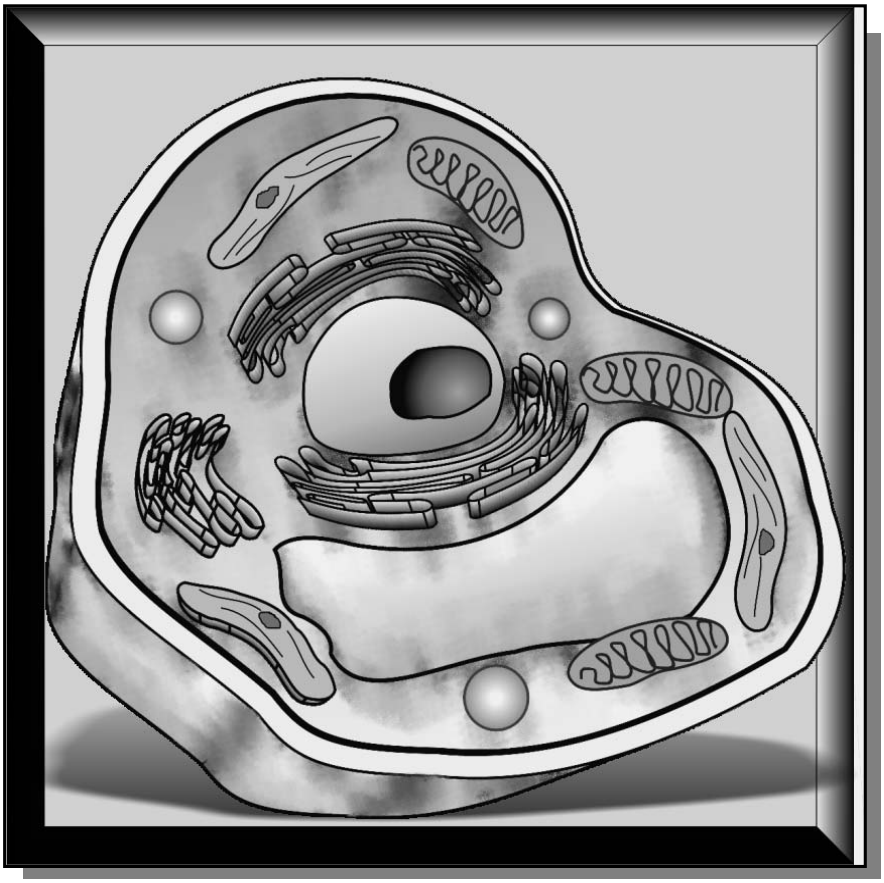
The Principles, Theories & Precepts of Biology

This chapter requires a companion activity book in which students respond to questions on text content. Answers are found in the *Teacher's Resource Kit*.



Chapter 2

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PROFESSIONAL CREDITS

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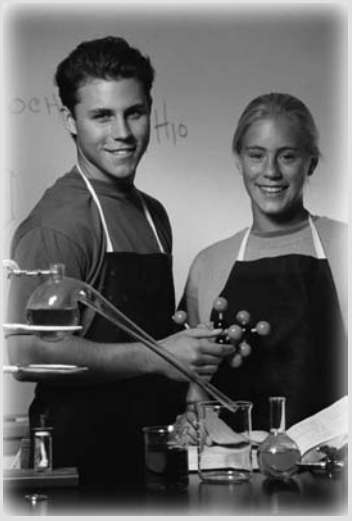
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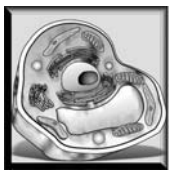
"Biology is man's attempt to understand who he is, where he came from, why he is here, and where he is going."

—Ronald E. Johnson, C.Ph.D.



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Cells

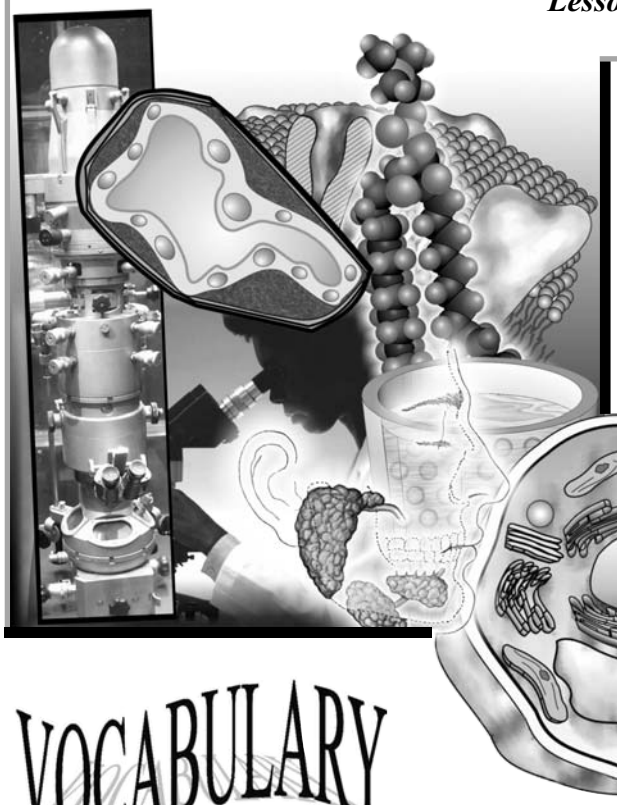
Lesson 1

Chapter 2

THE CELL— A BRIEF HISTORY

Section 1

Lessons 1-5



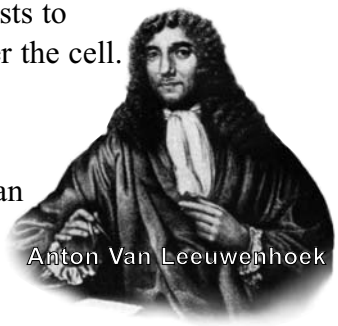
This chapter is one of the most intriguing studies in science. The following fifteen lessons lay the foundation for understanding how your marvelous body develops through cell growth. You will, however, need to concentrate while absorbing some rather complex terms and processes. Keep in mind that the rest of this biology course rests on the foundational information you will learn in this chapter, which is probably the most challenging of the entire study of biology. Consider the activity questions carefully and you will complete the chapter with a wonderful sense of appreciation for the magnificent, purposeful way you are designed to function.

VOCABULARY

Cell: smallest working unit of living things
Micrometer: a unit of length used in mircroscopic measurements; one thousandth of a centimeter
Microscope: an instrument that produces magnified images of tiny structures
Monastery: a large residence for monks (single men who have taken religious vows of separation from society)
Contemporary: living and working during the same time period as someone else

THE CELL—A BRIEF HISTORY

Cells are the smallest working units of living things. Most cells are very small and cannot be seen by the naked eye. These microscopic cells are between 1 and 100 ***micrometers*** in diameter. To put this in perspective, 4,000 average-sized cells laid side-by-side would make a row only about an inch long. Although biologists study cells with a variety of tools, the most important tool is the ***microscope***. Invention of the microscope enabled scientists to magnify tiny structures and thereby discover the cell.



Anton Van Leeuwenhoek

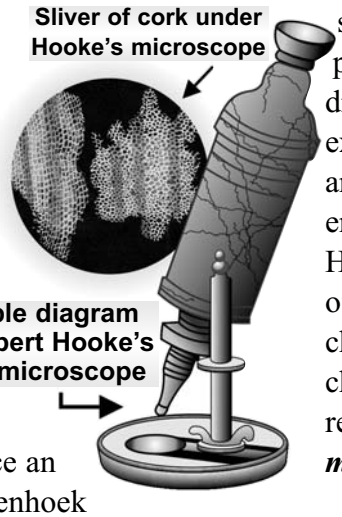
EARLY MICROSCOPES

In the late 1600's, Dutch businessman Anton Van Leeuwenhoek discovered a new purpose for glass lenses he was grinding.

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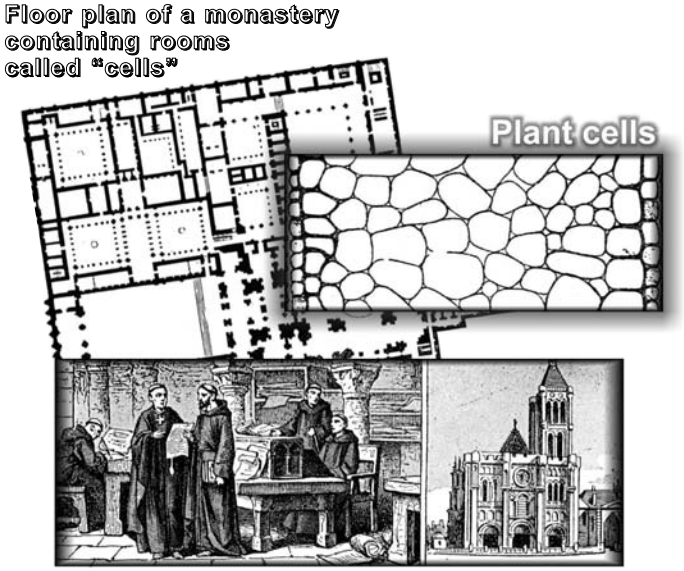
Leeuwenhoek found that by placing several magnifying lenses at proper distances from each other, images of very small objects could be magnified. Although this first microscope looked simple and primitive, it could magnify objects a few hundred times greater than their actual sizes.



Leeuwenhoek's microscopes were predecessors to the most familiar type of microscope used today, the *light microscope*. In a light microscope, rays of light are bent through lenses to produce an enlarged image. Leeuwenhoek used his light microscope to examine drops of pond water and other liquids. To his amazement, he discovered that many liquids were filled with tiny living things. He called these things *animacules*, meaning "little animals."

In the same time period, Robert Hooke, an English physicist, used light microscopes to observe flowers, insects, spider webs, and slices of cork. In 1665, he published *Micrographia*, a book of drawings of his observations. Hooke examined a sliver of cork under a microscope and observed microscopial pores—the spaces enclosed by the cell walls of dead cork tissue. Hooke also pointed out that the woody parts of plants contained tiny, rectangular chambers which he called *cells*. Hooke chose this name because the chambers reminded him of the tiny rooms in a ***monastery***, which are also called cells.

Hooke believed that only plants were made of cells—an idea that scientists did not challenge for nearly 200 years.



In 1839, during a dinner conversation between German biologists Theodor Schwann and Matthias Schleiden, a general *cell theory* was born. Schwann realized that plant cells described by Schleiden were very similar to structures Schwann had observed in the nerve tissue of animals. Schwann's

VOCABULARY

Biogenesis: the theory that living organisms originate from other living organisms
Protoplasm: living substance, the material of cells
Fibrils: small threadlike fibers
Cytoplasm: a portion of the cell outside the nucleus which means "cell fluid"; contains many complex organelles
Electron microscope: a microscope that uses a beam of electrons to examine a sample
Compound light microscope: a microscope that uses lenses and light to magnify an image
Scanning probe microscope: a microscope that traces the surface of a sample with a small tip called a probe

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further studies proved that all tissues—blood, skin, bone, nerve and muscle—are composed of cells. He was also the first scientist to point out that eggs were cells, despite their comparatively large size.



A very important extension of the cell theory was contributed in 1858 by Rudolf Virchow of Germany. Virchow said that all living cells arise from pre-existing living cells and that there is no spontaneous generation of cells from non-living matter.

Virchow was a brilliant pathologist who researched the underlying causes of disease and made multiple contributions to medicine and science. He was one of the most renowned scientists of the last half of the 19th century. As a ***contemporary*** of Charles Darwin, Virchow opposed Darwinism and advocated banning it from schools because, he stated, its logical outcome would be socialism. (Virchow also refuted Darwinism on the basis of it having only "speculative evidence.")

The discoveries and observations pioneered by Schwann, Schleiden and Virchow make up what is now called the *cell theory*, which forms the basis of the way biologists study living things today.

Cell Theory Tenents

(1) Cells are the fundamental units of life, the smallest working units of living things.

(2) All organisms are made up of cells.

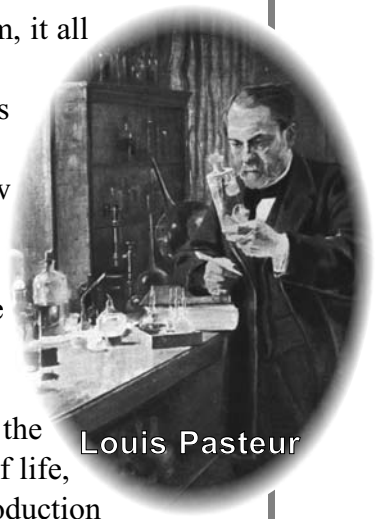
(3) Cells arise only by division of other cells.

(4) Cells contain an organism's genetic information.

(5) All cells have the same basic chemical composition.

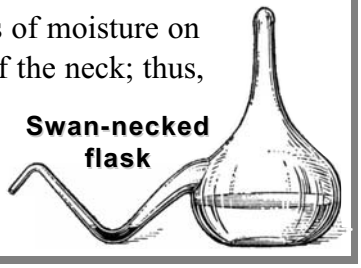
(6) All metabolism and biochemistry of life occurs in cells.

The cell theory applies to all organisms. Some organisms, such as the paramecium, contain only one cell. Other organisms, such as a dog or a rose bush, contain millions of cells—all acting together to help the organism function as a single unit. Regardless the size of the organism or how many cells it contains, each of its cells is produced by cell division. How marvelous is the fact that regardless of the complexity of an organism, it all began with just one cell.



Proof of Virchow's theory of ***biogenesis***, life from life, came only a few years later through the premier work of Louis Pasteur in France. Before Pasteur's experiment, many scientists as well as non-scientists believed in the *spontaneous generation* of life, meaning the supposed production of life from non-living matter.

Pasteur's now-classic experiments finally settled the matter that life begets life; it does not just happen spontaneously. Pasteur placed various nutrient broths into long-necked flasks and then bent the necks of the flasks into curves. Next, he boiled the broths in the flasks to kill any microorganisms (germs) that might be in the flasks. While the flasks were left standing, germ laden dust particles in the air settled into the opening of the flasks but were trapped in the films of moisture on the humid curves of the neck; thus, the curved neck acted as a filter. Although the broths were left



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standing in their "swan-neck" containers for months, no life appeared in them. Control broths, boiled in flasks with straight-necks, did not remain free of microorganisms and were soon teaming with life. Similarly, when the swan-neck was broken off, the experimental broth rapidly developed colonies of molds and bacteria. Thus, Pasteur proved that air was the source of microorganisms that grew in the flasks, and that the organisms did not arise spontaneously from the nutrient media. Pasteur triumphantly exclaimed, "Never shall the doctrine of spontaneous generation recover from the mortal blow that this one, simple experiment has dealt it."

Some of Pasteur's original, swan-necked flasks remain on display at the Pasteur Institute in Paris, France. Still open to the air, the broth in the flasks remains sterile after 140 years! Yet, the theory of spontaneous generation is "alive and well" today. By assuming that anything can happen if given enough time, many modern scientists continue to attempt to explain how the first living cell supposedly arose from non-living material.

As microscopes improved, evidence for cell theory accumulated as more and more structures could be discerned within the jelly-like substance of the cell. Jan Evangelista Purkinje, an outstanding Czech anatomist with a religious background, called the jelly of the cell ***protoplasm*** after the theological term, *protoplast*, which means "the first formed being".

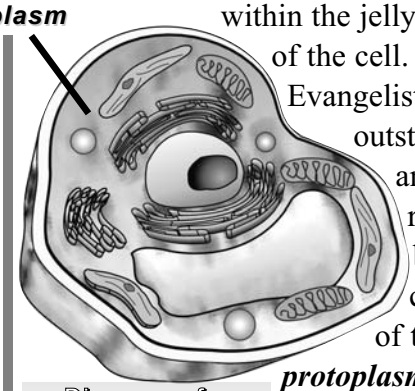
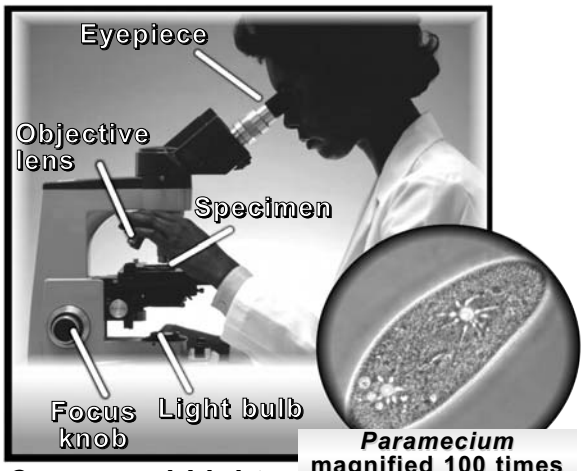


Diagram of a single plant cell, as revealed by the electron microscope

The protoplasm was at first thought to be just liquid, but eventually tiny particles and ***fibrils*** could be distinguished within protoplasm. Scientists have proven that protoplasm is composed of an enormous variety of remarkable structures and has, in more modern times, been renamed ***cytoplasm***. Many of these structures have been studied intensely under the light microscope, but the high power of the modern ***electron microscope*** has revealed the organization of the cell in significant detail.

MODERN MICROSCOPES



Compound Light Microscope

The most common, familiar type of microscope is the ***compound light microscope***. The word *compound* indicates that the instrument contains more than one lens. This is the type of microscope used in most biology classrooms or laboratories. Most compound light microscopes can magnify an image up to 1000 times, which makes this microscope very useful for studying many kinds of cells and small organisms. In addition, with the compound microscope, cells and organisms can often be studied while they are still alive.

In the 1930's, German professor E. Ruska built the first electron microscope,

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which used a beam of electrons instead of light to examine a sample. (Research with the electron microscope led to the development of television.) Electron microscopes have been steadily improved and can now magnify one million times, which means points no more than one thousandth of a micron apart can be distinguished. Obviously, the electron microscope can magnify much smaller structures than an ordinary light microscope.

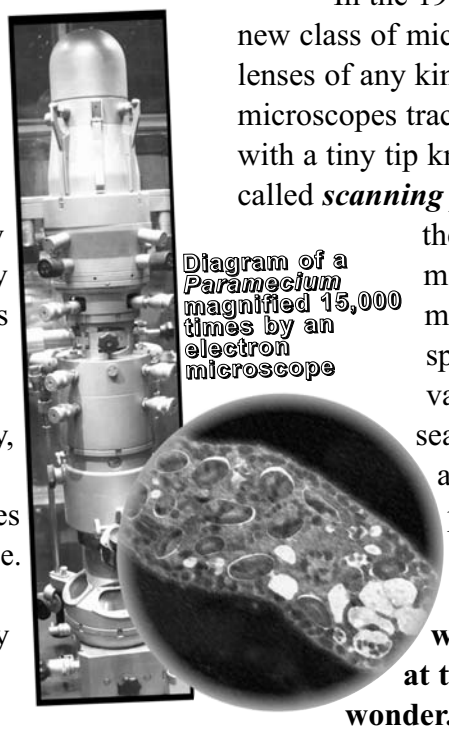


Diagram of a *Paramecium* magnified 15,000 times by an electron microscope

Although electron microscopes are powerful, they do have their limitations. The sample must be kept in a vacuum, which is a space without air, because collisions between the electron beam and air particles would blur the image. As a result, electron microscopes can be used to study only non-living specimens.

In the 1980's, researchers developed a new class of microscopes that do not use lenses of any kind to produce images. These microscopes trace the surfaces of a sample with a tiny tip known as a probe and are called ***scanning probe microscopes***. Unlike the standard electron microscope, scanning probe microscopes do not require specimens to be placed in a vacuum. Researchers eagerly search new and different applications to apply powerful new tools to the study of biology.

In the next lesson, we will take an overall look at the cell—a manufacturing wonder.

LIFE PRINCIPLE

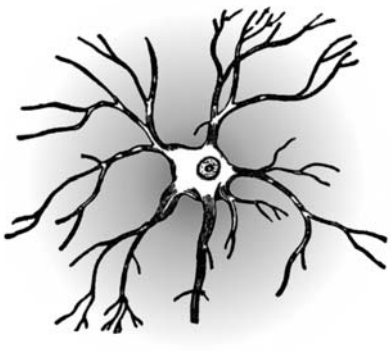


"If we all worked on the assumption that what is accepted is really true, there would be little hope of advance."

