) followed by a guanine (the only thing that binds with cytosine) followed by a cytosine (the only thing that binds to guanine). That tRNA, which carries the amino acid serine, is the *only* kind of tRNA that can bind to that codon of the mRNA. Well, that codon of mRNA *codes for serine*.

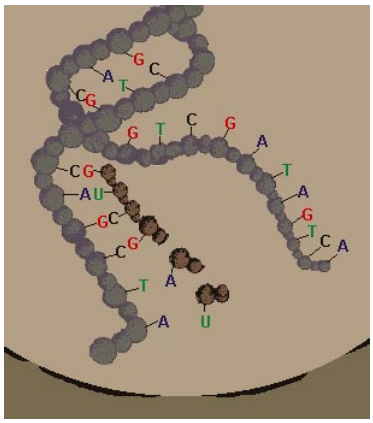
Do you see how this works, then? The three-nucleotide sequences on mRNA (codons), code for a specific amino acid. The tRNA molecules carry a specific amino acid, based on the tRNA anticodon. The tRNA molecules go looking for mRNA codons with which they can bind. Since an anticodon can bind only with one specific codon, only the tRNA with the right amino acid can bind to the mRNA at that point! Pretty clever, isn't it?

When the tRNA links to the mRNA, its amino acid lines up with the amino acid of the tRNA on the codon next to it, and a chemical process involving enzymes then links the two amino acids by a peptide bond. As this happens over and over again, a large protein is formed. Figure 1.4 illustrates this procedure.

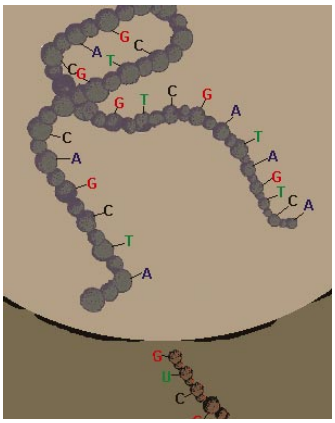
FIGURE 1.4
A Schematic Describing Protein Synthesis in Cells



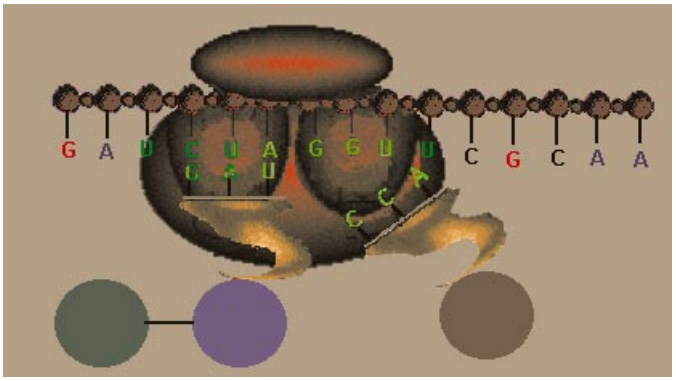
In the nucleus of the cell, DNA unwinds



RNA nucleotides in the nucleus bond to the exposed DNA nucleotides. This forms 2 strands of mRNA.



The mRNA then leaves the nucleus through a nuclear pore and goes to a ribosome.



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

We went through this rather quickly, but it *should* be review for you. If you are having trouble with it, please review it in your first-year biology course.

Now there is one little fact regarding codons that you need to know. A given amino acid can be coded for by several different codons. For example, the amino acid cysteine can be determined by the codon uracil, guanine, and cytosine or by the codon cytosine, adenine, and guanine. Of course, a single codon cannot code for more than one amino acid, but a single amino acid can have several codons which code for it.

ON YOUR OWN

1.9 What part or parts of Figure 1.4 illustrate transcription and what part or parts of Figure 1.4 illustrate translation?

1.10 Suppose an mRNA strand has the following nucleotides:

uracil, guanine, cytosine, uracil, adenine, adenine

a. How many codons are on the mRNA?
b. How many tRNAs will bind to this strand?
c. What are the nucleotide sequences of the anticodons on those tRNAs?
d. What was the original sequence of nucleotides on the DNA strand from which this mRNA strand was formed?

A Review of Cellular Mitosis

We want to review one more thing about cells before we move on to information that should be new to you. One of the most fundamental processes that a cell must do is reproduce. Most of the cells in your body must reproduce so that you can grow, repair injuries, etc. Thus, cellular reproduction is important.