—Orville Wright (1871-1948)
American aviation pioneer

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Cells

Lesson 2

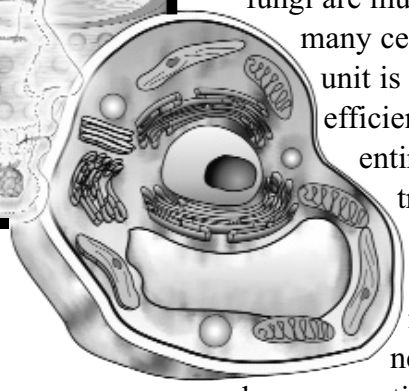
Chapter 2

THE CELL—A FUNCTIONAL MIRACLE

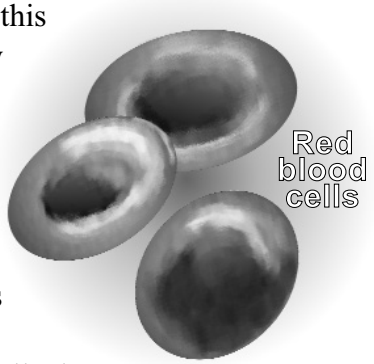
Section 1

Lessons 1-5





Cells are the smallest structures capable of sustaining basic life processes, such as taking in nutrients, breaking down the nutrients, expelling wastes and reproducing life. All living things are composed of cells. Some microscopic organisms, such as ***bacteria*** and ***protozoa***, are unicellular, which means each consists of a single cell. Plants, animals and fungi are multicellular; that is, they consist of many cells working in concert. The cell unit is a marvel of design and efficiency, whether it makes up an entire bacterium or is just one of trillions in a human body. Cells carry out thousands of biochemical reactions each minute and continually reproduce new cells. The activity of a cell never ceases and many reactions happen simultaneously. Miraculously, the cell retains a consistent process of order. A biologist would never think of making two different products in the same vessel if he wished them to be distinct and separate. Yet, the cell does this over and over without a moment's delay and does it with perfection.



Red blood cells

Cells vary in size. The smallest cell, a type of bacterium known as a *mycoplasma*, measures 0.0001mm (0.000004 in.) in diameter; 10,000 mycoplasms in a row are only as wide as the diameter of a human hair. Some of the largest cells are the nerve cells that run down a giraffe's neck; these cells can exceed 3 meters (9.7 feet) in length! Human cells exist in a variety of sizes, from a small red blood cell that measures 0.00076mm (0.00003 in.) to a liver cell that is about ten times larger than a red blood cell.

VOCABULARY

Bacteria: prokaryote with a cell membrane and genetic material not surrounded by a nuclear envelope

Protozoa: a class of primitive, eukaryotic and unicellular organisms

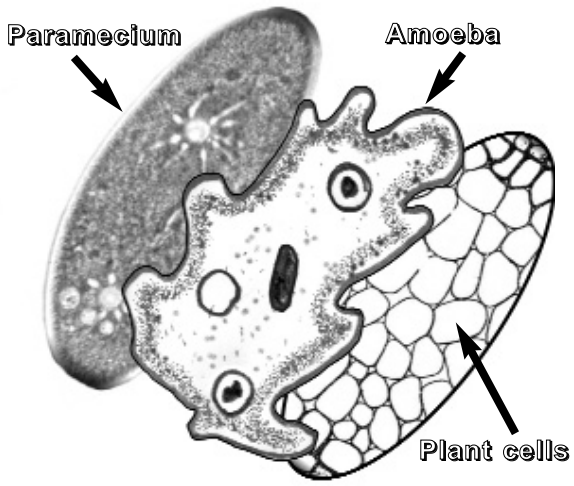
Absorption: the transport of dissolved substances into cells

Digestion: the chemical breakdown of food into materials that can be absorbed and used by an organism for nourishment

Respiration: the oxidation of food molecules which produces energy and releases carbon dioxide

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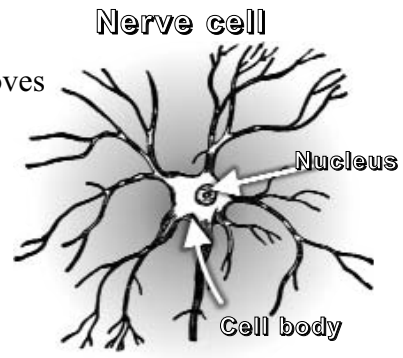
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VOCABULARY

Biosynthesis: the process by which living organisms produce needed substances
Excretion: the removal of soluble waste materials from the cell
Egestion: the removal of non-soluble waste materials from the cell
Secretion: the release of biosynthesized substances for use by other cells
Movement: the function by which a cell either moves from one point to another or moves something within the cell itself
Irritability: the function of a cell as it senses and responds to the changing environment
Homeostasis: maintaining the status quo in a cell; maintaining the order in the cell and making sure that all substances needed by the cell are continuously available
Reproduction: the process by which a cell produces more cells
Prokaryotic: a type of organism that does not contain nuclei; typically a small, single-celled bacteria
Eukaryotic: organisms made of cells, each of which contains a nucleus, a cell membrane and membranes around the different organelles

Cell shape varies as well. Some, such as the bacterium Escherichia coli, resemble rods. The *paramecium*, a type of protozoan, is oval and long; and the *amoeba*, another protozoan, has an irregular form that changes shape as it moves around. Plant cells typically resemble cubes. In humans, the outermost layers of skin cells are flat, while muscle cells are long and thin. Some *nerve cells* have elongated, tentacle-like extensions somewhat like the appendages on an octopus.



In multicellular organisms, shape is typically tailored to accommodate the cell's job. For example, flat skin cells pack tightly into a layer that protects the underlying tissues from invasion by bacteria. Long, thin muscle cells contract to move bones. The many extensions from a nerve cell allow it to connect to several other nerve cells in order to send and receive messages rapidly and efficiently.

By itself, each cell is a model of independence and self-containment. Like a miniature walled city in a 24-hour rush zone, the cell constantly bustles with traffic, shuttling essential molecules from place to place to carry out the business of living. Despite their independence, cells display a remarkable ability to join, communicate and coordinate with other cells. The human body, for example, consists of an estimated 20 to 30 trillion cells. Dozens of different kinds of cells are organized into specialized groups. For example, tendons and bones are composed of one type of specialized group called connective tissue. Skin and mucous are built from another specialized group.

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Different groups are then designed into organs like the heart, stomach and brain. Organs, in turn, are designed into systems such as the circulatory, digestive or nervous systems. All together, these systems—all made from individual cells—form the human body.

As you learned in the previous lesson, the components of cells are molecules, which are nonliving structures formed by connecting atoms. *Proteins*, *nucleic acids*, *carbohydrates* and *lipids* are the four major building blocks of cell structure. For example, biochemical reactions in cells are guided and catalyzed by enzymes, which are made of proteins. The nucleic acid DNA contains hereditary information for cells. Cell membranes are made of lipids and proteins.

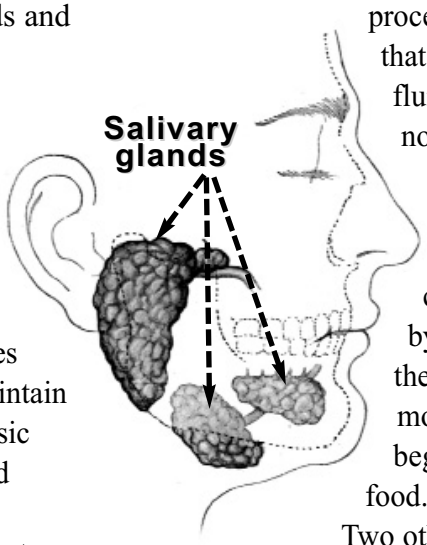
Cell Functions

In the process of life, cells must carry on several different functions. Primarily, cells must maintain sufficient energy to live and perform the duties for which they are designed. To maintain energy, cells must perform three basic functions: ***absorption***, ***digestion*** and ***respiration***.

In *absorption*, dissolved substances must enter the cell from outside. Because some substances are poisons which would kill the cell, the absorption process is actually a complicated process in which the cell "recognizes" the substances which are trying to enter. A mysterious design agent allows the cell to identify useful substances which are allowed in, while harmful substances are rejected.

In the process of *digestion*, large molecules are broken down into smaller ones. For example, digestion occurs when polysaccharides are broken down into monosaccharides. In *respiration*, the monosaccharides are broken down to produce energy for the cell. Digestion occurs also when proteins are broken down into their individual amino acids, but instead of being used for an immediate source of energy, or respiration, the amino acids are used by the cell to build a new protein. This function of the cell is called ***biosynthesis***.

Since a cell absorbs substances from the outside environment, the cell must also eliminate excess substances. The cell uses three methods to eliminate substances: ***excretion***, ***egestion*** and ***secretion***. *Excretion* involves the removal of substances that can be dissolved in the fluids of a cell. *Egestion* is the process of removing substances that cannot be dissolved in the fluids of the cell. *Secretion* does not involve the removal of wastes. Instead, it is the process the cell uses to transport substances that the cell has manufactured for use by other cells. For example, the salivary glands in your mouth secrete saliva which begins the digestive process of food.

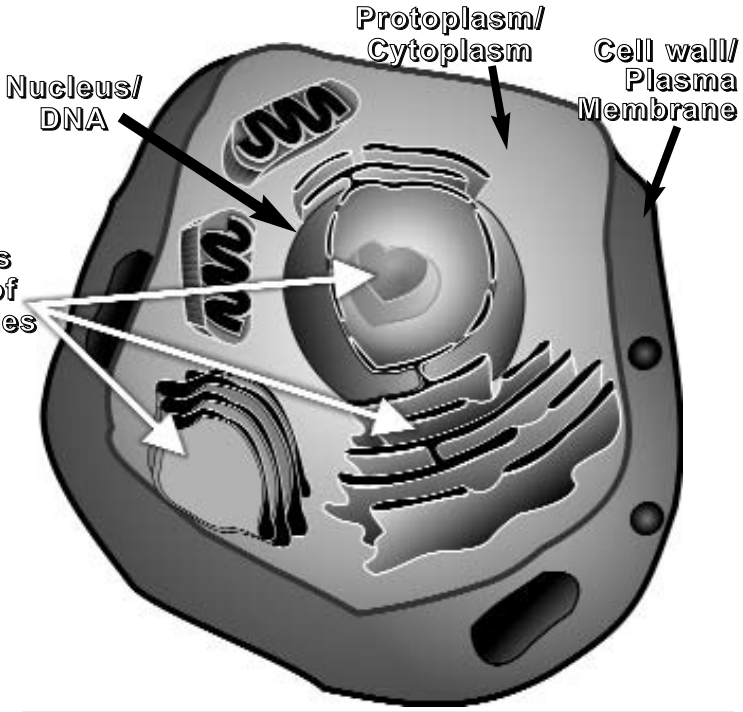


Two other important cell functions are ***movement*** and ***irritability***. *Movement* involves the locomotion of a cell from one point to another or moving things within the cell. *Irritability* refers to the ability of the cell to sense and respond constantly to the changing environment, both inside and outside of the cell boundary.

In order for a cell's continued existence, two other functions must be performed: ***homeostasis*** and ***reproduction***. *Homeostasis* involves maintaining the order in the cell and making sure that all substances needed by the cell are continuously available. *Reproduction,*

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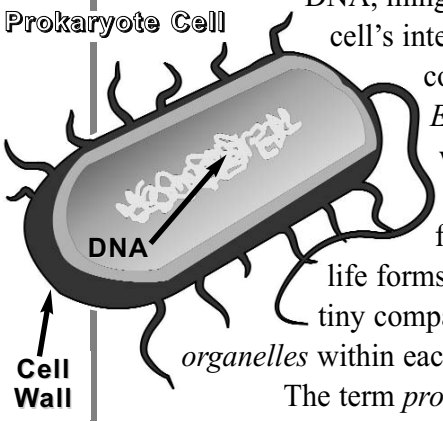
of course, is the process of making new cells, a very important function for maintaining life. In the entire history of *cytology*, the study of cells, scientists have seen cells produce in only one way: from other cells. Chemicals or any other non-living substances have never produced a living cell. Scientists, even in cloning, must have a living cell with which to start production of a new cell. That is an integral part of cell theory as discussed in the previous lesson.



Eukaryotic Cell

Prokaryotic and Eukaryotic Cells

Cells fall into one of two categories: ***prokaryotic*** or ***eukaryotic***. In *prokaryotic* cells (bacteria), all the components, including the DNA, mingle freely in the cell's interior, single compartment. *Eukaryotic* cells, which make up plants, animals, fungi, and all other life forms, contain numerous, tiny compartments or *organelles* within each cell.



The term *prokaryote* comes from the Greek words that mean "before nucleus" or "pre-nucleus." *Eurkaryote* means "true nucleus."

Prokaryotic cells are among the tiniest of all cells. About a hundred typical prokaryotic cells lined up in a row would match the thickness of a book page. These cells are surrounded by a protective cell wall. Like most cells, prokaryotic cells live in a watery environment, whether soil moisture, a pond, or the fluid surrounding cells in the human body.

Eukaryotic cells are generally about ten times larger than prokaryotic cells. In animal cells, the plasma membrane, rather than a cell wall, forms the cell's outer boundary. With a design similar to the prokaryotic cell, the plasma membrane separates the cell from its surroundings and regulates the traffic across the membrane. Moreover, each eukaryotic cell houses a nucleus and numerous other membrane-enclosed *organelles*. Like separate rooms of a house, these organelles enable specialized functions to be carried out efficiently.

Regardless of the cell type, the cell is a manufacturing wonder. In the next few lessons, we will be examining the intricate design and complex components within the cell.

In the next lesson, we will examine the amazing structures that protect the cell—the cell membranes and cell walls.

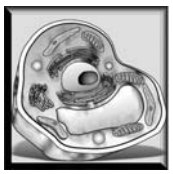
Life Principle



"Opportunity is missed by most people because it is dressed in overalls and looks like work ."

—Thomas A. Edison (1847-1931)
American inventor, entrepreneur and industrialist

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Cells

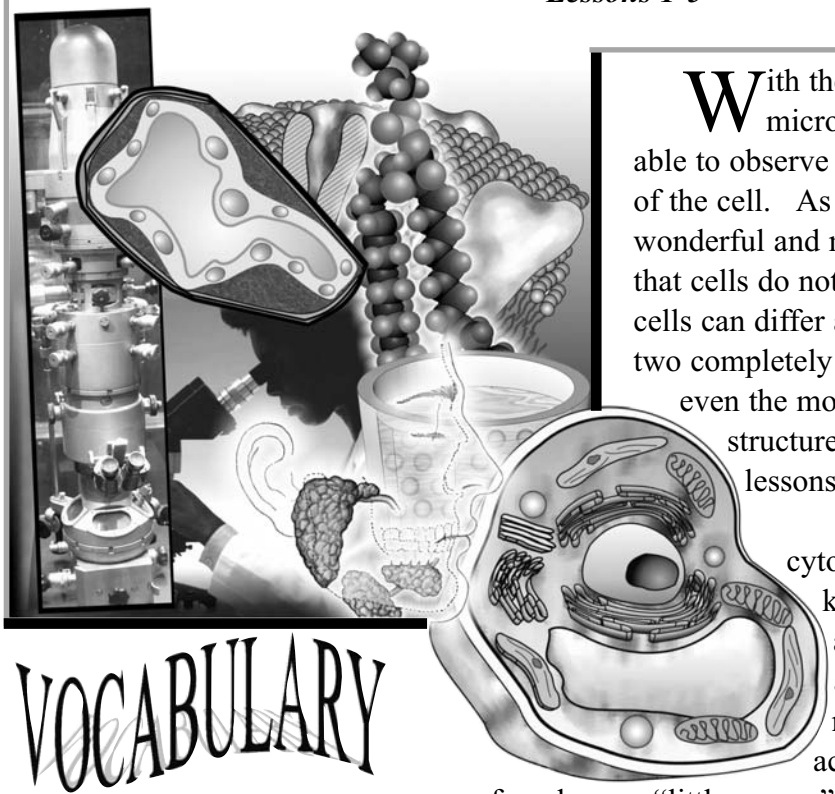
Lesson 3

Chapter 2

CELL WALLS AND CELL MEMBRANES

Section 1

Lessons 1-5



With the development of powerful microscopes, scientists have been able to observe the intricacies and complexities of the cell. As scientists peer into these wonderful and marvelous units of life, they find that cells do not all look alike. In fact, two cells can differ as much from each other as can two completely different organisms. However, even the most distinctive cells have many structures in common, as the next few lessons will illustrate and describe.

Every cell is made up of cytoplasm, a ***cell membrane*** (also known as the plasma membrane) and a nucleus. The cytoplasm is a living material outside of the nucleus in which various activities take place and in which are found many "little organs" called ***organelles*** with specific functions. The cell membrane surrounds the cytoplasm and acts as a protective boundary for the cell. The nucleus contains the genetic material for the cell. In addition to these universal components, each cell of plants, as well as algae and bacteria, has a cell wall which is located just outside the cell membrane.

VOCABULARY

Cell membrane: part of the cell's outer boundary; contains a lipid bilayer

Organelles: small structures within the cell that perform specialized functions

Phospholipids: a class of lipid molecules, each molecule having a polar, hydrophilic head and two, non-polar hydrophilic tails; important components of biological membranes

Cell wall: tough, porous boundary that lies outside the cell membrane; found in plant cells and in some bacteria, but not in animal cells

CELL MEMBRANES

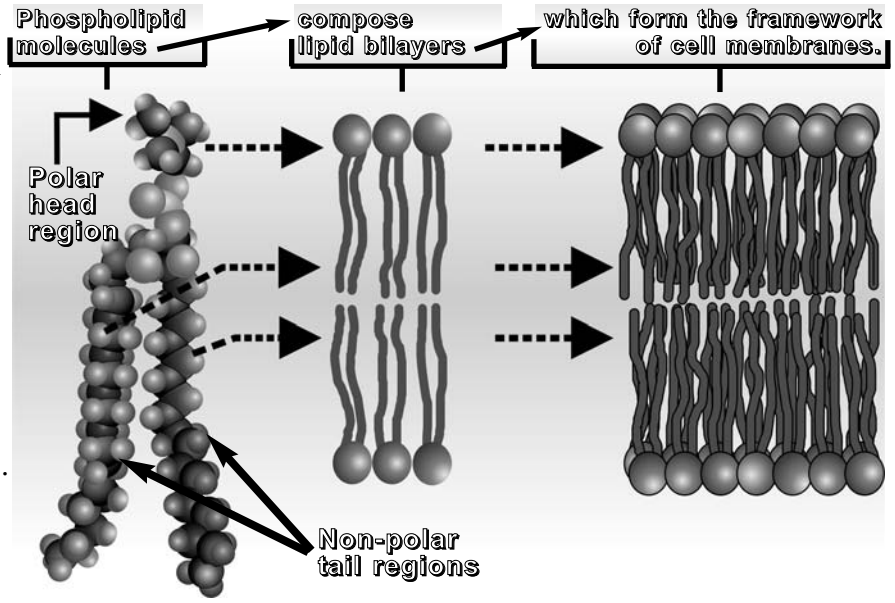
The cell membrane has one vital role: to separate and protect the cell from its surroundings by controlling what enters and leaves the cell. In this sense, the cell membrane is similar to the walls that surround and protect a house or the walls that divide the individual apartments in an apartment building. However, a cell could not survive if its cell membrane were an ordinary wall or container. To stay alive, every cell must take in raw materials and eliminate waste

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products. This means that the cell membrane must allow certain substances to *permeate* it, or pass through it. For this reason, the cell membrane is described as *selectively permeable*. As you might recall from the previous lesson, this function is called *homeostasis*.

The membrane is too thin to be seen with a light microscope. However, many biologists of the early 1900's believed in its existence because of the way cells respond to certain chemical treatments. Electron microscopy finally confirmed that the cell membrane is a real structure.

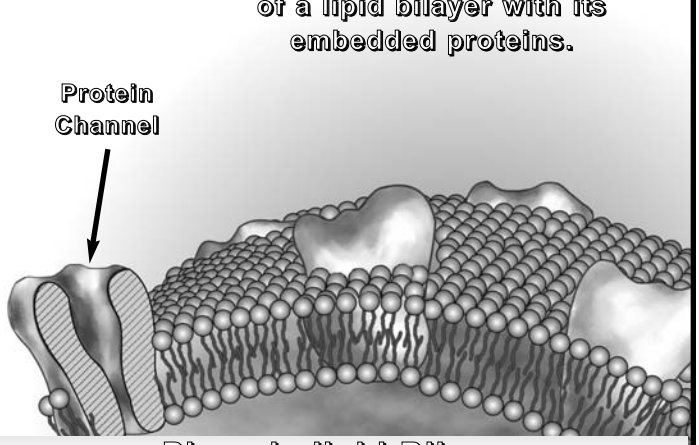
Cell membranes are so thin that they are very difficult to study, and thus their structure has been debated for many years. In 1972, two biologists named S.J. Singer and Garth Nicolson proposed the Fluid Mosaic Model for the cell membrane that is widely accepted today. According to this model, cell membranes are built around a core of lipid molecules, many of which are ***phospholipids***. A phospholipid molecule has a polar end called the *head* and a non-polar end called the *tail*. Polar substances tend to attract water and non-polar substances tend to avoid water. As a result, these phospholipids form a double-layered pattern.