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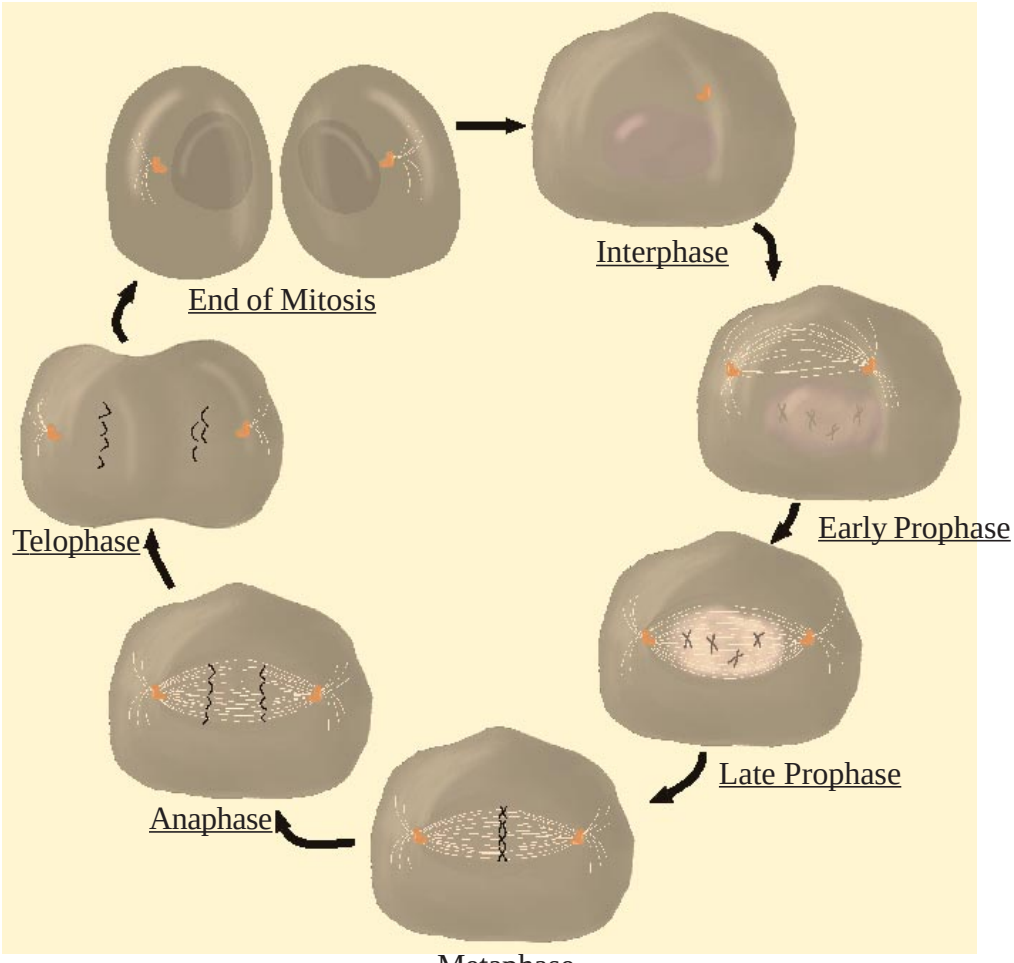
FIGURE 1.5
Mitosis



As you should have learned in your first-year biology course, cells reproduce according to a process known as **mitosis** (mye toh' sis). This process takes place in four broad steps: **prophase**, **anaphase, metaphase,** and **telophase**. When a cell is not reproducing, it is said to be in **interphase**, which is the "normal" state for a living cell. These phases of a cell's life are summarized in Figure 1.5. In the figure, the only organelles shown are the nucleus and the centrioles. Those are the most important 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. During prophase, four things happen. The centrioles duplicate and begin to form a spindle of microtubules between them. They also move towards opposite ends of the cell so that the spindle spreads across the cell. Also, the duplicated DNA forms chromosomes. Those chromosomes head towards a line that crosses the center of the cell. That line is called 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 the duplicated chromosome is attached to its partner. At that point, the spindle begins to pull, so that the duplicate and original are pulled apart. That's the beginning of anaphase. During anaphase, the duplicates and originals are being separated and pulled to opposite ends of the cell.