Magnified Phospholipids

This pattern is known as a *lipid bilayer*. The polar heads group together on the outside of the lipid bilayer and are attracted to water (due to containing phosphorus and nitrogen). The non-polar tails group together on the inside of the lipid bilayer because they like to avoid water. Because water is the main component of the cell, this grouping pattern represents a purposeful design.

In addition to lipids, most cell membranes have proteins embedded in the lipid bilayer, and many of these proteins have carbohydrates or other types of molecules



Phospholipid Bilayer

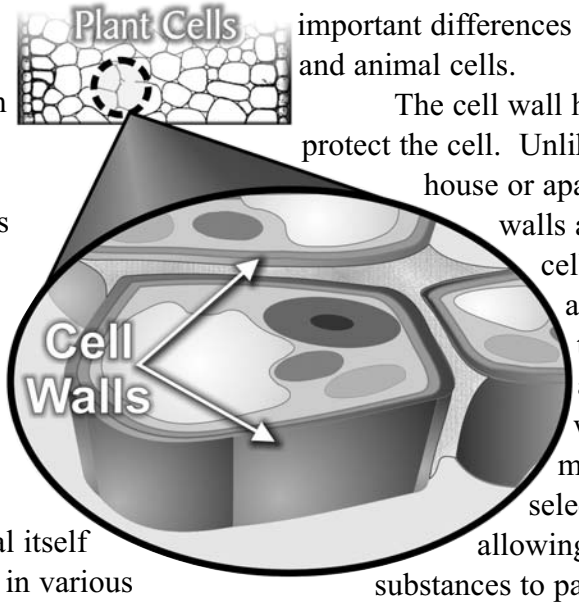
VOCABULARY

Cellulose: a structural polysaccharide in cell walls; a tough, flexible compound that gives plants and cells much of their strength and rigidity

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attached to them. Some of these proteins form channels and pumps to move material across the cell membrane. Other proteins protect the membrane. Many of the carbohydrates act as chemical identification cards, or markers, allowing the organism to recognize which cells belong in the organism and which are foreign.



The cell membrane is called "fluid" because the lipids can move about relatively freely in the membrane and many of the proteins can also move freely. The fluidity is advantageous because it permits the membrane to seal itself if it is broken and to change in various ways. The lipid bilayer provides cell membranes with a tough, flexible barrier that protects the cell from many substances, although not all. In general, substances that dissolve in lipids will easily pass through the cell membrane, but lipid-insoluble substances cannot pass through.

Cell Walls

In many organisms, including plants, algae and bacteria, a ***cell wall*** is located outside the cell membrane. Animal cells do not have cell walls. This is one of the most important differences between plant cells and animal cells.

The cell wall helps to support and protect the cell. Unlike the walls of your house or apartment, most cell walls are very porous. The cell wall's open pores allow the unregulated traffic of materials in and out of the cell, whereas the cell membrane is selectively permeable, allowing only certain substances to pass through.

Most cell walls are made of fibers of carbohydrate and protein. In the cell walls of plants, the main carbohydrate is ***cellulose***. Cellulose is a tough, flexible compound that gives plant cells much of their strength and rigidity. Cellulose is also the main component of both wood and paper. In fact, the paper on which this book is printed is made of cellulose.

In the next lesson, we will examine the selective permeability of the cell membrane and how it regulates the traffic of substances in and out of the cell.

Life Principle

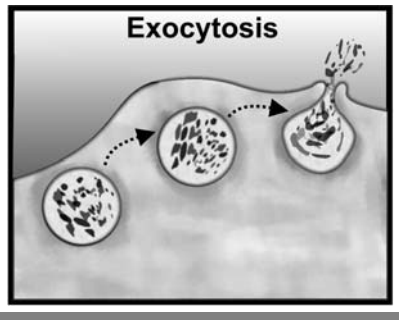


"Since we cannot know all that there is to be known about anything, we ought to know a little about everything."

—Blaise Pascal (1623-1762)
French mathematician
and physicist

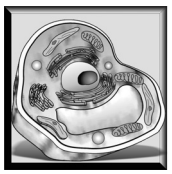
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Cells

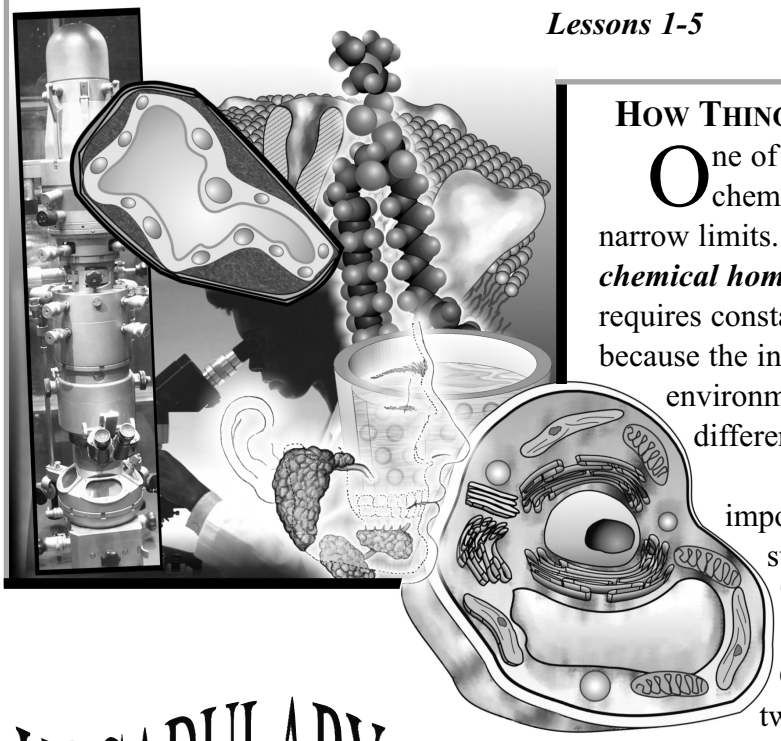
Lesson 4

Chapter 2

THE CELL'S TRAFFIC CONTROL CENTER

Section 1

Lessons 1-5



How Things Move In and Out of Cells

One of the cell's vital roles is keeping its chemical composition constant and within narrow limits. This function is known as ***chemical homeostasis***. It is a process that requires constant monitoring and modification, because the interior of the cell and the environment outside the organism are very different in chemical composition.

The cell membrane performs the important role of determining what substances enter and leave the cell. The cell membrane can be called the "traffic control center" of the cell. Controlling cellular traffic occurs by two different mechanisms: ***passive transport*** and ***active transport***. In *passive transport*, substances cross the cell membrane without the cell expending energy. In *active transport*, substances move across the cell membrane with the help of chemical reactions, thus requiring energy to be expended.

Passive Transport

Passive transport takes place because of two important concepts: ***diffusion*** and ***osmosis***

The random movement of molecules causes diffusion. *Diffusion* is the process by which substances spread through a liquid or gas. In diffusion, substances move from regions of higher concentration to regions of lower concentration. For example, when a drop of food coloring is added to water, the dye *diffuses* through the water until the color becomes evenly distributed. Another example of diffusion occurs when air freshener is sprayed into a room. At first, all the air freshener is concentrated at one end of the room. Soon, it diffuses into the entire room, and the scent becomes evenly spread across the room.

VOCABULARY

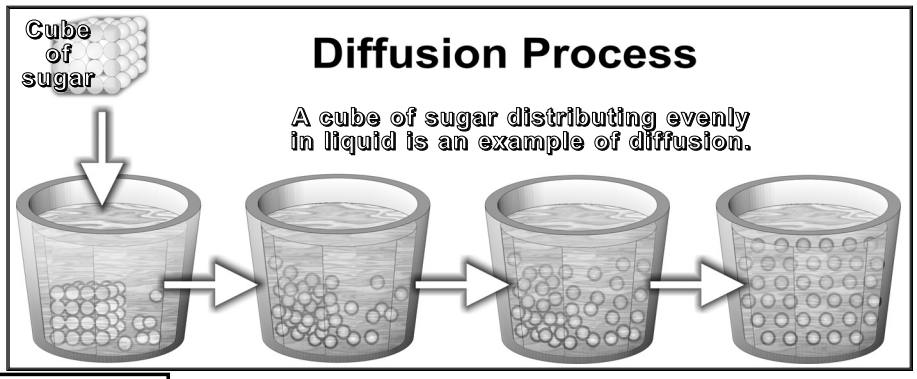
Chemical homeostasis: maintaining the status quo in a cell; maintaining cell order; making sure all substances needed by the cell are available continuously

Passive transport: movement of substances across the cell membrane from regions of high concentration to regions of low concentration; occurs without the cell expending energy

Active transport: movement of a substance against a concentration difference; a process that requires energy

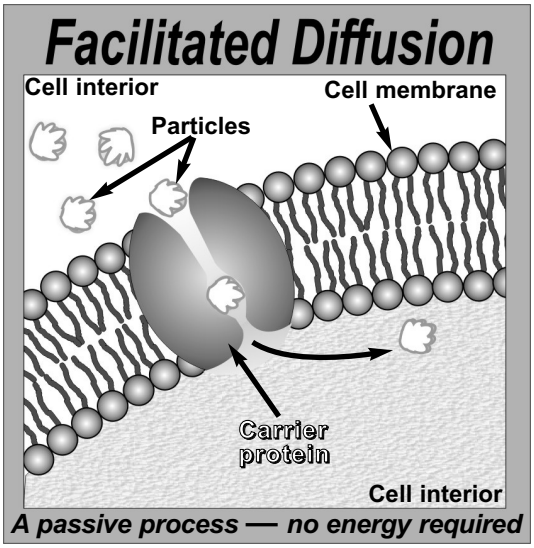
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In passive transport, the action of diffusion causes substances to move from regions of high concentration to regions of low concentration. Substances such as alcohol, water and small lipids easily cross the lipid bilayer of the cell membrane. In other words, they diffuse directly across the cell membrane.

Many membranes contain protein ***carrier molecules*** that allow only certain substances to pass through. The cell membranes of red blood cells, for example, contain a protein channel that allows free passage to only one substance—glucose. As a result, glucose can diffuse either into or out of the cell through this carrier protein, a process called facilitated diffusion. In ***facilitated diffusion***, substances diffuse across the cell membrane through special channels in these carrier proteins. Researchers have discovered hundreds of different carrier proteins—each designed to facilitate the movement of a specific ion, sugar, salt or other substance.



As you learned earlier, only substances that dissolve in lipids can pass

VOCABULARY

Diffusion: process by which substances spread through a liquid or gas from regions of high concentration to regions of low concentration

Osmosis: diffusion of water through a selectively permeable membrane; water flows from regions of high concentration of water to regions of low concentration of water

Carrier molecules: a protein molecule embedded in the cell membrane lipid bilayer which is involved in facilitated diffusion of substances across the cell membrane; each carrier molecule is unique and designed to transport a specific substance

Facilitated diffusion: diffusion of substances across cell membranes through special carrier proteins that facilitate the diffusion process

Osmotic pressure: the pressure created by the differences in concentration of water in two regions separated by a semi-permeable membrane; the region with more pure water will have a higher osmotic pressure than the region with less pure water; water will therefore flow from the higher concentration region to the lower concentration region

Cytolysis: the rupturing of a cell due to excess internal osmotic pressure

Plasmolysis: a collapse of the cell due to water flowing out of the cell

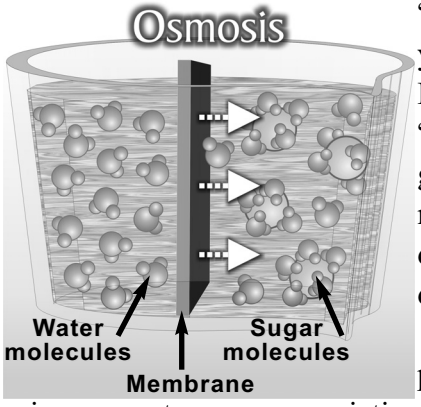
Endocytosis: the process by which cells take in substances by causing a part of the plasma membrane to surround the substance

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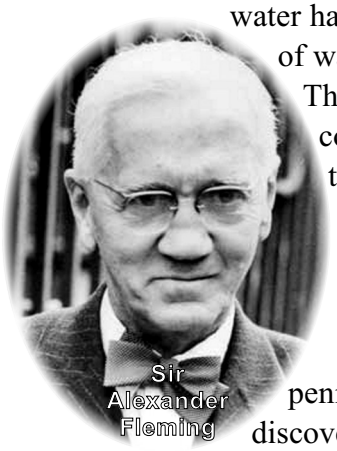
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through the cell membrane. However, water is an important exception to this rule. Water is not lipid soluble, yet it passes through most biological membranes very easily. This fact has important consequences for the cell.

The diffusion of water through a selectively permeable membrane is called *osmosis*. The cell membrane is permeable to water but not permeable to sugar. In the accompanying illustration, on one side of the membrane is a sugar solution and on the other side of the membrane is pure water.



After a period of time, a net flow of water diffuses into the sugar solution. This occurs because water, like any other substance, diffuses from regions of high concentration to regions of low concentration. In this example, the pure water has a higher concentration of water than does the sugar. This illustrates again the concept of passive transport.



Osmosis and The Penicillin Story

The effects of penicillin were accidentally discovered by the Scottish bacteriologist, Sir Alexander Fleming, in 1928. Upon entering his lab after an absence of several days, he examined a culture of Staphylococcus bacteria in a dish that had been left uncovered. Fleming noticed that specks of mold were growing in the dish, but that the bacteria around this mold had died. Further examination revealed that the bacteria had simply fallen apart. A substance from that mold called *Penicillium* was later isolated and *penicillin* became the first antibiotic, but not without a struggle. The medical/scientific elite ridiculed the concept as "quackery". In Fleming's own words, "Penicillin sat on a shelf for ten years while I was called a quack." Penicillin was finally hailed as a "miracle drug" in the 1940s and greatly used. (Since then, many more antibiotics have been developed to fight infectious diseases.)

Bacteria are single-celled prokaryotic organisms. Countless varieties of bacteria exist everywhere. Many types of bacteria cause no ill effects, while other types grow beyond tolerable limits and harm organisms.

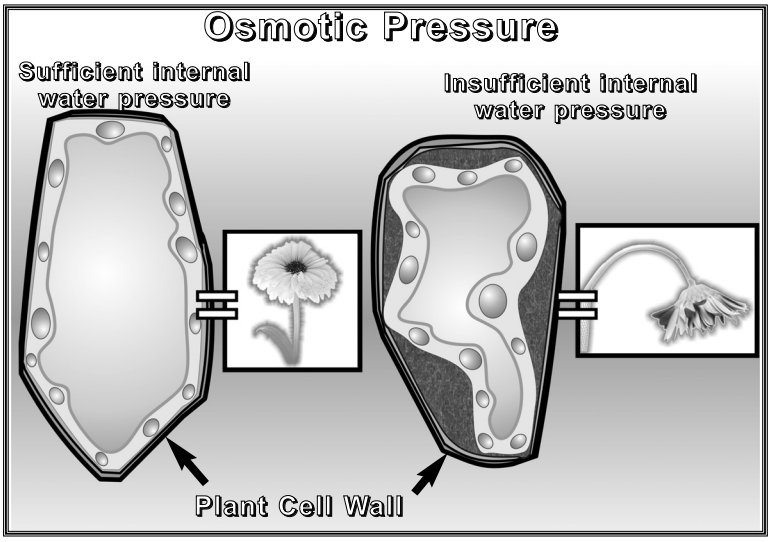
Penicillin works by weakening cell walls of bacteria. Because penicillin "looks" like a protein which makes up cell walls, the bacteria are fooled into incorporating penicillin into the bacterial wall. When this happens, the walls become weaker. Bacteria depend on their cell walls to control osmotic pressure. Because of osmosis, bacteria are constantly subjected to water pressure across their cell membranes, and because the penicillin-affected walls are much weaker, the cell walls eventually disintegrate, killing the bacteria cells.

Osmotic Pressure

When water moves by osmosis, it can produce a powerful pressure called ***osmotic pressure***. The pressure can be so great that a cell can burst or rupture and be destroyed, a process called ***cytolysis***.

The cytoplasm of a typical cell is filled with salts, sugars and other dissolved substances. Therefore, if a dilute water

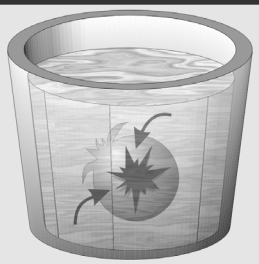
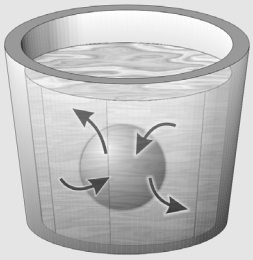
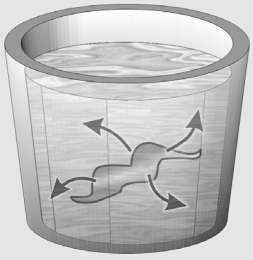
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solution should come in contact with a cell, water would rapidly enter the cell by osmosis, because water diffuses from regions of high concentration of water to regions of low water concentration. If this flow of water into the cell were uncontrolled, the cell would swell up like a balloon and burst. The solution outside the cell is said to be *hypotonic* when the concentration of solutes (substances dissolved) is less than that of the cell, meaning that more pure water is on the outside of the cell membrane than is on the inside. Therefore, the osmotic pressure is greater on the outside of the cell.

The opposite can occur as well. Solutions that have higher concentrations of solute than the inside of the cell are called *hypertonic* solutions. For example, if you placed the cell in a solution containing a high concentration of salt relative to the salt concentration within the cell, the water would flow out the cell (from an area of higher water concentration to an area with lower water concentration) and cause the cell to implode, wilt or collapse, a process called ***plasmolysis***.

Cells control this powerful osmotic pressure force in one of three ways:

Solution types		Conditions	Water Movement
Hypotonic solution ("hypo" means *lower* or *less*)		**Solute concentration around the cell is lower than in the cell.** (Cell is *hyper*tonic, solution is *hypo*tonic)	**Fluid buildup in the cell causes cell to rupture or burst.** ↓ **Cytolysis**
Isotonic solution ("iso" means *equal* or *same*)		**Solute concentration around the cell is equal to that in the cell.**	**Fluids move into and out of the cell in equal amounts so that cell volume is maintained (as with blood cells).**
Hypertonic solution ("hyper" means *higher* or *more*)		**Solute concentration around the cell is higher than that in the cell.** (Cell is *hypo*tonic, solution is *hyper*tonic)	**Insufficient fluid inside the cell causes cell to collapse.** ↓ **Plasmolysis**

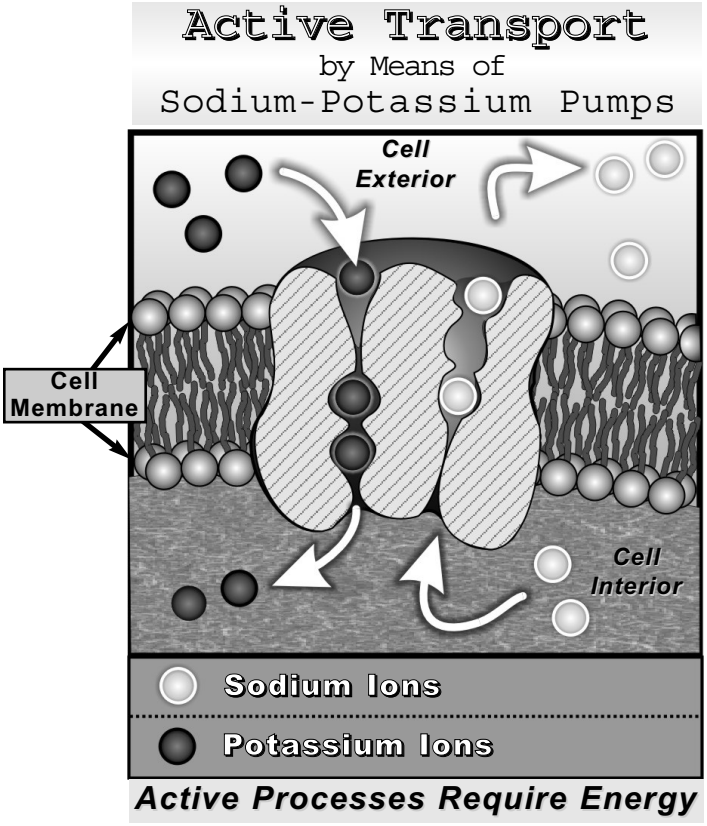
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(1) A cell wall is utilized. Each bacteria and plant cell is surrounded by a strong cell wall that prevents the cell from bursting. This also helps to counteract external osmotic pressure, causing plants to be sturdy and upright. Insufficient water causes plants to wither.

(2) Cells pump out the water. Many single-celled organisms remove excess water as quickly as it enters the cell by means of little pumps.

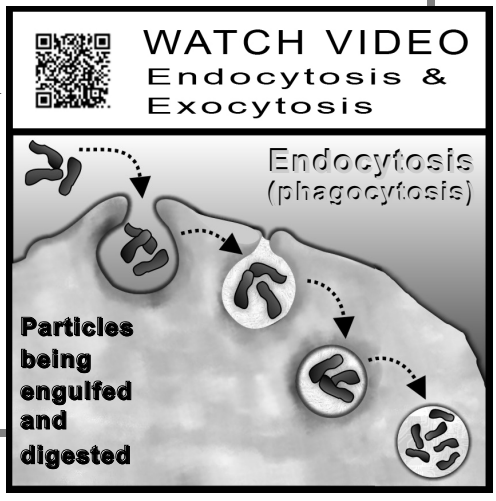
(3) Cells use blood to act as a buffer. Most large animals prevent their cells from coming in direct contact with pure water, even if the animals drink or swim in water. The cells are bathed in blood or blood-like liquids which keep water from flowing in and causing damage to the cells. Blood is an *isotonic solution*, a solution in which the concentration of solutes is essentially equal to that of the cell it surrounds. Therefore, the osmotic pressure on both sides of the cell membrane is equal.



Active Transport

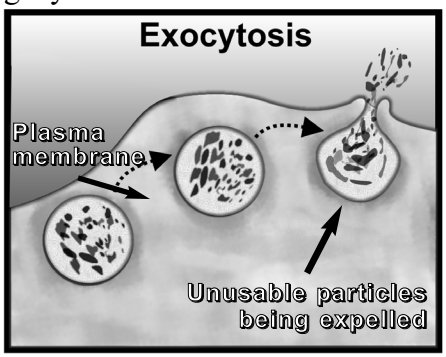
As you have learned, passive transport moves substances from regions of high concentrations to regions of lower concentrations. However, cells can also move substances in the opposite direction, from lower to higher concentrations. In fact, this is a frequent occurrence. However, cells pay a price for this transaction; that price is called *energy*. Movement of a substance against a concentration difference is called *active transport* and always requires the expenditure of energy. The process of active transport is accomplished by microscopic sodium-potassium pumps or protein channels. Most animal cells, for example, have membrane proteins that pump sodium (Na) ions out of the cell through one channel and pump potassium (K) ions into the cell through another channel of the same pump. Each channel houses precisely engineered receptor sites to accommodate specific ions and is capable of transporting an amazing 300 sodium ions out of a cell in just one second! These sodium-potassium pumps are so critical to the life and well-being of the organism that more than a third of the energy expended by human cells is used to keep the pumps working. Active transport is not limited to small ions or molecules. Many cells expend energy to transport large molecules, clumps of food or even whole cells.

One way in which cells import larger materials is to turn part of the cell membrane inside out.



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This process is called ***endocytosis.*** When the particles are very large, the process is sometimes called *phagocytosis*. In vertebrates (animals with backbones), phagocytosis plays a part in defense against bacteria. Some types of white blood cells (phagocytes) engulf invading bacteria and digest them, thus serving as an important barrier to disease. However, some diseases, such as leprosy and tuberculosis, are caused by bacteria that have made adaptations which make them resistant to digestion by phagocytes.



Materials can be discharged from a cell as well as being engulfed by it. In *exocytosis*, cells release substances such as indigestible food particles or secretions such as hormones. In this process small recepticles, or "trashbags", full of unusable particles work their way to the plasma membrane and then discharge their contents outside the cell.

In the next lesson, we will study the individual organelles within the cell, their functions and how they work together in this incredible "manufacturing" process of the cell.

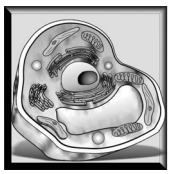
LIFE PRINCIPLE



"Never leave until tomorrow that which you can do today."

—Benjamin Franklin (1706-1790)
American statesman and scientist

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Cells

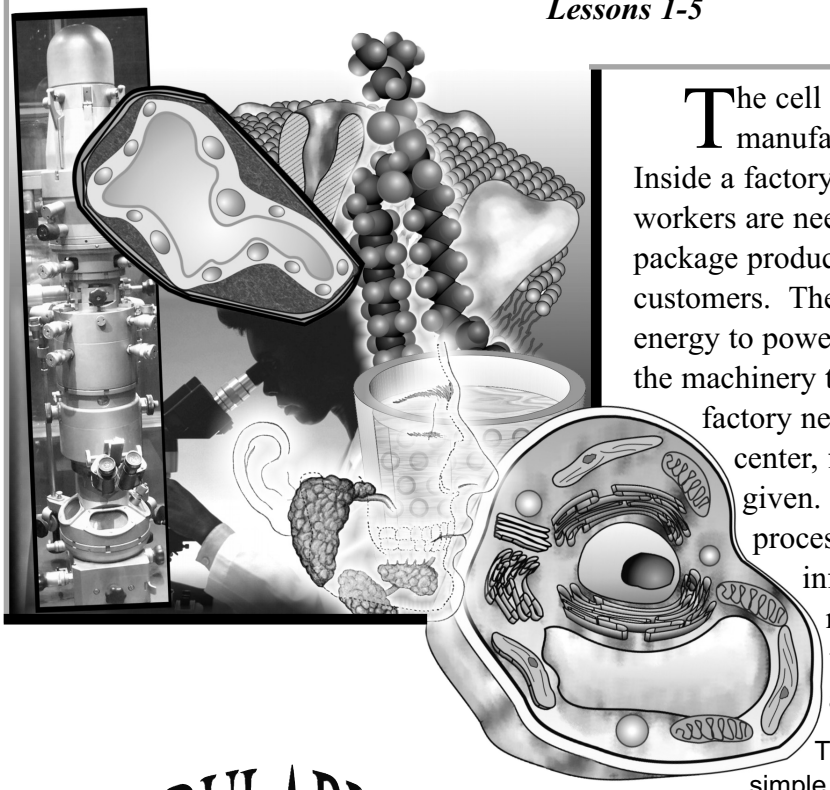
Lesson 5

Chapter 2

INSIDE THE CELL—A WONDEROUS FACTORY

Section 1

Lessons 1-5



The cell can be compared to a manufacturing site in many ways. Inside a factory, the proper machines and workers are needed to assemble products, package products and to deliver them to customers. The factory also needs a source of energy to power machines and mechanics to fix the machinery that breaks. Additionally, the factory needs a main office, or control center, from which all orders can be given. A smooth operation requires processing of huge amounts of information within the cell. The magnitude of this information was noted by the ***late*** astronomer Carl Sagan;

The information content of a simple cell has been established as around 10^{12} bits, comparable to about a hundred million pages of the Encyclopedia Britannica.

VOCABULARY

Late: refers to a person who is deceased

Nucleus: (plural is *nuclei*) a structure within the cell that contains almost all the cell's DNA; a large, dense structure that is considered the most important organelle in the cell; may be referred to as the cell's "control center"

Chromatin: the material in the nucleus from which chromosomes consisting of DNA and proteins are made

THE NUCLEUS

In the cell, the ***nucleus*** acts as the control center. As discussed in a previous lesson, only eukaryotic cells have distinct, membrane-bound nuclei. The nucleus is a large, dense structure that is considered the most important organelle in the cell. If the nucleus of a cell is carefully removed with a fine needle, the cell may still go on living by expending energy and oxygen; but even the hardiest of cells cannot live more than a week or two without a nucleus. The nucleus contains almost all of the cell's DNA (deoxyribonucleic acid). As you will recall, DNA is the molecule that contains coded instructions for making proteins and other important molecules. By storing DNA in the nucleus, the cell is better able to control and regulate DNA.

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The DNA molecules and proteins form a material called ***chromatin***. Chromatin is usually spread throughout the nucleus, but when the cell divides, the chromatin condenses to form larger structures called ***chromosomes***. Chromosomes are the instructions for the cell and are sent out to the cell to control all activities.

Most nuclei also contain a small, dense region known as the ***nucleolus***. For many years, the function of the nucleolus was unknown. Biologists now know that the nucleolus is the site where ***ribosomes*** are made. As you will see shortly, ribosomes are very important in the production of proteins.

VOCABULARY

Chromosomes: structures in the nucleus that form from chromatin when the cell prepares to divide

Nucleolus: a small, dense region in the nucleus where ribosomes are made

Ribosomes: small particles in the cell, made of RNA and protein; sites of protein assembly

Golgi apparatus: network of membranes within a cell that, in conjunction with the endoplasmic reticulum, processes and transports proteins and other macromolecules; contains special enzymes that attach carbohydrates or lipids to a protein.

Cilia: short, hairlike projection in some cells; often used to pull the organism through water with a coordinated rowing movement

Flagella: whiplike projection found on some cells; usually used for cell movement

ATP (Adenosine TriPhosphate): energy produced by the mitochondria from chemical fuel and oxygen

WATCH VIDEO:
Workings of a Cell

The nucleus is surrounded by a double membrane called the *nuclear envelope*. The nuclear envelope contains fairly large pores, which serve as channels for materials to move between the nucleus and the cytoplasm of the cell.

CYTOPLASM

The portion of the cell outside the nucleus is known as the *cytoplasm*, which means "cell fluid." Biologists who have used powerful microscopes to study cells have discovered many wonderful and complex organelles within the cytoplasm. *Organelle* means "little organ" and refers to small structures in the cell that perform specialized functions, just as machines perform specialized functions in a factory. The graphic illustration in the text shows many various organelles in a typical animal cell and plant cell. Although some organelles are specific to either plant or animal cells, many are found in both types of cells. Please refer to illustrations as each of the organelles is discussed below.

RIBOSOMES

Ribosomes are small organelles made of RNA and protein. Some cells have ribosomes that number in the tens of thousands. Ribosomes are responsible for producing proteins, a very important function within the cell. You will learn much more about ribosomes and protein synthesis in a later section.

THE ENDOPLASMIC RETICULUM AND GOLGI APPARATUS

After a cell has made a protein, the cell can either use the protein immediately or send it to another location for further

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processing. Many proteins need to be delivered to specific locations within the cell, while others need to be packaged for export from the cell. In addition, some proteins need special components attached to them before they can be used.

Processing and transporting proteins and other macromolecules is the function of the endoplasmic reticulum (ER) and the ***Golgi apparatus***. Both the ER and Golgi apparatus are composed of an extensive network of folded membranes. The term *endoplasmic reticulum* means "network inside the cell." In animal cells, the ER helps to maintain the shape of the cell, since no cell wall exists to perform this task.

Two types of ER occur: smooth ER and rough ER. The *rough ER* is dotted with ribosomes; the *smooth ER* has no ribosomes.

Since the rough ER has ribosomes, it plays a part in protein synthesis. Although no protein synthesis occurs in the smooth ER, lipids are produced in this organelle. In addition, the smooth ER inactivates certain harmful by-products of cell functions and then sends them to the plasma membrane to be expelled.

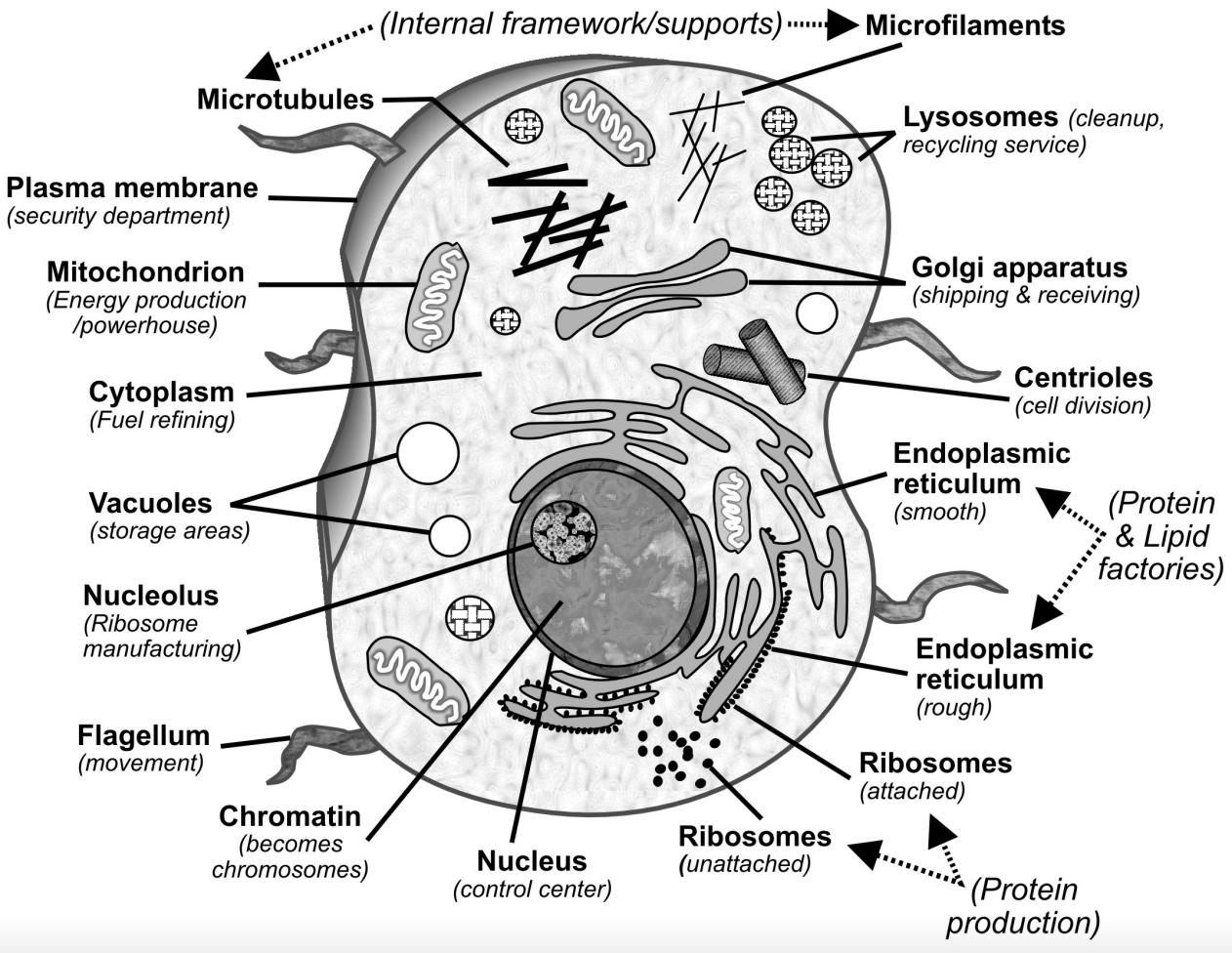


Diagram of a generalized composite of a eukaryotic/animal cell, depicting relative locations, sizes and functions of major cell components.

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After proteins or lipids are made in the ER, they travel through the ER network into the Golgi apparatus where they are sorted and stored until needed. When a protein or lipid is needed by the cell, the Golgi apparatus packages the molecule so it can be transported to the place where it is needed. The "packaging" usually involves adding a small molecule to the protein or lipid being processed which acts as a marker or "address" to indicate where the molecule should be sent. Thus, the Golgi apparatus acts as a "mailing service" for the cell, taking in molecules synthesized by the ER, packaging and addressing them and then sending them where they are needed.

The Golgi apparatus is named after Camillo Golgi, the Italian scientist who first identified it. The Golgi apparatus resembles a cross section of a stack of pancakes.

Lysosomes

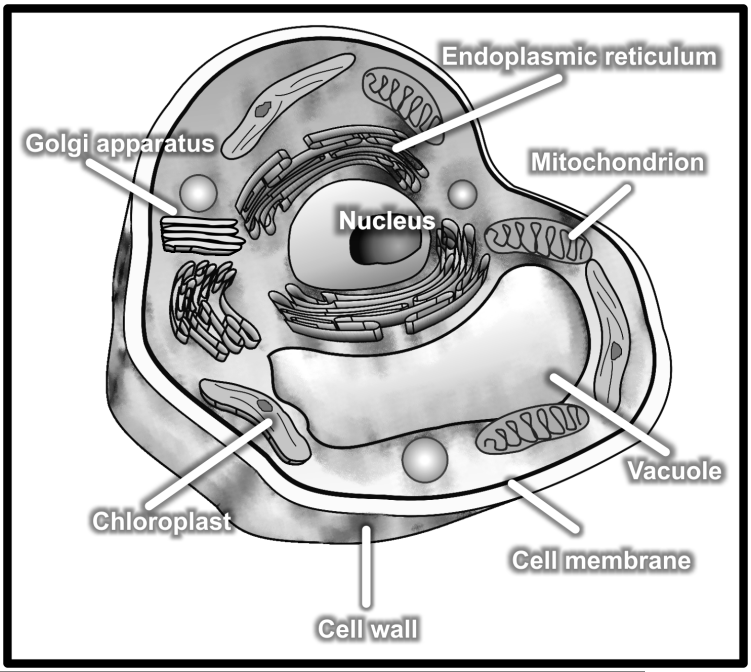
Lysosomes work as the clean-up crew of the cell. Lysosomes are saclike membranes filled with chemicals and enzymes that break down almost any substance within the cell. Lysosomes are especially active in breaking down the tail of a tadpole when the tadpole changes into a frog. In some cases, lysosomes will fuse with a damaged organelle and literally break it apart into basic chemical compounds. As a result, the lysosomes both clear away the damaged organelle and recycle its components for other uses in the cell.

When the lysosome was first discovered, it was called the "suicide sac" because prior to the death of certain cells, the lysosomes would release chemicals that destroyed the cell. Later on, scientists realized that as the cell dies, the membrane which encloses the lysosome is generally the first thing to deteriorate. Logically, this makes sense. As the lysosome itself breaks down, it spills its contents into the cytoplasm which in turn starts breaking down things in the cytoplasm. Therefore, the cell dies.

Cytoskeleton

Every factory needs an internal structure for support. Eukaryotic cells contain a supporting framework called the cytoskeleton meaning "cell skeleton." The cytoskeleton (a dynamic network of protein tubes, filaments and fibers) crisscrosses the cytoplasm, anchoring the organelles in place and providing shape and structure to the cell. Microtubules and microfilaments are two components that provide a tough, flexible framework of support for the cell. Microtubules also make up hair-like structures called ***cilia*** and ***flagella***. These are found on the surfaces of many cells and serve many useful functions. In some organisms, such as various protists, the flailing motion of cilia and flagella propel the cell from one location to the next.

Eukaryotic/Plant Cell



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Many components of the cytoskeleton are assembled and disassembled by the cell as needed. During cell division, for example, a special structure called a *spindle* is built to move chromosomes around. After cell division, the spindle is no longer needed and is dismantled. Some components of the cytoskeleton serve as microscopic tracks along which proteins and other molecules travel like miniature trains.

Vacuoles

Many cells store materials in saclike structures called vacuoles. In animal cells, vacuoles may store proteins, fats or carbohydrates. In plant cells, a large central vacuole often stores water and dissolved salts. In addition, it stores the blue, red and purple pigments that give certain flowers their colors. The central vacuole also contains plant wastes that taste bitter to certain insects, thus discouraging insects from feasting on the plant.

The central vacuole of a mature plant cell is so large that it typically takes up most of the room in the cell and actually crowds the cytoplasm and organelles to the edges of the cell. Vacuoles also provide plant cells with support. The pressure inside the vacuoles allows a plant to grow quickly and to support heavy structures such as leaves and flowers. This pressure, called *turgor pressure*, helps keep a plant rigid. Fresh lettuce, for example, is crisp because its cells are highly pressurized. As the lettuce gets old, however, this pressure decreases because of loss of water, which causes the lettuce to wilt. Soaking the wilted leaves in ice water can increase *turgor pressure* which restores the lettuce to original crispness.

Mitochondria and Chloroplasts

The mitochondria are the "powerhouses" of the cell factory where all energy is produced. Within these long, slender organelles, which can appear oval or bean shaped, enzymes convert glucose and other nutrients into useable energy called ***ATP (Adenosine TriPhosphate)*** for the cell. This molecule, in turn, serves as an energy battery for countless cellular processes, including the shuttling of substances across the plasma membrane, the building and transporting of proteins and lipids, the recycling of molecules and organelles, and the dividing of cells. Muscle and liver cells are particularly active and require dozens and sometimes even a hundred mitochondria per cell to meet energy needs. Mitochondria are found in eukaryotic cells, including both plant and animal cells.