In the last phase, telophase, the original chromosomes are on one side of the cell, and the duplicates are on the other. The plasma membrane constricts so as to "pinch" the cell in two. The result, then, is two cells that go back to interphase.

Now remember, this should all be review for you, so if you are having trouble, please review your first-year biology course. We want to remind you of one more thing before we go on. The "X" shapes that you see for the chromosomes during prophase and anaphase exist *because* the chromosome has been duplicated. An unduplicated chromosome does not have the "X" shape that most people think of when they think of chromosomes. Instead, a "normal," unduplicated chromosome looks more like the chromosomes shown in the illustration of telophase.

There is one thing we want to tell you about mitosis that you probably did not learn in your first-year biology course. Although *most* of the cells in your body must be able to reproduce via mitosis, there are three types of cells which cannot: mature neurons (nervous system cells), skeletal muscle cells, and cardiac (heart) muscle cells. These cells lack centrioles and thus cannot form the spindle for mitosis. This means that if muscle cells or brain cells die, you lose them forever and cannot get them back! If a part of your liver gets injured, your liver cells can reproduce and repair that injury. However, since neurons cannot reproduce, if you injure your brain and kill some brain cells, you have completely lost them! They cannot reproduce and therefore will not be replaced!

ON YOUR OWN

1.11 A human cell has 46 chromosomes. If the illustration in Figure 1.5 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 not be review for you. When we look at the plasma membrane of the cell, we are going to find a *beautiful* relationship between structure and function. That is, we can look at how it's put together and what's it made of, and then we 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's 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. Let's look first at its structure, as illustrated in Figure 1.6.

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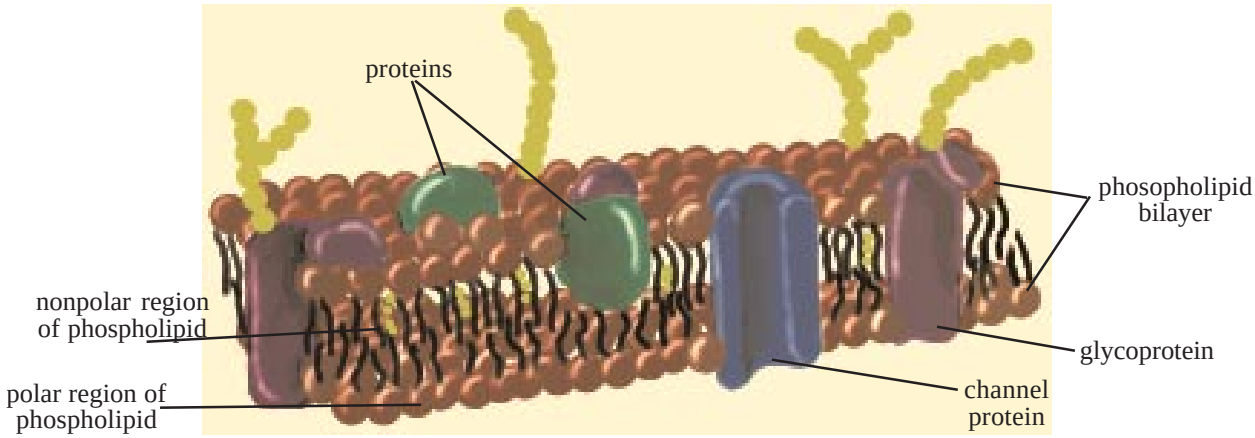
FIGURE 1.6
The Plasma Membrane



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? Well, you should remember from your first-year biology course that a phospholipid is a fat molecule with one fatty acid replaced by a phosphate group. The result is a molecule that is polar on one side and non-polar on the other. In the figure, the red balls represent the polar region of each phospholipid, while the two black tendrils coming out of the red ball represent two fatty acids, which make up the nonpolar region of the phospholipid. Okay, so that's the "phospholipid" part. "Bilayer" means, as you can see, two layers: a set of phospholipids on top and then a set on the bottom.

Now, phospholipids are interesting molecules. They have a "head," as you can see, and two "tails." The heads are water soluble because they are polar. Sometimes, biologists use the word "hydrophilic" instead of "water soluble." Since "hydrophilic" means "water-loving," the term works. The other end of the molecule (the tail), however, is just the opposite. It's nonpolar. This means it will dissolve in oil (another nonpolar substance) but not water. Biologists often call this "hydrophobic," that is, "water-hating."