Plants have an added component to their energy production called *chloroplasts*. Chloroplasts are found only in plant cells and convert light energy, typically from the sun, into sugar (glucose), in a process known as *photosynthesis*.

In the next lesson, we will examine the energy production within a cell, a central key to life.

Life Principle



"Nothing just happens; someone or something must make things happen."

—Anonymous

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Energy

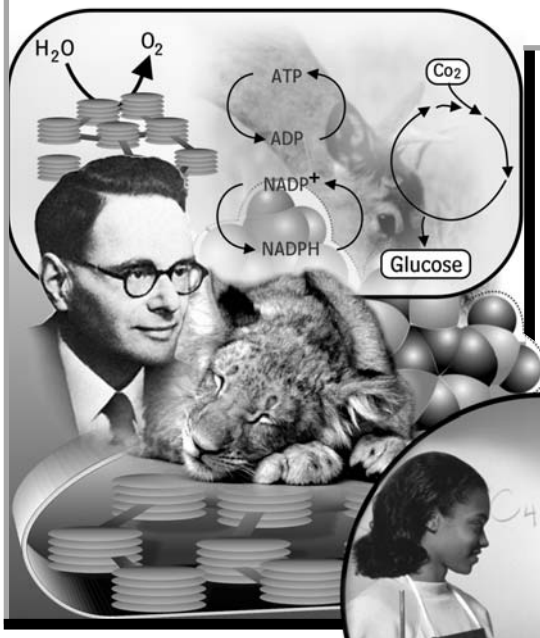
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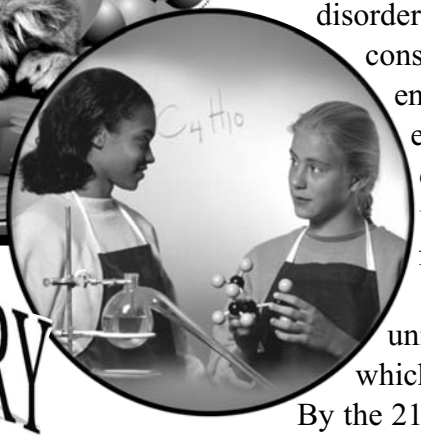
Chapter 2

THE ENERGY OF LIFE

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Pogo the Possum, the hero of a classic comic strip, once stated that he did not like bombs because "they put everything too everywhere." What he may not have understood was that everything will go everywhere anyway if left to its own devices; bombs are just a faster way to arrive at that end. This principle is called the ***Second Law of Thermodynamics***; it states that the amount of disorder, or ***entropy***, in the universe consistently increases. Furthermore, as entropy increases, the ***free energy***, or energy that can do useful work, decreases. In other words, the universe is winding down in terms of free energy.

At the beginning of the universe, mass, substance and order which introduced energy came into being. By the 21st century, scientists acknowledged that free energy has been winding down since the origin of the solar system.

Living cells may seem to defy this principle of nature; however, the cell actually confirms this law. Cells work hard at maintaining and creating an orderly chemical composition which is very different from its environment. A cell also increases orderliness by growing and increasing the amount of matter which is organized into a living system. However, the cell is not really an exception to the Law of Thermodynamics because the order



VOCABULARY

Second Law of Thermodynamics: the amount of disorder (entropy) in a system tends to increase, always tending toward less usable energy, or energy that can do useful work

Entropy: measure of the unusable or unavailable energy in a system; also the measure of the disorder in a system

Free energy: usable energy in a chemical system: energy available for producing change

Kinetic energy: the energy of motion, which is related directly to the speed of that motion.

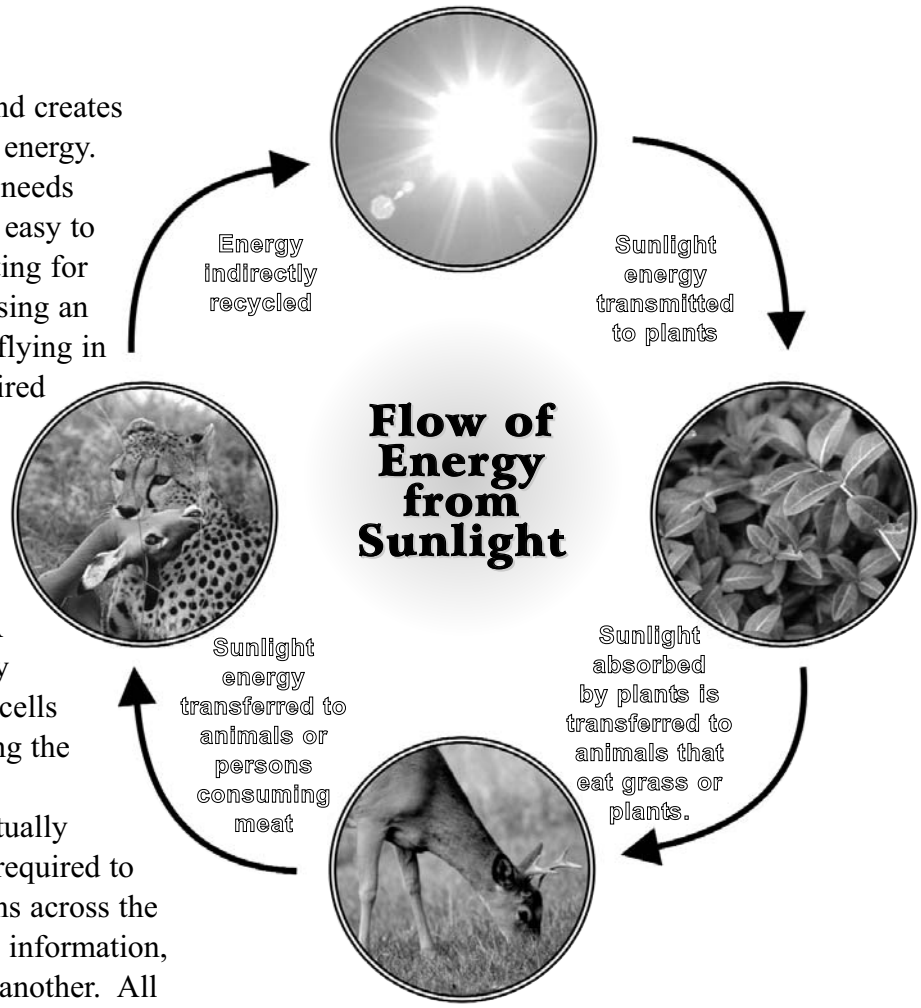
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and organization it maintains and creates must be paid for in the form of energy.

Everything that is alive needs energy. The need for energy is easy to see in a group of athletes sprinting for the finish line, in a leopard chasing an antelope, or in a flock of birds flying in formation. Energy is also required for other, slower tasks. A tree standing in a field is silently, but constantly, using an enormous amount of energy with its root system to draw water from surrounding soil. A sleeping cat draws on its energy reserves to rebuild and replace cells that were damaged or lost during the day's activities.

Cells use energy for virtually everything they do. Energy is required to build new proteins, to pump ions across the cell membrane, to copy genetic information, and to move from one point to another. All the cells in your body get their energy from the food you eat; all of the energy in food ultimately comes from the Sun.



VOCABULARY

Potential energy: the energy stored by matter as a result of its location or position

Cellular respiration: the process by which the cell converts a food fuel such as glucose into ATP in the presence of oxygen

ATP (Adenosine TriPhosphate): energy storage compound in cells; composed of a sugar, adenosine and 3 phosphate groups

Cilium: a microscopic hair; plural is *cilia*; cilia are attached to certain kinds of cells that line certain body passageways

Energy is generally defined as the capacity to do work. Energy occurs in many familiar forms such as heat, light, chemical and electrical energy. Energy can be transformed or changed from one form into another. For example, the filament of a light bulb converts the energy of an electric current into light energy and heat energy.

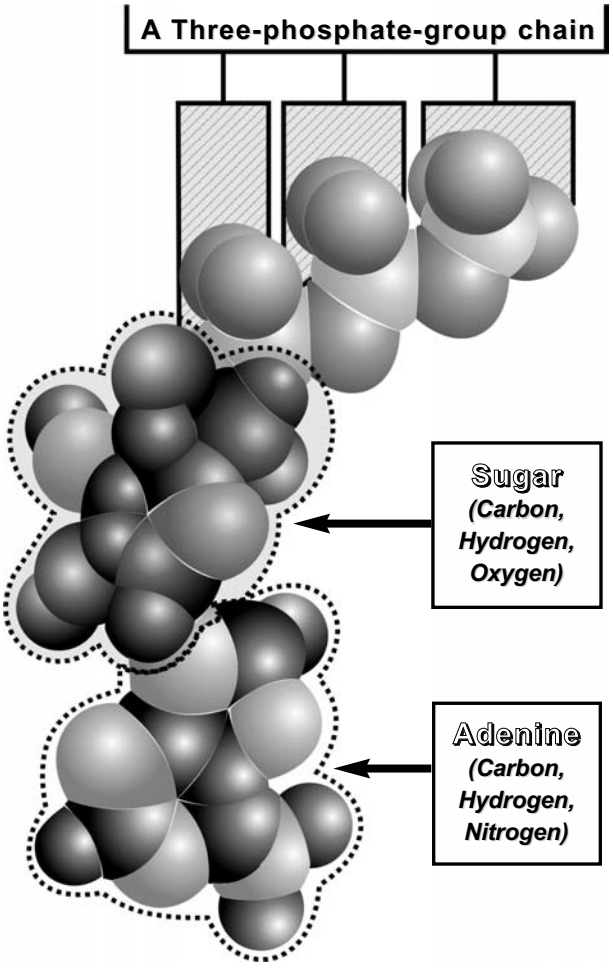
Scientists and engineers must distinguish between ***kinetic energy*** and ***potential energy***. *Kinetic energy* involves motion such as a rolling stone, a moving current or a running animal. *Potential energy* is associated with position; it is the possible energy capable of being released if the position or catalytic activity were permitted to change. A car parked on a steep hill has potential energy by virtue of its position; when the brake is released, the car rolls down

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the hill, converting its potential energy into the kinetic energy of motion. A lump of coal or a piece of wood contains potential energy which is released as kinetic energy when the object burns. Potential energy occurs in a bond between atoms; it becomes kinetic energy when that bond is broken.

Living cells draw primarily on *chemical energy* by utilizing the potential energy in chemical bonds. Compounds such as glucose store energy in their chemical bonds. This energy is released when the bonds are broken and new bonds, storing less energy, are formed. When glucose and oxygen are mixed in a cell, a tremendous amount of energy is released. Cells, however, need to capture energy in small amounts. Therefore, the reactions in living things take place in small controlled steps, releasing small amounts of energy at a time. This process is called ***cellular respiration*** and involves a three-stage process in which the cell converts a glucose molecule into a usable, storable energy source called ***ATP (Adenosine TriPhosphate)***.



ATP (Adenosine TriPhosphate) Molecule

As its name suggests, ATP has three phosphate groups. These are called *high-energy phosphate bonds*, because they release considerably more energy than is released by most other chemical bonds. A similar compound, called *ADP* (adenosine diphosphate), has two phosphate groups while *AMP* (adenosine monophosphate) has just one group. Think of AMP as an uncharged battery. Through the process of cellular respiration, cells add phosphate groups to AMP to make ADP, which takes a significant amount of energy. This energy is stored in the phosphate bonds in much the same way that electricity is stored in a battery.

A similar amount of energy is required to attach the third phosphate group, converting ADP to ATP. ATP is similar to a fully charged battery, ready to supply energy to do the work of the cell. The cell accomplishes work through binding sites on the enzymes that require ATP to do work. When one of these enzymes needs energy to complete a chemical reaction, one phosphate breaks off, converting ATP to ADP. Breaking this phosphate bond may release just enough energy to pump an ion across a membrane, attach an amino acid to a growing protein, or flick a ***cilium*** just once. The molecule of ADP is then available to store energy by forming ATP again. This process continues over and over again—storing energy and then releasing it as needed.

This remarkable process enables multiple functions within the cell to be

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energized by ATP. In fact, the energy released by converting ATP to ADP enables the cell to power almost all its activities. To meet its potential energy needs in everything from growth to division to movement, all that a cell has to do is recharge its chemical batteries by attaching phosphates to AMP and ADP to make ATP.

In the next lesson, we will begin to examine cellular respiration, the processes by which ATP—the battery of the cell—is produced.



LIFE PRINCIPLE

"Most human beings have an almost infinite capacity for taking things for granted."

—Aldous Huxley (1894-1963)
English novelist and essayist

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Cells

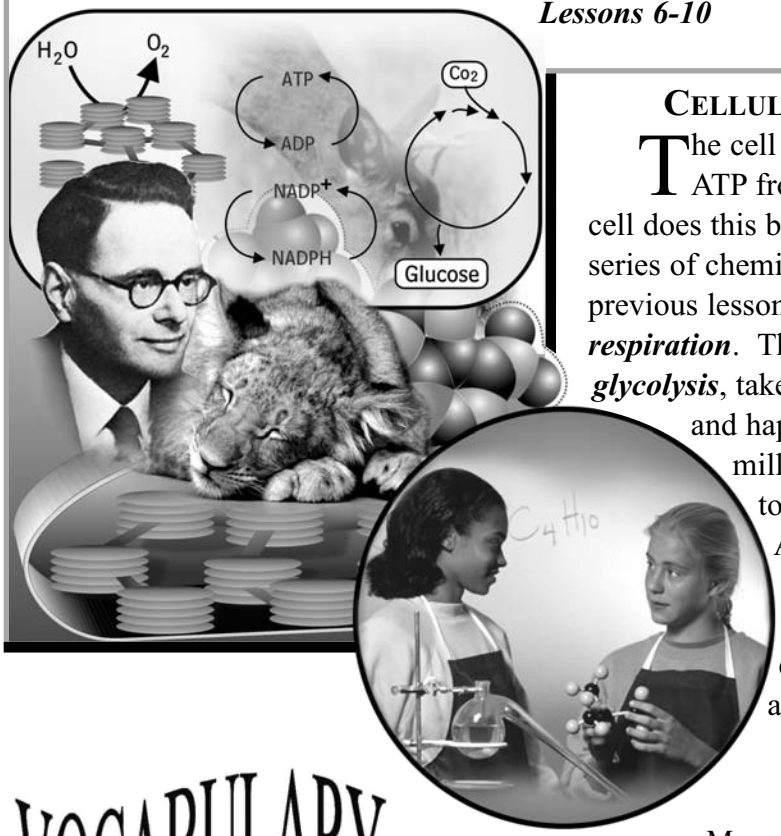
Lesson 7

Chapter 2

GLYCOLYSIS

Section 2

Lessons 6-10



CELLULAR RESPIRATION: STAGE I

The cell must release energy in the form of ATP from glucose a little bit at a time. The cell does this by breaking down the glucose in a series of chemical reactions. As mentioned in the previous lesson, this process is called ***cellular respiration***. The first of these reactions, called ***glycolysis***, takes place in the cytoplasm of the cell and happens very quickly. Only a few milliseconds are needed for most cells to produce thousands of molecules of ATP. Each of the reactions in cellular respiration requires specific enzymes to activate the process, and each enzyme is carefully controlled and monitored by the cell.

VOCABULARY

Cellular respiration: the process by which the cell converts a food fuel such as glucose into ATP in the presence of oxygen

Glycolysis: a series of reactions in which a molecule of glucose is broken down to produce a net gain of two ATP molecules.

Coenzymes or ***Cofactors :*** additional molecules that are required before an enzyme will catalyze a reaction; many are from vitamins and each can be reused repeatedly

COENZYMES

Many enzymes require certain molecules, in addition to their substrates, before the enzymes will begin to work. These additional molecules are called ***coenzymes*** or ***cofactors***, many of which are synthesized from vitamins in the organism's food.

Three important coenzymes take part in cellular respiration: ***NAD^+*** (***Nicotinamide Adenine Dinucleotide***); ***FAD*** (***Flavin Adenine Dinucleotide***) and ***CoA*** (***Coenzyme A***). (Niacin, riboflavin and pantothenic acid, ***respectively***, are the vitamins from which these coenzymes are made.) Coenzymes are very important to cellular respiration and can be used over and over again. For this reason, the cell requires only very small quantities of these coenzymes.

GLYCOLYSIS

The first of the reaction series in cellular respiration is called *glycolysis*, which means "sugar-breaking." Surprisingly,

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two molecules of ATP are required to begin this reaction. It produces a 6-carbon sugar which is then broken down into two 3-carbon molecules, called ***PGAL (PhosphoGylcerALdehyde)***. The two PGAL molecules advance through several more chemical reactions to produce a compound called ***pyruvic acid***. These reactions produce four molecules of ATP for each molecule of glucose, resulting in a net gain of two molecules of ATP for each glucose molecule that is broken down by glycolysis.

In addition to the net gain of 2 molecules of ATP, glycolysis also produces two pairs of high-energy electrons. These electrons are passed to the coenzyme NAD^+ to form NADH. In order for glycolysis to continue, a constant supply of NAD^+ must be available.

VOCABULARY

NAD^+ (Nicotinamide Adenine Dinucleotide): a coenzyme present in all cells and is required in cellular respiration

FAD (Flavin Adenine Dinucleotide): a coenzyme present in all cells and is required in cellular respiration

Coenzyme A (CoA): a coenzyme present in all cells and is required in cellular respiration

Respectively: referencing a series of items in the order listed

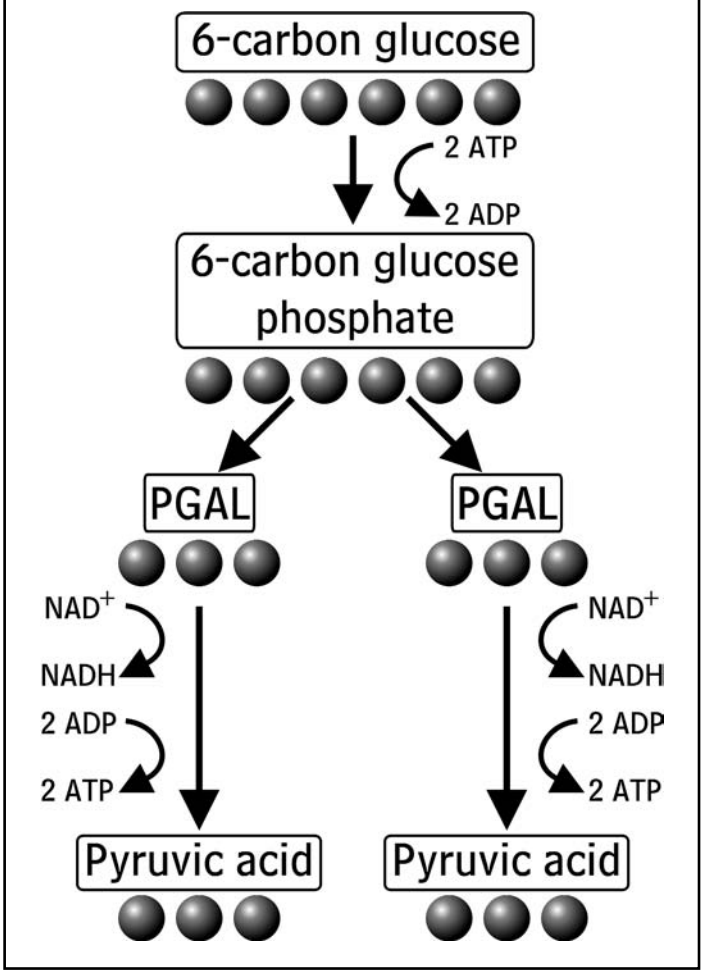
PGAL (PhosphoGylcerALdehyde): an intermediate molecule formed in the process of glycolysis

Pyruvic acid: the end-product molecule of glycolysis

Anaerobic step: a reaction step that requires no oxygen for completion

Fermentation: regeneration of NAD^+ to keep glycolysis running in the absence of oxygen

Glycolysis:
First Stage of Cellular Respiration



During this first stage of cellular respiration, oxygen is not involved. However, the energy in these electrons can be utilized only when oxygen is available. Therefore, if oxygen is not available, NADH cannot unload the high energy electrons it carries. Within a few seconds, all the cell's available NAD^+ supply would be converted to NADH and glycolysis would stop. If this were the case, ATP production would also stop and the cell would be in danger. As you can see, cellular respiration is an orderly and delicate process that reflects precision, sequence and purposeful design.