Because phospholipids have this interesting property (hydrophilic on one end, hydrophobic on the other), the plasma membrane can automatically reform if it gets disturbed for some reason. This will happen because the non-polar tails of each layer are attracted to one another, and the polar heads of each layer are attracted to the water outside of the cell and the cytoplasm inside of the cell. Thus, the phospholipids, even if they are moved and disoriented, will re-orient themselves so that the heads of the phospholipids on the bottom point in towards the cell and the heads of the phospholipids on the top point out towards the water environment surrounding the cell. The tails of each phospholipid, then, are pointed towards each other. This works out, because the tails are attracted to one another.

Of course, phospholipids are not the only thing 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 the figure, and they have different functions. Some are **channel proteins**. They have a little channel to let things in and out. Some are **glycoproteins**. The prefix "glyco" means "glucose." Remember from your first-year biology course that glucose is a carbohydrate. Thus, 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 cells that belong to you and foreign cells that must be destroyed. The glycoproteins allow for such identification. There are also **receptor proteins** that take in messages from other cells. For example, in order for a nerve cell to be able to tell a muscle cell to contract, it must release a chemical that will bind to the receptor protein on the muscle cell. That chemical will trigger the response of contraction in the muscle cell.

The third type of 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 fat-soluble, which means it is nonpolar. Thus, cholesterol is found among the tails of the phospholipids. It is important to realize that cholesterol is absolutely important to the plasma membrane. So many of us have the idea that cholesterol is a toxin. It is not. It is a necessary substance that every cell membrane in every cell of our body uses to stabilize the cell membrane. You see, the phospholipids by themselves just wouldn't 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 fat molecules. Thus, the phospholipids form a kind of fluid. The word "mosaic" refers to the fact that there are many different kinds of proteins floating within the phospholipid bilayer.

ON YOUR OWN

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

Functions of the Plasma Membrane

So 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.

Now, receptors are extremely important. You've probably heard of diabetes. There are two types of diabetes. In Type I diabetes, the person lacks the ability to make a chemical called insulin. Insulin signals the plasma membrane to allow glucose to enter the cell. In Type II diabetes, which is much more common in adults than Type 1, the receptors aren't responding. There is more than enough insulin in the body, yet the cells don't respond to the insulin because the receptors don't work. As a result, glucose cannot enter the cell. Thus, the plasma membrane's receptors are important. 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

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. Thus, selective permeability is the ability to let certain materials in or out of the cell while restricting others.

Why does the plasma membrane have this selective permeability? Well, there are several reasons. Let's start with the easiest one first. Remember from first-year biology that lipids are fats, and that they are nonpolar. Also, remember from first-year chemistry that 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 fatty), 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 in the fatty plasma membrane, because nonpolar dissolves nonpolar. Thus, the fat can then travel through the plasma membrane and get into the cell. As a result, fatty substances can get into the cell rather easily. This is practically applicable. I am sure you have heard that there is a nicotine patch which can help you quit smoking. This patch works by putting a drug that reduces your craving for nicotine into a patch. The patch is placed on your skin, and your skin cells absorb the drug. Why? Because the drug is nonpolar! Thus, it can travel through the plasma membranes of your skin cells.

The next reason that the plasma membrane has selective permeability is also pretty 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 1.6 illustrates), a channel protein has a channel running through it. Small molecules can travel through that channel. Practically speaking, that means water, which is one of the smallest molecules, easily goes 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. Big molecules (such as proteins) cannot get into the channel of a channel protein, so they cannot penetrate the plasma membrane so easily. There are *other* processes that allow *certain* proteins into the cell. We will discuss those in a moment.

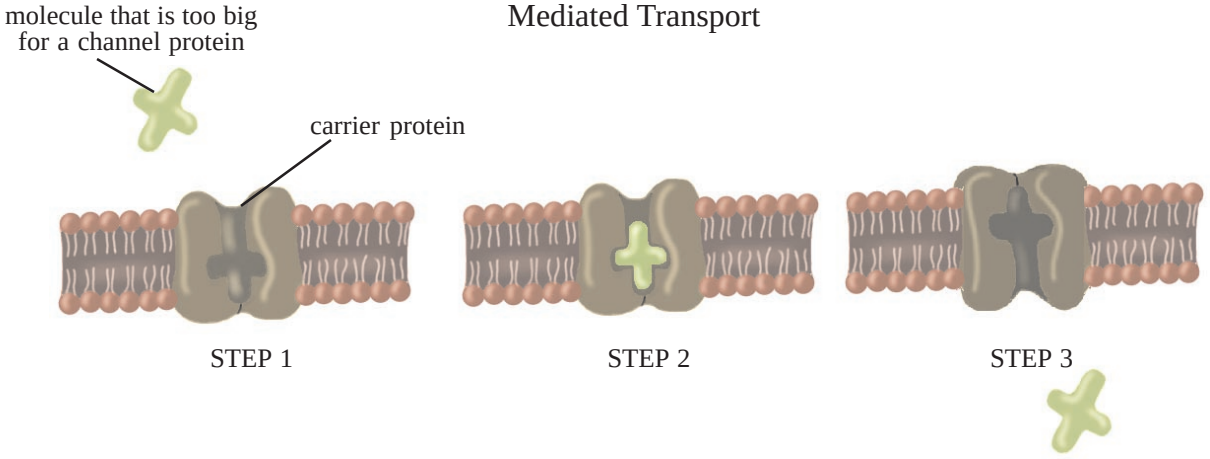
Now, the third factor that affects permeability is charge. There are certain ions (a term you should remember from your chemistry course) that a cell needs. There are also ions it must release. Thus, ions need to go into and out of cells. Well, small ions can go in and out through the channel proteins, as we just discussed. However, here is a neat twist. 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. Thus, channel proteins not only allow small molecules in and out of the cell,

they also can attract certain ions. Sodium ions, for example, are important for the cell. These ions enter the cell through channel proteins whose channels are negatively charged.

Now all of this is pretty amazing, but these three facets of the plasma membrane's selective permeability are simply the *easy* ones. At this point, we need to talk about a more complicated facet. For example, there are certain chemicals that cells have to have which are slightly too big to fit into channel proteins. We're not talking about huge molecules like proteins. Instead, we are talking about the intermediately-sized molecules, like glucose. Glucose, as you should remember from your first-year biology course, is the favored fuel for most cells. It is the only fuel that brain cells can use. However, glucose is too big to get into the cell 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 **carriers**. Carriers allow certain molecules into the cell through a process called **mediated transport**. The best way to explain mediated transport is to start with a figure.

Illus. By Megan Whitaker

FIGURE 1.7
Mediated Transport



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 molecule. In order to work, however, the molecule must have the shape for which the carrier protein is designed. In the illustration, the carrier protein works for a molecule that is shaped like a "+" sign. Because the molecule fits into the carrier protein, the carrier protein accepts it. In chemical terms, we usually 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 in the

cell via mediated transport, you need at least one carrier in which that 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 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's the same way with carrier proteins. If the cell wants glucose, it needs at least one carrier protein designed to accept glucose.

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 people in your family and three people in his, and let's say that the car can hold six people. If, in a very unChristian manner, everyone starts to run for the car at once, the car will fill up after six people get into it. That will leave two people with no way to church. That's competition. Eight people competed for six spaces. Now consider this. Which family will, most likely, have the best representation at church? Your family, most likely, since it had more members. Your family had a better chance at getting in 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. Remember, it's 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 win.

Finally, let's discuss saturation. Remember, in our car analogy, there is room for only 6 people. If you could walk to church, all of your family and all of your neighbor's family could go. However, after 6 people, the car is saturated. Thus, having a carrier (the car) limits the number of people that can be transported (to church). 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 molecules in any faster. On the other hand, if a carrier protein spends a lot of time not doing transport, 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 fatty nature. That 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 larger molecules through the membrane.

Now you should have noticed something. We have not yet told you how the cell allows proteins in. Cells make their own proteins, according to the protein synthesis process discussed in an earlier section. 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. Thus, we will discuss it in the next section.

ON YOUR OWN

1.13 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.

a. chloride ions b. simple sugars c. fatty acids d. water molecules

Membrane Transport

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's what we will cover now. Along the way, we will also discuss how huge molecules like proteins are transported through the plasma membrane.