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FERMENTATION

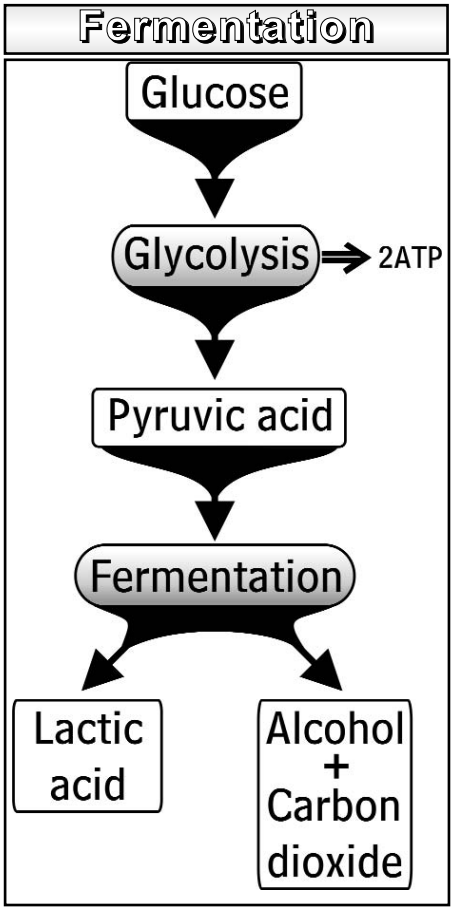
As we have learned, the first stage of cellular respiration (glycolysis) uses no oxygen. Thus, glycolysis is often called the ***anaerobic step*** in cellular respiration. However, this does not mean that oxygen is unavailable to the cell.

If oxygen is not available to the cell, the condition may be called *anaerobic*. (When oxygen is available, the condition is called *aerobic*.) Fortunately, the cell has a built-in design to unload its high energy under anaerobic conditions. The cell passes the high-energy electrons from NADH back to the same pyruvic acid molecules from which they came, thereby freeing the NAD^+ so that it may be used over and over again. The cell, at the same time, will begin to accumulate the carbon compounds which are formed by accepting these electrons.

This process—the regeneration of NAD^+ to keep glycolysis running in the absence of oxygen—is called ***fermentation***. In nature, fermentation occurs only in cells and organisms that lack oxygen.

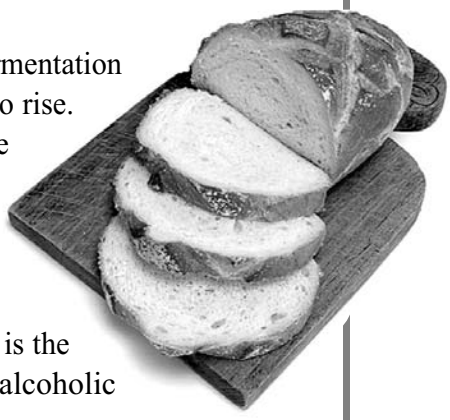
Two types of fermentation occur: *lactic acid* fermentation and *alcoholic fermentation*.

In most animals, as well as in humans, the pyruvic acid that accumulates due to glycolysis is converted to lactic acid when it accepts the high energy electrons from NADH. This kind of fermentation is called *lactic acid fermentation*.



Lactic acid is produced in the muscles when the body cannot supply enough oxygen to muscles to meet their needs. Lactic acid fermentation occurs when you run, ride a bike or swim fast for just a few seconds. The large muscles in your body quickly run out of oxygen. These muscles begin to make ATP by lactic acid fermentation. You can tell when you are beginning to produce lactic acid in your muscles because it causes a painful, burning sensation in the leg and/or arm muscles, familiar to every athlete. When this happens, the cell is performing *anaerobic respiration.* As you will see, anaerobic conditions produce much less ATP energy than would the condition of an abundant supply of oxygen (aerobic condition).

Another kind of fermentation occurs in yeasts. Yeasts are one-celled organisms that are used in baking or brewing. In the absence of oxygen, pyruvic acid is broken down to produce alcohol and carbon dioxide instead of lactic acid. This process is called *alcoholic fermentation*.



Alcoholic fermentation causes bread dough to rise. When the yeast in the dough is starved for oxygen, it gives off tiny bubbles of carbon dioxide. The same carbon dioxide is the source of bubbles in alcoholic beverages.

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Classic Experiments in History:

Pasteur and Yeasts

The word *enzyme* means "in yeast." Most of the early studies on enzymes and their actions were attempts to understand the alcoholic fermentation by which wine was made. As early as 1785, the Academy of Florence in Italy offered a prize for a theory of fermentation that could be applied to keeping wine in better condition while it was transported. However, no discoveries were made until the industry asked Louis Pasteur to investigate the condition called "l'amer" which was destroying large quantities of Italy's best burgundy wine every year.

From his experiments, Pasteur concluded that fermentation occurred only when yeast was present. He then discovered that l'amer, which turned wine sour, was caused by bacteria. Microscopic examination showed that the sour wine contained more bacteria than yeast cells.


Louis Pasteur

He concluded that l'amer could be prevented by greater cleanliness, including sulfur sterilization, which is now standard practice in many winemaking steps. Pasteur also showed the importance of excluding air during fermentation; wine yeasts produce alcohol under anaerobic conditions, but if oxygen is present, other yeasts and bacteria that convert alcohol into acetic acid (vinegar) will overwhelm the wine yeasts.

In the next lesson, we will study the last two stages of cellular respiration in which ninety-percent of the cell's energy is produced.



Life Principle

"In everything, I believe the secret of success is prolonged effort."

—Louis Pasteur, (1822-1895)
French chemist and founder of microbiology

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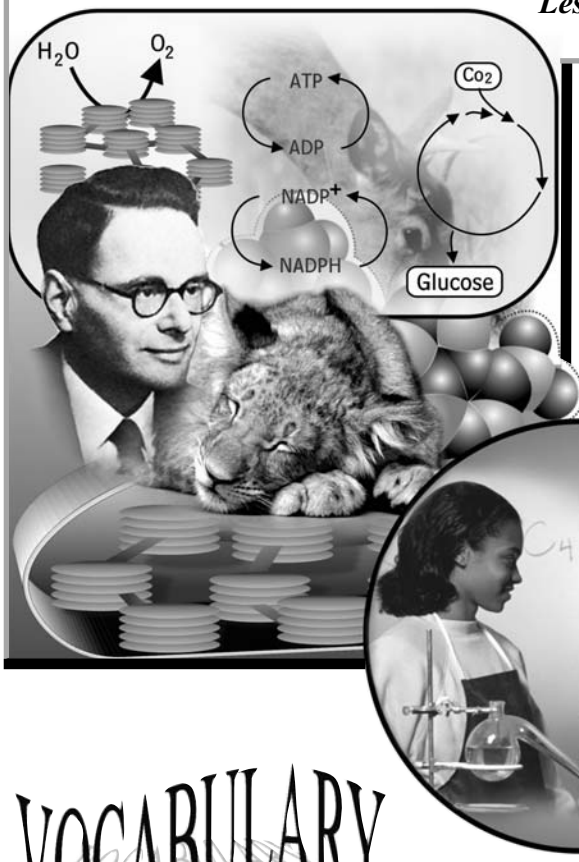
Lesson 8

Chapter 2

Section 2

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KREBS CYCLE



Cellular Respiration: Stage II

In stage one of cellular respiration, glycolysis releases only about five percent of the total energy stored in a glucose molecule. About ninety-five percent of the available energy is still unused at this point.

As we saw in the previous lesson, the process of glycolysis takes place in the cytoplasm without the need of oxygen. In eukaryotic cells, the pyruvic acid produced by glycolysis then enters the mitochondria where it is converted into a form that can be used in the next stage of respiration. (In prokaryotes, which lack mitochondria, the plasma membrane carries out the functions performed by the mitochondria in eukaryotes.) Because the last two stages of respiration take place inside the mitochondria, we need to examine the structure of the mitochondria.



Vocabulary

Cristae: the inner, infolded membrane of a mitochondrion that houses the third stage of respiration; increases the surface area within the mitochondrial matrix; enables the cell to produce larger amounts of energy

Mitochondrial matrix: the compartment of the mitochondrion enclosed by the inner membrane; contains enzymes and substrates for the Krebs Cycle

Mitochondrial Structure

A mitochondrion is separated from the cytoplasm by its outer membrane; this membrane is permeable to a variety of molecules. The inner membrane is less permeable and has many folds called ***cristae*** that are inwardly directed. This inner membrane surrounds a compartment containing a protein-rich solution called the ***mitochondrial matrix***. Many of the enzymes needed for the next stages of cellular respiration are found in this matrix; the rest of the required enzymes are attached to the inner face of the inner membrane. This membrane also contains the electron transport molecules which will be needed in the third stage of respiration.

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Researchers have discovered that cells which are more active and have larger energy requirements have many more mitochondrial cristae. The cristae allow for much more inner-membrane surface area. For example, in rats, the surface area of the inner membrane per gram of liver mitochondria is about 40 square meters, whereas in heart mitochondria, the surface area is about 200-250 square meters. The flight muscles of blowflies have more than 400 square meters of inner membrane per gram of mitochondria.


Hans Krebs

The Krebs Cycle

The second stage of respiration which takes place in the mitochondria is called the ***Krebs Cycle***, named for Sir Hans Krebs, the German-British biochemist who first described the cycle in 1937. (It is also known as the ***Citric Acid Cycle***.)

Hans Krebz was born in Germany in 1900, the son of a Jewish surgeon. Hans became a medical doctor in 1925 and went on to work with the famous German biochemist, Otto Warburg, with whom Krebz distinguished himself. However, in 1933 he fled from Hitler's Nazi regime and settled in Britain where he adopted the English spelling of his name and made various contributions to science. In 1953, Krebs received the Nobel Prize for his work with citric acid. He was knighted in 1958, whereby he received the title, "Sir".

In the mitochondrial matrix, pyruvic acid loses one carbon in the form of carbon dioxide (CO_2) and then attaches to the coenzyme A molecule, forming acetyl CoA. Coenzyme A transfers its 2-carbon acetyl group to a 4-carbon compound called ***oxaloacetic acid*** to make a 6-carbon compound called ***citric acid***. (For this reason, the Krebs Cycle is often called the Citric Acid Cycle.)

Citric acid is gradually broken apart. First, one carbon is broken off, and then a second carbon breaks off. After a few more steps, the same 4-carbon compound (oxaloacetic acid) is produced to begin the cycle again. The most important features of the Krebs Cycle are:

1 The carbon dioxide (CO_2) that is released in the Krebs Cycle is the source of all the carbon dioxide in your breath. Every time you exhale, you expel the carbon dioxide produced by this cycle in the trillions of mitochondria throughout your body.

2 As the carbon atoms in glucose are broken down and released as CO_2, high-energy electrons in the form of hydrogen atoms are also released. These electrons are passed to two electron carrier coenzymes, NAD^+ and FAD^+. These two can each accept a pair of high-energy electrons, hold

VOCABULARY

Krebs Cycle or ***Citric Acid Cycle:*** a series of reactions in which the chemical bonds in pyruvic acid are broken to produce one molecule of ATP and five, high energy electrons.

Oxaloacetic acid: a 4-carbon intermediate compound in the Krebs Cycle which, when combined with acetyl CoA, initiates the Krebs Cycle

Citric acid: the 6-carbon intermediate compound in the Krebs Cycle (or Citric Acid Cycle)

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them for a short time, and then pass them along to another compound. During the Krebs Cycle, five pairs of high-energy electrons are removed. Energetically speaking, this is the most important outcome of the cycle, because these electrons are the greatest part of the energy derived from the original glucose molecule. The third part of cellular respiration will fully utilize these high-energy electrons.

3 One molecule of ATP is formed during each turn of the Krebs Cycle.

4 Because each glucose molecule gives rise to two pyruvic acid molecules, two "trips" are required around the Krebs Cycle to break down one molecule of glucose. Therefore, two ATP molecules are produced for each glucose molecule during the second stage of cellular respiration, the Krebs Cycle.

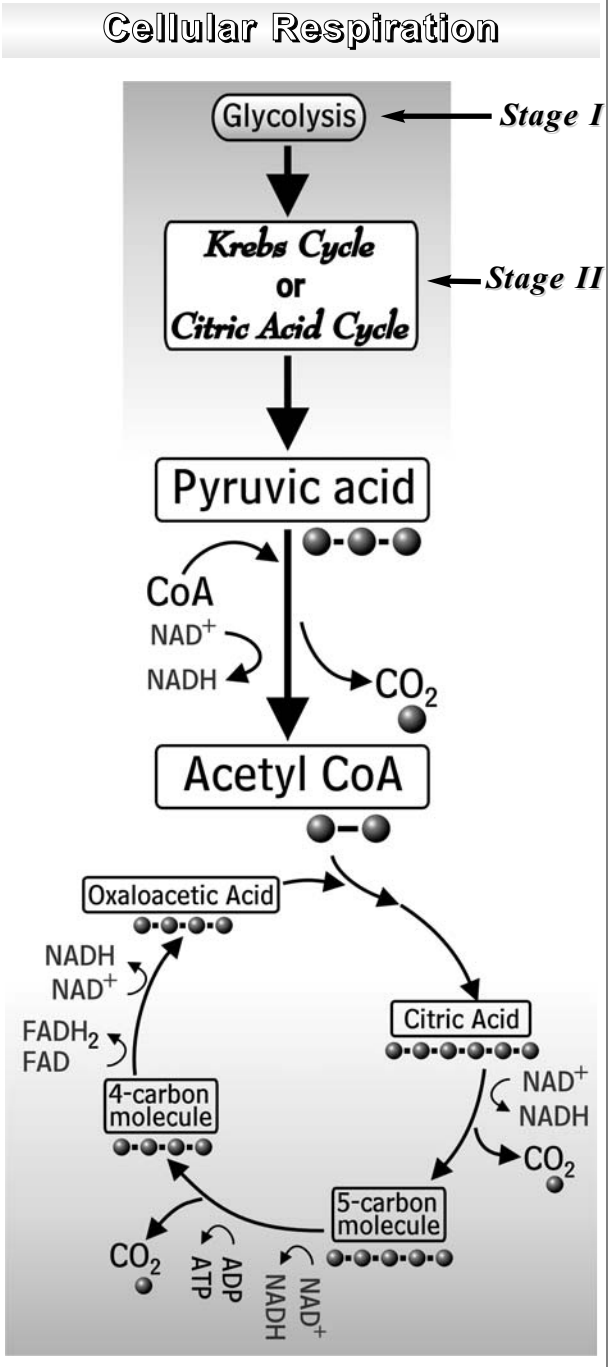
The Krebs Cycle is an economical way of turning food components in the cell into usable energy. Seven enzymes carry out the various reactions and produce many intermediate compounds that can be used again and again. Many of the intermediate compounds produced in the Krebs Cycle are also of value for the synthesis of amino acids, carbohydrates and other cellular needs.

You are probably thinking that this material is complex, "boring stuff". You are correct, but it lays the foundation for you to gain insight into, and appreciation of, the intricate design and function of life.

Career Bound

In the laboratory, biological technicians help scientists by setting up equipment, performing experiments and gathering information.

In the next lesson, we will examine the final stage of cellular respiration, called the *electron transport chain,* in which oxygen is utilized to form most of the cell's energy needs.



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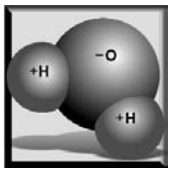
LIFE PRINCIPLE

"The more we learn of science, the more we see that its wonderful mysteries are. . . so connected together and. . . dependent upon each other. . . ."

—Olympia Brown (1835-1926)
Early woman's suffrage pioneer

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Molecules

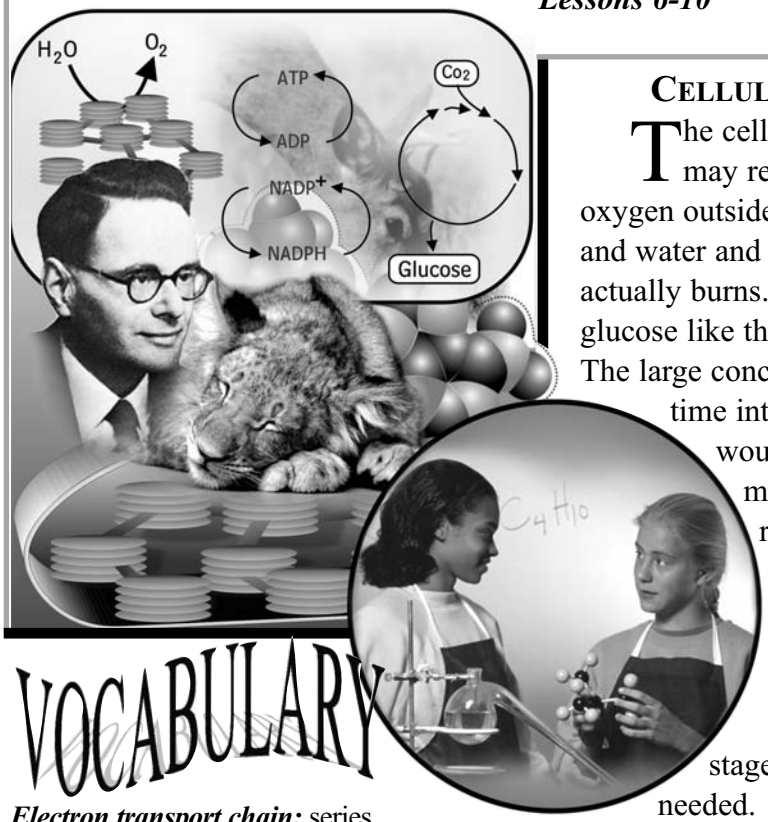
Lesson 9

Chapter 2

THE ELECTRON TRANSPORT CHAIN

Section 2

Lessons 6-10



CELLULAR RESPIRATION: STAGE III

The cell uses oxygen very efficiently. You may recall that when glucose reacts with oxygen outside the cell, it produces carbon dioxide and water and releases so much energy that it actually burns. If a cell were simply to burn glucose like this, the results would be disastrous. The large concentration of energy in such a short time interval would be so violent that it would destroy the cell. Instead, as mentioned in a previous lesson, the cell releases this energy in a very slow, controlled manner.

VOCABULARY

Electron transport chain: series of molecules located in the inner membrane of the mitochondrion that receive high-energy electrons from electron carriers

Macromolecules: large, complex molecules made up of smaller molecules linked together to form chainlike molecules

Synthesis: formation of a compound or complex substance from elements or simpler compounds

Triglycerides: fatty compounds formed when acid radicals replace 3 hydrogen atoms in glycerol

ELECTRON TRANSPORT CHAIN

So far, during the first two stages of respiration, oxygen has not been needed. At the very end of the cellular respiration process, the high energy electrons are passed along to oxygen in the final stage called the ***electron transport chain***. This is the very reason that we need to breathe oxygen. The steady supply of oxygen that is taken in is needed throughout the body for just one reason—to accept the high energy electrons at the end of the electron transport chain. Without oxygen, this final stage of respiration could not take place, the Krebs Cycle would stop and ATP could not be produced.

During the electron transport chain process, the electron carriers NAD^+ and FAD^+ take the high-energy electrons produced during the Krebs Cycle and transport the electrons directly to the inner membranes of the mitochondrion, where a series of highly specialized molecules is waiting to process the electrons. These molecules are known as the *electron transport chain* and receive the high-energy electrons. The carriers then go back into the Krebs Cycle for more electrons.

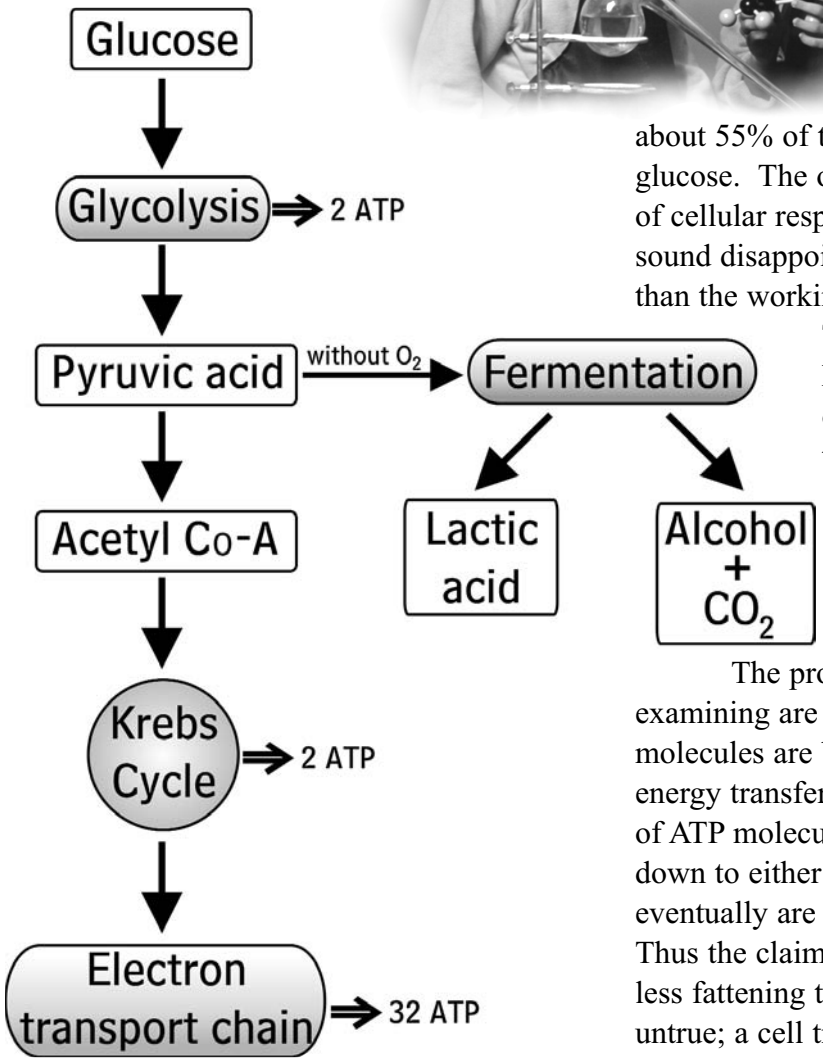
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These high energy electrons are then passed from one molecule in the electron transport chain to the next. At the end of the chain, an enzyme combines the electrons from the transport chain: hydrogen ions from fluid in the cell and oxygen to form H_20. With each transfer, the energy level of the electrons is gradually lowered as the energy is being used to produce ATP from ADP. Compared to the processes of glycolysis and the Krebs Cycle, the amount of ATP produced by the electron transport chain is very large. During glycolysis and the Krebs Cycle, a net total of four molecules of ATP are produced; during the final electron transport chain, up to 32 molecules of ATP can be produced.

This means that the cell gains a net total of 36 molecules of ATP. (The cell actually produces 38 molecules of ATP; however, two ATP molecules are needed to get the process of glycolysis going.) Although that may seem like a great benefit for the cell, the trade actually is not as good as it may appear to be. The cell produces only about 55% of the total available energy in glucose. The other 45% is lost in the process of cellular respiration. Although this may sound disappointing, it is still more efficient than the workings of any man-made machine. The most efficient machine known to man can produce only about 20% of the energy that is available in the fuel that powers that machine.





Alternative Food Molecules

The processes that we have been examining are those by which carbohydrate molecules are broken down and their stored energy transferred into the high-energy bonds of ATP molecules. Carbohydrates are broken down to either glucose or fructose and eventually are converted to pyruvic acid. Thus the claim that other "natural" sugars are less fattening than sucrose or glucose is untrue; a cell treats them all alike.

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Two other important classes of nutrients—fats and proteins—are metabolized in various ways; but they, too, ultimately reach either gylcolysis or the Krebs Cycle. If a cell receives more food than is needed for building ***macromolecules*** and releasing energy, the excess is converted and stored as fat. If not used immediately, both carbohydrates and proteins can be converted to acetyl CoA, which in turn is the basic building block for the ***synthesis*** of fatty acids. The fatty acids are then converted to ***triglycerides*** and stored as body fat. High triglyceride levels contribute to heart disease. Eating more food than we need—whether carbohydrate, protein or fat—results in weight gain (obesity). For each extra pound of body fat, the body must produce 100 miles of capillaries. This results in a heavy load on the heart and puts a person at risk for a heart attack.

In the next lesson, we will study photosynthesis—the incredible process by which plants use sunlight to produce food.

WATCH VIDEO:
Electron Transport Chain



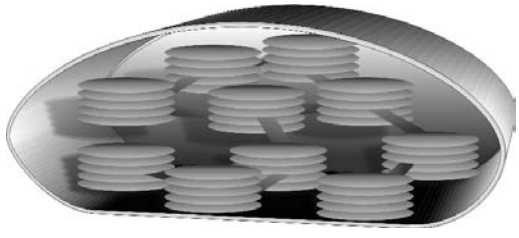
LIFE PRINCIPLE

"The power of the unknown. . . .drives us into nature's hidden powers and secrets, down to the immeasurably little world of the microscope. . . ."

—Roald Amundsen (1872-1928)
Explorer (first person to reach the South Pole)

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Photosynthesis

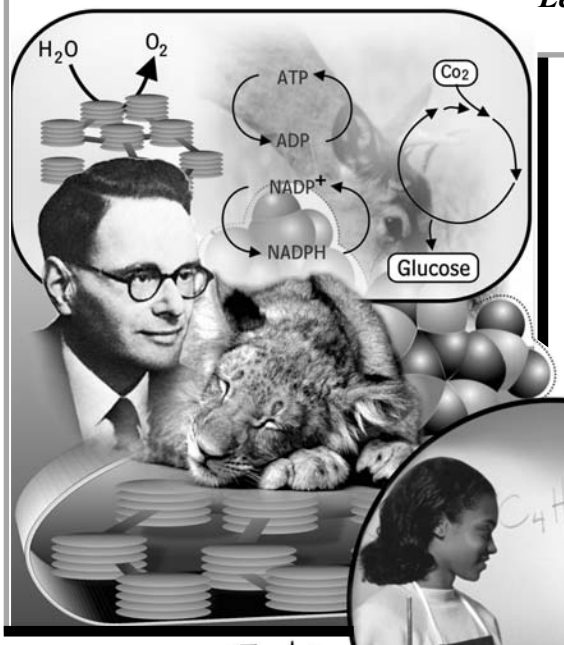
Lesson 10

Chapter 2

Section 2

Lessons 6-10

PHOTO-SYNTHESIS





VOCABULARY

Photosynthesis: process by which green plants use the energy of sunlight to produce carbohydrates

Cellulose: a structural polysaccharide in cell walls; consists of glucose monomers

Chloroplasts: organelles found in plants and certain types of algae; harvests the energy of sunlight

Thylakoids: flattened membrane sacs inside the chloroplasts; the location of chlorophyll and the photosynthesis process

Chlorophyll: principal pigment of green plants

A Critical Process for the Life Cycle

The ultimate energy source for most living things is sunlight. Green plants and microscopic organisms are able to trap sunlight energy and use it to build the high-energy complex molecules that make up food. Whether an animal is a meat eater or a plant eater, the animal's source of energy can be traced back to plants and sunlight.

Photosynthesis is the process by which green plants use the energy of sunlight to convert carbon dioxide and water into the simple sugar, *glucose*. In doing so, photosynthesis provides the basic energy source for virtually all organisms. An extremely important by-product of photosynthesis is *oxygen*, on which most organisms depend.

Photosynthesis occurs in green plants, seaweeds, algae and certain bacteria. These organisms act as little sugar factories, producing millions of new glucose molecules every second. Plants use much of this glucose as an energy source to build leaves, flowers, fruits and seeds. They also convert glucose to ***cellulose***, the structural material used in cell walls. Most plants produce more glucose than can be used, however, and the excess glucose is stored in the form of starch and other carbohydrates in roots, stems and leaves. The plants can then draw upon these reserves for extra energy or for building materials. Each year, photosynthesizing organisms produce about 170 billion metric tons of extra carbohydrates, about 30 metric tons for every person on Earth.

Photosynthesis has far-reaching implications. Humans and animals also depend on glucose as an energy source, but are unable to produce glucose on their own and must rely ultimately on the glucose produced by plants. Moreover, the oxygen which humans and animals breathe is the oxygen

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released during photosynthesis. Thus, virtually all life on earth, directly or indirectly, depends on photosynthesis as a source of food, energy and oxygen, making photosynthesis one of the most important biochemical processes known to man.

Historical Development

As early as 1772, an English clergyman and chemist, Joseph Priestly (1733-1804), demonstrated that green plants actually reverse the effects of breathing. Priestly set a plant alone in a closed jar and a mouse alone in another closed jar. After some time, both the plant and the mouse died. Priestly then placed a mouse and a plant together in a closed jar; in this experiment, both lived and thrived. Priestly's experiment demonstrated that plants produce oxygen, although he did not realize what was happening; nor did he realize that light was essential for oxygen production. Seven years later, Dutch physician Jan Ingen-Housz (1730-1799) showed the importance of sunlight for oxygen production. In 1792, a Swiss pastor and part-time scientist, Jean Senebier (1742-1809), showed that the photosynthetic process was dependent on carbon dioxide. In 1804, another Swiss worker, Nicolas Theodore de Saussure (1767-1845), found that water is necessary for photosynthesis to occur.

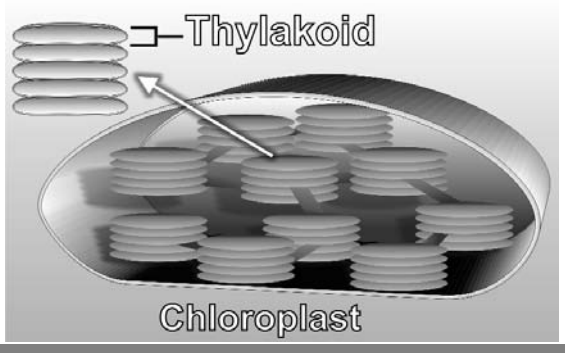
VOCABULARY

Visible spectrum: that part of the light spectrum visible to the human eye
Light-dependent reactions: the reaction process during photosynthesis that requires direct involvement of light
Photosynthetic electron transport chain: the process during photosynthesis in which electrons are passed from one molecule to another in order to release energy
$NADP^+$ (Nicotinamide Adenine Dinucleotide Phosphate): an electron carrier used during the photosynthesis process
NADPH: the electron carrier $NADP^+$ which has been converted by electrons
Light-independent reactions: the reaction process during photosynthesis that requires no direct involvement of light
PGA (PhosphoGlycericAcid): a 3-carbon intermediate compound produced during the Calvin Cycle
Calvin Cycle: chemical pathway used to convert energy from ATP and $NADP^+$ into sugars; also called *light-independent reactions*

The Process of Photosynthesis

In a way, photosynthesis is the reverse of the cellular respiration process. In respiration, cells use the high-energy electrons found in glucose to provide energy to make ATP. The products of respiration—carbon dioxide and water—contain low-energy electrons. In photosynthesis, plant cells trap the Sun's energy and then pass this energy along to carbon dioxide and water to raise their energy levels. Glucose can then be produced along with oxygen as a by-product.

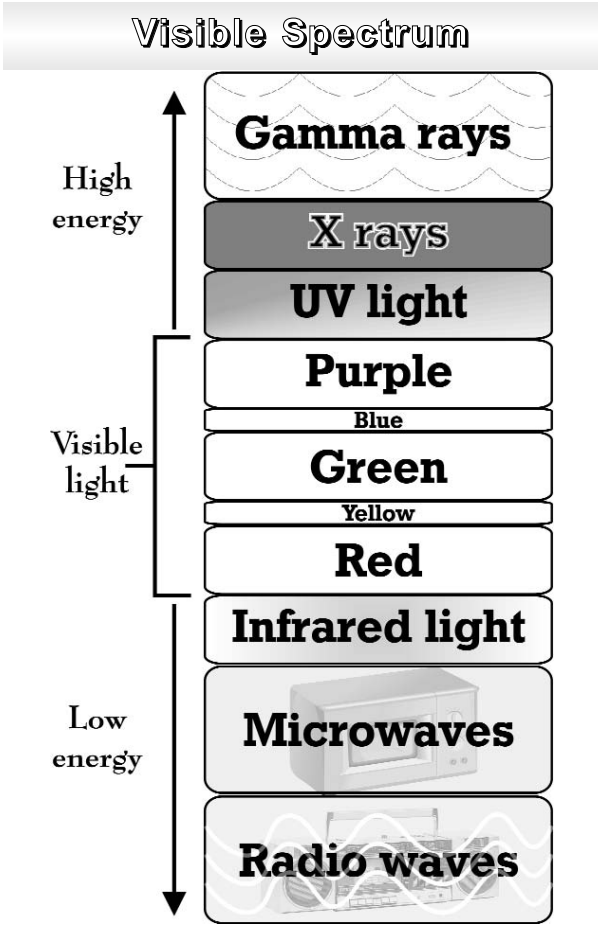
Plant photosynthesis occurs in leaves and green stems of plants within specialized



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cell structures called ***chloroplasts***. Each plant cell contains 40 to 50 chloroplasts. The chloroplast is an oval-shaped structure and is divided by membranes into numerous disk-shaped compartments called ***thylakoids***.

Embedded in the membranes of the chloroplast thylakoids are hundreds of molecules of ***chlorophyll***, a light-trapping pigment required for photosynthesis. Sunlight is necessary to activate the process of photosynthesis. What your eyes perceive as white light from the sun is actually a mixture of various wavelengths of light. Many of these wavelengths are visible to your eye and make up what is known as the ***visible spectrum***. Chlorophyll absorbs light very well in the blue and in the red regions of sunlight's visible spectrum. However, chlorophyll does not absorb light in the green region of the spectrum. This is why chlorophyll appears green to the human eye.



Because light is a form of energy, compounds which absorb light also absorb energy. When chlorophyll absorbs light, much of that energy is transferred directly to electrons in the chlorophyll molecule.

Light-Dependent Reactions

Two stages of photosynthesis occur. The first stage consists of the ***light-dependent reactions***, which require the direct involvement of light.

When chlorophyll absorbs light energy, it releases high-energy electrons that are passed to the ***photosynthetic electron transport chain*** in the membranes of the chloroplast. Just as in cellular respiration, these electrons are passed from one electron to another, like individuals in a bucket brigade passing water from the top of a hill to the bottom. Each electron carrier is at a lower energy level than the one before it, and the result is that electrons release energy as they move down this chain. Thus, the energy of the sunlight is converted into chemical bond energy.

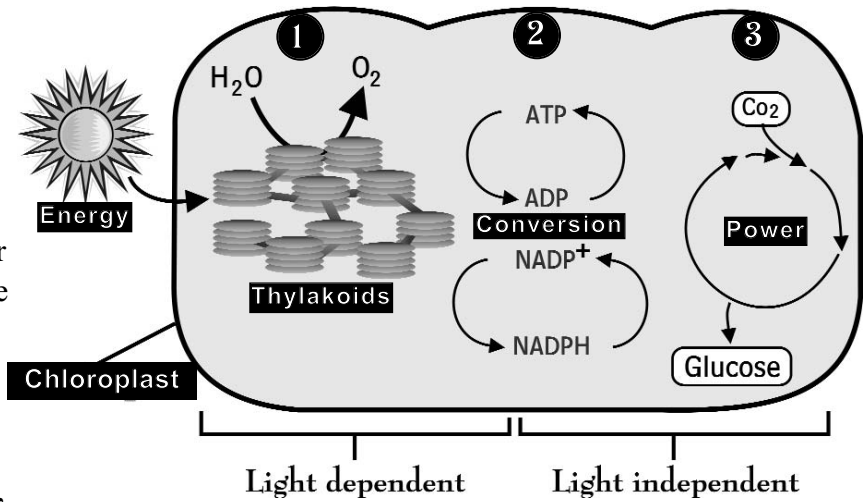
This conversion occurs in two pathways. In the first pathway, the electrons in the chlorophyll, excited by sunlight, move through an electron transport chain and their energy is used to form ATP. In the second pathway, other excited electrons are captured by the electron carrier, ***Nicotinamide Adenine Dinucleotide Phosphate*** (***$NADP^+$***), to form ***NADPH***. ATP and NADPH both have an important role in the plant cell. They will provide energy to make carbohydrates in the second stage of photosynthesis.

Electrons that were excited by the sunlight and then removed from the chlorophyll as high-energy electrons must be

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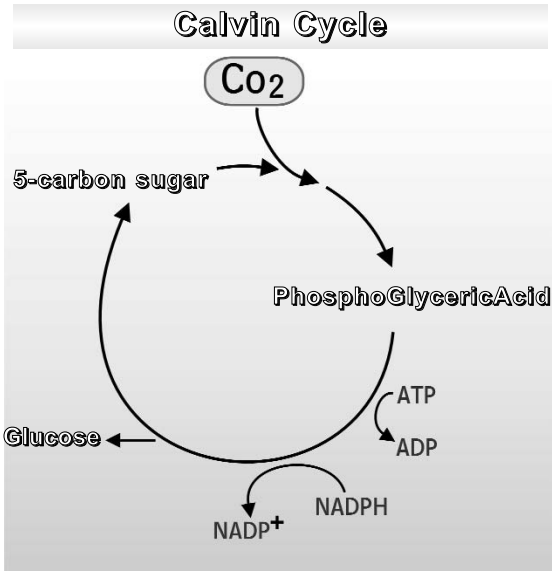
replaced; otherwise in just a few milliseconds, the chlorophyll will break apart. These electrons will be replaced from water. Enzymes on the inner surface of the photosynthetic membrane split water molecules in two. Four electrons are removed from two molecules of water, leaving four hydrogen ions and two oxygen atoms. The electrons are returned to the chlorophyll to replenish their supply, and the oxygen is released into the atmosphere. This precisely designed reaction is the source of most of the oxygen in the Earth's atmosphere.



Light-Independent Reactions

The second stage of photosynthesis involves ***light-independent reactions***. This set of reactions does not involve light directly. Light-independent reactions convert the energy from ATP and $NADP^+$ into sugars—a form of energy that can be stored indefinitely.

The raw materials from which the cell builds sugars are carbon dioxide and water. Carbon dioxide is collected from the atmosphere and is combined with a 5-carbon sugar to produce two, 3-carbon molecules called ***PhosphoGylcericAcid (PGA)***. The two PGA molecules enter a chemical pathway that uses the energy from the ATP and the $NADP^+$ produced during the light-independent stage. This pathway is called the ***Calvin Cycle***, named after Melvin Calvin, the American scientist who discovered it.



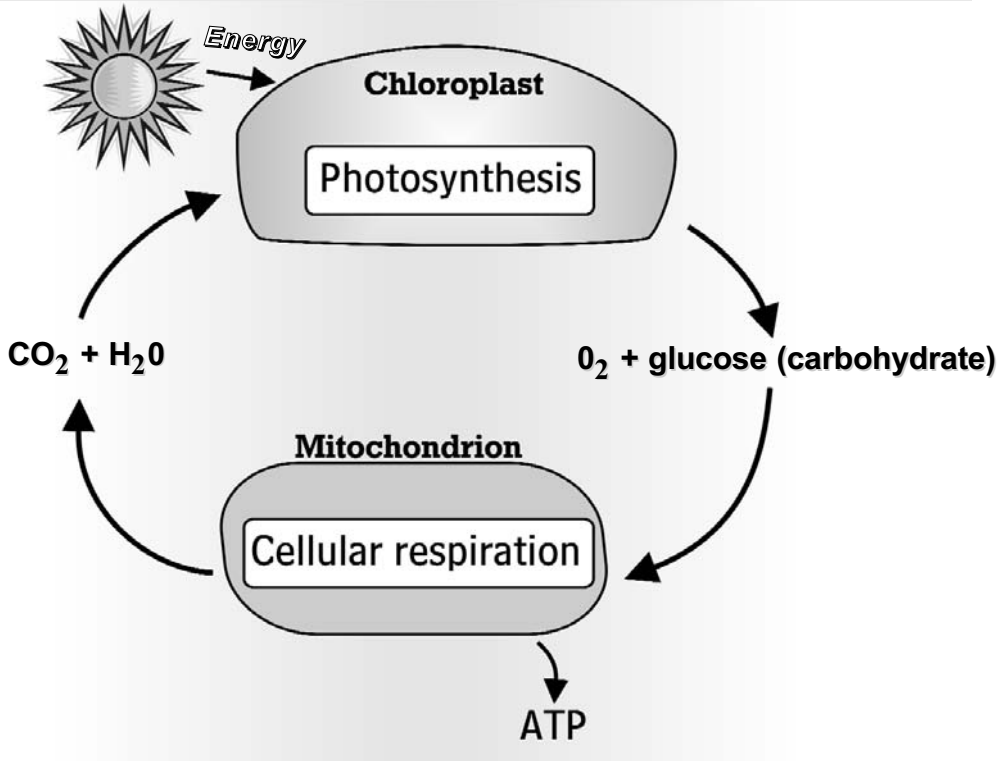
Calvin (1911-1997) was the son of Lithuanian/Russian immigrant parents who operated a small grocery store in Detroit. Calvin distinguished himself in many scientific areas, and was awarded the prestigious Nobel Prize in 1961 for his work that came to be called the *Calvin Cycle*.