As you should remember from your first-year biology course, 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 processes: **diffusion** and **facilitated diffusion**. Now remember what diffusion is. It is the movement of ions or molecules from an area of high concentration to an area of low concentration. The best example of diffusion in cells is probably sodium ions (Na^+). When we discuss the nervous system, you will see that cells are in an environment which has a larger concentration of sodium ions than what is found inside the cell. Now remember, sodium ions can travel through channel proteins, typically ones with negatively-charged channels. Since molecules and ions diffuse from areas of high concentration to low concentration, the sodium ions can travel through the channel proteins and into the cell. That's how diffusion works. In the case of another important cellular ion, potassium (K^+), there is a higher concentration of potassium ions *inside* the cell than outside. Potassium ions will travel through the channel protein the other way, 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 we 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 if the cell wants a ready store of energy, it will have to make another ATP molecule to replace the broken-down one. Thus, we often used the term "ATP" instead of energy when we talk about the cell. In the case of diffusion, then, we can say that the cell doesn't use any ATP.

It's pretty easy 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 in mediated transport as well. When that happens, we call it facilitated diffusion. Now think about this for a moment. Look back to Figure 1.7. It's 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 could transport either way. Thus, molecules can *enter or leave* the cell through mediated transport. If that

happens according to the dictates of diffusion (the molecules are moving from a higher concentration to a lower concentration), that's facilitated diffusion.

What's 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. Thus, 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. Thus, 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 wastes no ATP on the process.

Active transport is transport that requires energy. Thus, 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 dictates of diffusion. Remember, diffusion happens naturally. If, instead, the cell wants to move a substance from an area of low concentration to an area of high concentration (against the dictates of diffusion), it can do so, but that costs ATP!

Here is an example. Remember, we already said that sodium ions travel through channel proteins and, typically, the concentration of sodium ions is higher outside of the cell than inside. As a result, the sodium ions diffuse into the cell. This creates a problem. Cells cannot stand a high concentration of sodium ions: it kills them. Thus, even though sodium is constantly moving into the cells by diffusing through channel proteins, cells have to get the sodium right back out. Of course, the outside of the cell is exactly where the sodium ions don't "want" to go. After all, they diffused into the cell because chemicals tend to move from areas of high concentration to areas of low concentration. Thus, the cell must get rid of the sodium, even though the sodium doesn't "want" to leave. The only way to force the sodium out is to expend energy by breaking down some ATP molecules. That energy will force the sodium ions out, even though they "want" to stay 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. Thus, 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 that diffusion demands, so the cell must "pump" the sodium out. This is done with a carrier. The carrier grabs the sodium and pushes it 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 potassium ions within them; in other words, they like a high concentration of potassium inside. Typically, the concentration of potassium ions outside of a cell is quite low. Thus, potassium tends to diffuse out of the cell. To fight this, cells are constantly pumping potassium ions in. This requires ATP, because the potassium ions are going the opposite way that they would normally go. This, then, is another example of active transport.

There are two more types of active transport processes that we should discuss. The first is called **endocytosis** (en' doh sigh toh' sis). "Endo" means "within," and "cytosis" means "cell." Thus, the definition is pretty 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** (faj' oh sigh toh' sis). Pinocytosis, which means "cell drinking," is the process which 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 1.8.

FIGURE 1.8
Pinocytosis

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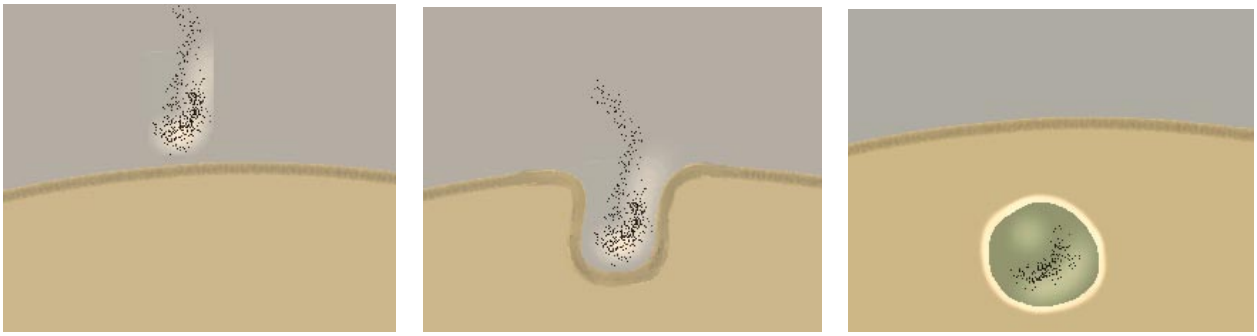


A protein is dissolved in the fluid outside of the cell.

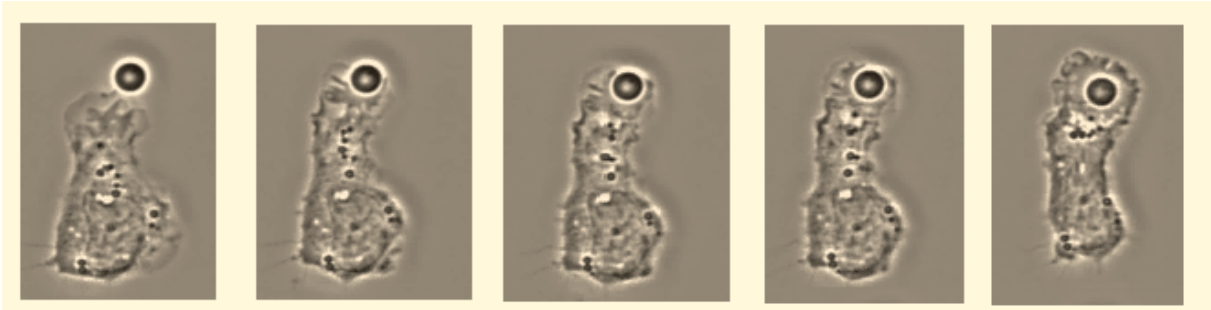
The membrane folds inward, creating a "pocket" for the protein.

The "pocket" pinches off, forming a vesicle with the protein inside.

Phagocytosis means "cell eating." Compared to pinocytosis (cell drinking), then, you can see that phagocytosis is used to ingest solids rather than fluids. In phagocytosis, the cell engulfs what it is trying to take in. Not all cells can perform phagocytosis. White blood cells, abbreviated as WBC, are probably the most common cells to use phagocytosis. They do this in order to kill foreign cells or chemicals in our bodies. Figure 1.9 is a series of microscopic photographs showing a white blood cell engulfing a yeast cell.

FIGURE 1.9
A White Blood Cell Ingesting a Yeast Cell

Photos copyright James A. Sullivan CELLS Alive!



The last active transport process that we want to 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

The Golgi apparatus often plays a role in exocytosis. Remember, we already mentioned that the Golgi apparatus packages chemicals so that they can be sent throughout the cell. Well, if a cell must secrete something, this is usually started in the Golgi apparatus, as illustrated in Figure 1.10.

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FIGURE 1.10
Exocytosis

The Golgi apparatus forms a bulge with the appropriate substance inside the bulge.

The bulge pinches off, becoming a vesicle that travels to the membrane.

The vesicle opens the membrane, releasing the chemical.

Many cells use exocytosis to secrete important chemicals for the body's use. We already discussed cells in the pancreas that secret insulin, which controls how glucose is absorbed by other cells. Insulin-secreting cells use exocytosis to release their insulin.

Now it is important to remember that both endocytosis and exocytosis are active transport processes. Thus, they require energy. In other words, the cell uses ATP in order to force these processes to work. This is regardless of the relative concentrations 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 self-reassemble. Thus, exocytosis and endocytosis work *only* because the plasma membrane has been so well-designed. If it weren't for the polar/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 our body! As the title of the course says, we are *truly* "…fearfully and wonderfully made!"

ON YOUR OWN

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

1.15 A calcium ion travels outside a cell from the inside. This process requires ATP. What can you say about the relative concentration of calcium ions inside and outside of the cell?

ANSWERS TO THE ON YOUR OWN PROBLEMS

1.1 The text says that connective tissue attaches one thing to another in your body. That's what the tendons are doing: attaching muscles to the skeleton. Thus, tendons are made of connective tissue.

1.2 The levels are: organism, organ system, organs, tissues, cells, organelles, and molecules.

1.3 This is clearly a negative feedback system, because the stress (temperature decreases) results in the opposite effect (temperature increases).

1.4 The control center is the hypothalamus. Please note that you don't need to know *anything* about the hypothalamus to answer this question. The first paragraph tells you that the hypothalamus 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 stress. The muscles are the effectors, because they generate the heat.

1.6 In this description, no hormones are mentioned. Thus, 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 amounts of an organelle if that organelle is used a lot. Thus, the cell probably secretes chemicals.

1.8 The plasma membrane is the boundary of the cell. Thus, it is the first structure encountered by any substance attempting to enter the cell.

1.9 Transcription is the process by which a "negative" of DNA's nucleotide sequences is made by RNA. That is really the middle illustration at the top of the figure. If you said all three of the top illustrations, that's fine, but typically transcription is looked at as just the specific time when the negative image is made. Translation is given by the bottom illustration in the figure, because that's when the RNA sequence is translated into a protein.

1.10 a. A codon is 3 nucleotides, and there are 6 in this sequence. Thus, there are 2 codons in this sequence.

b. Each tRNA binds to a single codon. Thus, 2 tRNAs will bind to the sequence.

c. The tRNAs must have a sequence of nucleotides that will bind to each of the three nucleotides in a codon. Thus, the tRNA must have a uracil if the mRNA has an adenine, it must have a cytosine if the mRNA has a guanine, etc. This means that the first tRNA will have adenine, cytosine, guanine in its anticodon, and the second tRNA will have adenine, uracil, and uracil in its anticodon.

d. The mRNA sequence (uracil, guanine, cytosine, uracil, adenine, adenine) resulted from the mRNA binding to the DNA. Thus, the DNA sequence will have the nucleotides which bind with these. Remember, DNA has thymine; only RNA has uracil. Thus, when mRNA has an adenine, the DNA will have a thymine, not a uracil. Thus, the DNA sequence is adenine, cytosine, guanine, adenine, thymine, thymine.

1.11 Remember, each "X" is a chromosome *and its duplicate*. The duplication 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.

1.12 The plasma membrane would not reassemble. Remember, the reason the plasma membrane can reassemble is because the polar parts of the phospholipids point towards the inside and outside, because the cell's interior is polar, as is the outside. In this hypothetical case, the outside is nonpolar, so the phospholipids on the outer part of the membrane would not know where to point.

1.13 a. The chloride ions, since they are charged, will go through charged channel proteins.

b. Simple sugars are larger molecules. Glucose is an example. Since we talked about glucose needing carrier proteins, it should make sense that simple sugars in general need carrier proteins.

c. Fatty acid molecules are, of course, fat soluble. Thus, they will dissolve through the phospholipids.

d. Water molecules go through channel proteins.

1.14 Glucose travels into cells via mediated transport. If it took no ATP, that means it took no energy, which means it is passive transport. That only happens if the motion is consistent with the dictates of diffusion. Thus, the glucose had to move from a region of *high* concentration to one of *low* concentration. Thus, the concentration of glucose inside the cell is lower than that outside the cell.

1.15 If the process required ATP, then it happened against the dictates of diffusion. This means the calcium traveled from a region of *low* concentration to that of *high* concentration. Thus, the concentration of calcium is higher outside the cell than inside.

STUDY GUIDE FOR MODULE #1

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
    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 our environment that threaten homeostasis?

8. Suppose your heart rate began to increase to a point that was dangerous. 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 are the two organ systems that control 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 we discussed and briefly give their main function.

12. How many nucleotides are in a codon?

13. Suppose the first nucleotide on a codon is adenine. What will the first nucleotide be on the corresponding anticodon? What was the nucleotide that was originally on DNA?

14. List the phases of mitosis in order.

15. In which phases of mitosis do chromosomes have the "X" shape that most people associate with chromosomes?

16. What property of phospholipids gives the plasma membrane the ability to self-reassemble?

17. What is the function of a glycoprotein in the plasma membrane?

18. What is the function of a receptor protein in the plasma membrane?

19. The model of the plasma membrane that we discussed is the fluid mosaic model. What is the "fluid?" What does "mosaic" refer to?

20. 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 6. That's fine, too.

21. 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
e. an invading bacterium
f. a lipid

22. If a protein enters a cell, and the outside of the cell has a higher concentration of that protein than the inside of the cell, is that an active transport process or a passive transport process?

23. If a glucose molecule enters a cell, and the concentration of glucose inside the cell is less than the concentration of glucose outside the cell, did the cell expend ATP?