Each turn of the Calvin Cycle uses one molecule of carbon dioxide and two atoms of hydrogen. After six turns, a 6-carbon sugar molecule (e.g. glucose) is produced. As photosynthesis continues, the Calvin Cycle works steadily, producing energy-rich sugars and removing carbon dioxide from the atmosphere. The plant will use the sugars produced to meet its energy needs and to build larger and more complex molecules, such as cellulose, that it needs for growth and development.

As the process of photosynthesis is examined, the marvelous balance and perfect design of life on this Earth is apparent.

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Photosynthesis & Cellular Respiration Work Together



$$CO_2 + H_2O + \text{Light} \xrightarrow[\text{Enzymes}]{\text{Chlorophyll}} CH_2O + O_2$$

(Carbon dioxide) *(Water)* *(Energy)* *(Carbohydrate or glucose)* *(Oxygen)*

Sunlight, the driving force behind photosynthesis, is the ultimate source of energy for nearly all life on earth. The process of photosynthesis takes the energy from sunlight to convert water and the exhaled carbon dioxide into virtually all food, directly or indirectly. Additionally, photosynthesis is responsible for all the oxygen we breathe. The process is simple to summarize, but is incredibly complex and efficient in its operation. The myriad of such precise complexities that exist throughout nature and the cosmos prompt many scientists to ponder, "Why?" Astrophysicist Paul Davies words it this way:

> . . .There is something going on behind it all. It seems as though somebody has fine-tuned nature's numbers. . . .The impression of design is overwhelming.

In the next lesson, we will begin to examine the process of cellular division and specialization—the way in which cells keep life going and how they have specialized purposes.

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LIFE PRINCIPLE



"Most people say that it is the intellect that makes a great scientist. They are wrong: it is character."

—Albert Einstein(1879-1955)
German-American physicist and mathematician

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Cycles

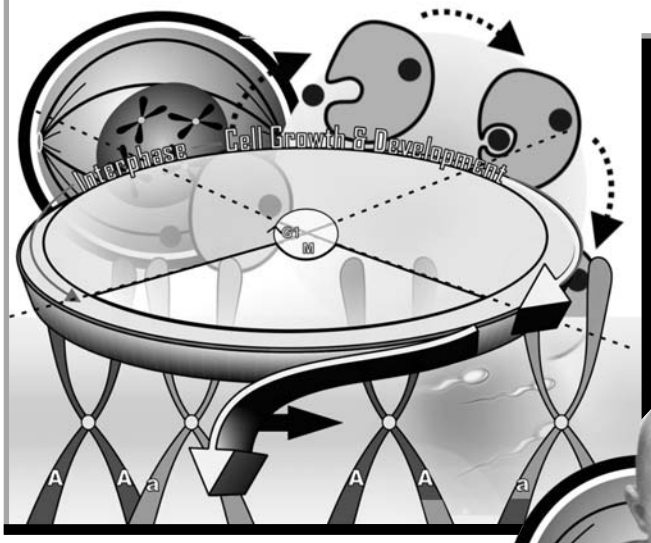
Lesson 11

Chapter 2

CELL GROWTH, DIVISION & CYCLE

Section 3

Lessons 11-15



CELL REPRODUCTION AND SPECIALIZATION

A cat, like all animals, is made up of cells. Kittens, like other newborn animals, are much smaller than their adult counterparts because they have fewer cells. Cells do not grow to enormous sizes to increase the size of the organism; instead, cells reproduce. As you may recall from the first lesson in this chapter, an important part of the cell theory is that *cells arise only by division of other cells*.



CELL GROWTH

Suppose that a cell were simply to grow larger instead of reproducing in order for an organism to increase in size. If a cell doubled its diameter, the cell's internal volume would grow by a factor of eight, whereas the surface area of the cell would be only four times as great. Clearly, the larger it grew, the more difficult would be the operation of getting things in and out of the cell. If cells grew too large, they would not be able to supply their own needs and growth would come to a stop. This is one of the main reasons why cells do not grow much larger, even when the organism does.

CELL DIVISION

Within all organisms, cells divide to produce new cells, each of which requires the genetic information found in the DNA. This process is called ***cell division***. The nucleus of the eukaryotic cell carries the DNA or blueprints for the development of the new cell. When the cell divides, a duplicate of the nuclear information must be transmitted in an

VOCABULARY

Cell division: process in which a cell divides into two independent daughter cells

Binary fission: reproduction by the division of a cell into two essential equal parts by a simple, non-mitotic process

Mitosis: process of cell division in eukaryotic cells in which each of the daughter cells has identical DNA information as the parent cell

Cytokinesis: division of the cytoplasm that takes place during mitosis in most cells

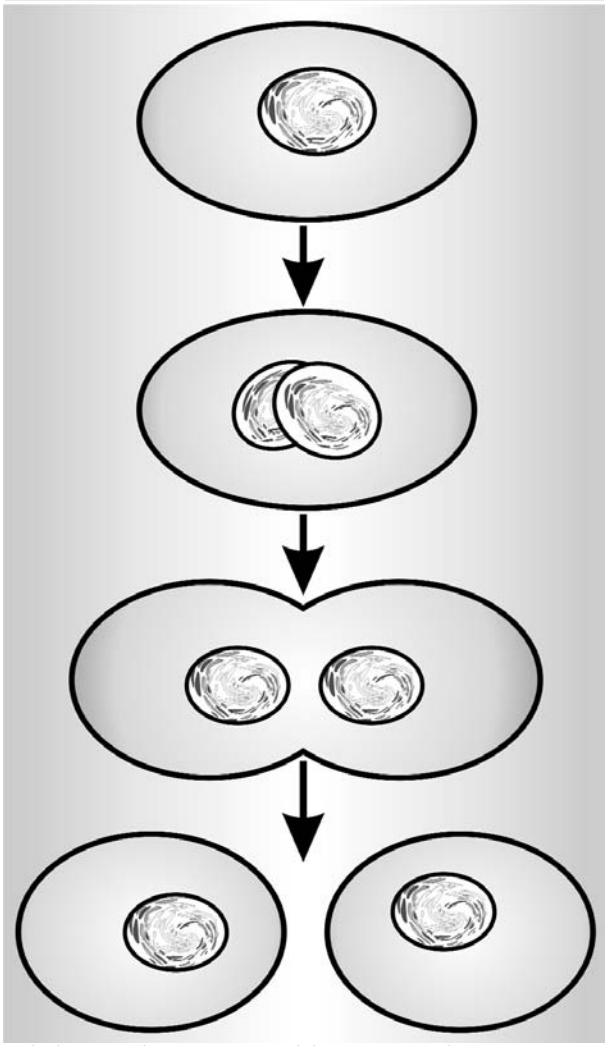
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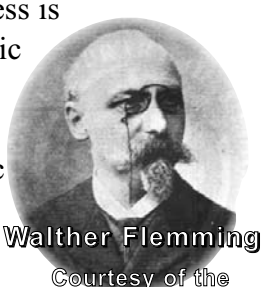
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orderly fashion to the new cell. The division cannot be a simple splitting of the information into two halves, because this would give neither of the cells a satisfactory blueprint. Just as you cannot have two identical buildings erected by cutting one blueprint in two and giving half to each of two contractors, so new cells cannot develop if each receives only half of the necessary information from the parent cell. If you wanted two contractors to erect identical buildings simultaneously, you would give each one a full copy of the blueprint. The same principle applies to the cell. If a parent cell is to divide, producing two viable new cells, it must first make a complete copy of the genetic information in its nucleus and then, as it divides, give one complete copy to each "daughter" cell. In other words, division of the nucleus is not simply a process of halving; it is a process of duplicating genetic information and distributing the duplicates.

In the *prokaryotic* cells of bacteria and blue-green algae, cell division appears to be a much less complex process than in the eukaryotic cells of true plants and animals. A ring of new wall material begins to form on the inner surface of the wall of the parent cell, usually at a point about midway of its length, cutting through both the cytoplasm and the nuclear area. This process is known as ***binary fission***. Genetic studies have shown that each new cell possesses a single complete complement of genetic information, which means that the genetic material has been replicated and one set included in each daughter cell.

Binary Fission





Walther Flemming

Courtesy of the National Library of Medicine

In *eukaryotic* cells, cell division involves an elaborate series of nuclear changes that can be seen and studied with the ordinary light microscope. Cell division was observed by many scientists during the nineteenth century and described in detail by Walther Flemming of the German University of Prague in the 1880s.

VOCABULARY

Meiosis: process of cell division that reduces the number of chromosomes in the cell by half; creates gametes used for sexual reproduction

Gametes: reproductive cell that can unite with another reproductive cell to form an organism

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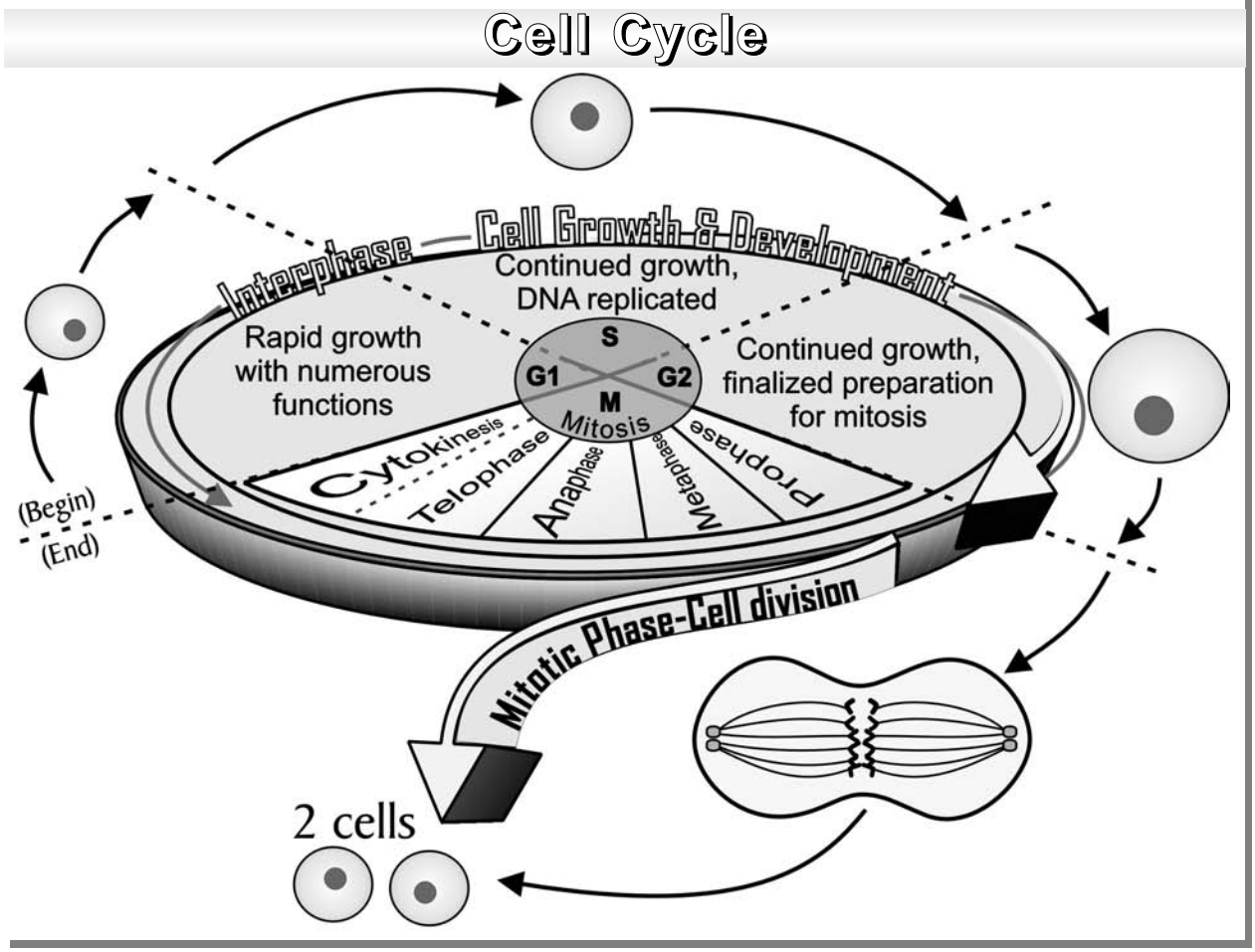
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Organisms use two types of cell division to ensure that DNA is passed down from cell to cell during reproduction. Cell division in eukaryotic cells involves two fairly distinct processes that often, but not always, occur together: division of the nucleus and division of the cytoplasm. The process whereby the nucleus divides to produce two new nuclei, each with the same number of chromosomes as the parent nucleus, is called ***mitosis***. The process of division of the cytoplasm is called ***cytokinesis***.

A different kind of cell reproduction occurs in all multicellular animals at the time of sexual reproduction. This process is called ***meiosis*** and it creates two special cells called ***gametes*** that combine during fertilization to create a new individual. Examples of two gametes are the egg and the sperm. When a sperm unites with an egg, a fertilized egg results and a whole new individual organism is conceived and begins to grow.

The Cell Cycle

In most plants and animals, cells increase in size and then divide into two cells. These two new cells increase in size and then divide again. The process continues over and over. This regular series of events, called the *Cell Cycle*, occurs in eukaryotic cells. The Cell Cycle is the period of time from the beginning of one cell division to the beginning of the next. During this time, the cell duplicates its contents so that it is ready to divide into two completely independent cells. The cell cycle is divided into four phases: the *G1*, *S*, *G2* and *M*.



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Thousands of events take place during the Cell Cycle, but two of those events are so important that they are used as landmarks during the cell's life. One of the major events in cell division occurs when either *mitosis* or *meiosis* takes place. This part of the Cell Cycle is appropriately called the *M phase*.

The other major event in the cell is the copying of the chromosomes or "blueprints" that contain the cell's genetic information. This part of the Cell Cycle is called the *S phase*. However, since most cells do not begin DNA synthesis right after cell division, the S phase is preceded by the G1 phase. This is the time period when the most rapid cell growth and activity takes place. The *G2 phase* occurs immediately following the *S phase.* During *G2*, the cell is making final preparations for cell division which occurs in the *M phase*.

Not all cells move through the Cell Cycle at the same rate. In the human body, most muscle and nerve cells do not divide at all after they have developed. In contrast, the rapidly dividing cells of a human embryo can complete the Cell Cycle in as little as 30 minutes. However, the average length of the Cell Cycle in a typical human adult cell is about 20 hours.

In general, when a cell stops growing, it stops in the *G1 phase*. Although a few exceptions exist, when a cell leaves the *G1 phase* and enters into the *S phase* the cell will usually continue through the rest of the Cell Cycle and enter cell division.

In the next lesson, we will examine in more detail the process of mitosis, the reproduction method programmed into most cells in order to continue life.

LIFE PRINCIPLE



"Listen to advice and accept instruction, and in the end you will be wise."

—Proverb of King Solomon (1034-975 B.C.)

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Cells

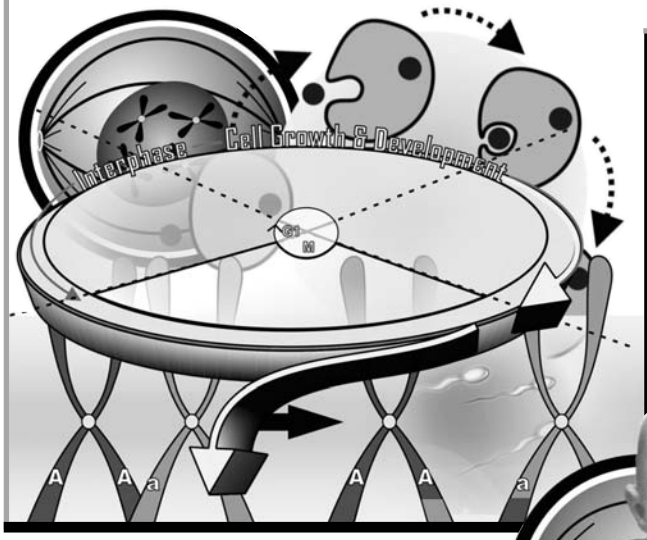
Lesson 12

Chapter 2

MITOSIS: THE CONTINUITY OF LIFE

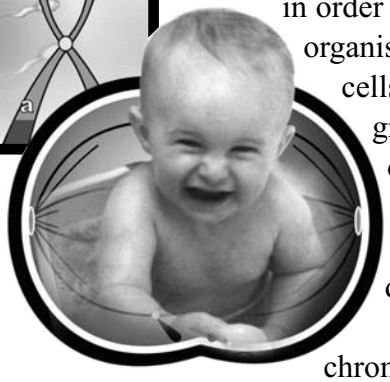
Section 3

Lessons 11-15



CELL REPRODUCTION AND SPECIALIZATION

Mitosis is a remarkable process which results in two cells that are genetically identical. It is a process that is vital for physical growth. All multicellular animals, plants, ***fungi*** and ***protists***, which begin life as single cells, carry out mitosis in order to develop into complex organisms containing billions of cells. Mitosis continues in full-grown organisms as a means of maintaining the organism—replacing dying skin cells, or repairing damaged muscle cells.



The number of chromosomes is usually constant for normal ***somatic cells*** of all individuals of the same species. For example, the nuclei of human somatic cells each contain 46 ***chromosomes***, while those of the fruit fly, *Drosophila melanogaster*, contain 8, and those of the onion contain 16. In order for the organism to ensure constant, normal growth, each daughter cell must receive a complete set of genetic instructions that was initially present in the parent cell.

The life cycle of eukaryotic cells is a continuous process. As we learned in the previous lesson, the cell cycle is divided into four phases: *G1*, *S*, *G2*, and *M*. This cell cycle is further divided into three more phases: *interphase*, *mitosis* and *cytokinesis*.

VOCABULARY

Fungi: (plural of fungus) once classified as plants, but now as a separate kingdom of organisms known as decomposers; includes yeasts, molds, and mushrooms

Protists: mainly one-celled eukaryotic organisms that do not fit the definition of plant, animal or fungi.

Somatic cell: any human or multicellular animal cell except those involved with reproduction

Chromosomes: threadlike bodies found in the nucleus of a cell when it divides; contains all of the cell's hereditary characteristics

INTERPHASE

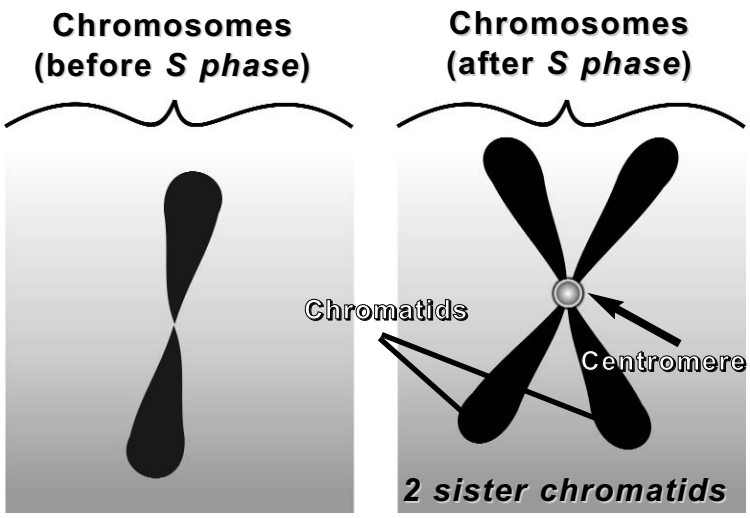
The non-dividing cell is said to be in the *interphase* state and includes the *G1*, *S* and *G2 phases* of the cell cycle. In past years, such a cell was commonly called a *resting cell*,

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but this terminology has been rejected in recent years. The interphase cell is definitely not resting; it is carrying out all the innumerable activities of a living, functioning cell: respiration, protein synthesis, growth, differentiation, and other functions. Furthermore, since interphase includes the *S phase* of the cell cycle, it is during interphase that the genetic material is replicated in preparation for the next division.

During interphase, the nucleus is a clearly visible, distinct, membrane-bounded organelle with usually one or more nucleoli prominent; but the chromosomes are not visible in the nucleus. No distinct rodlike bodies are clearly seen in a dividing cell. The chromosomes appear as an irregular mass of material. Although they may not appear to be active or organized, chromosomes are most active during interphase, using the information they contain to direct cell growth and development.



VOCABULARY

Chromatid: strand of a chromosome that occurs in identical pairs; combined with its sister chromatid, constitutes a chromosome
centromere: the part of a chromosome in which the chromosomes are attached
Centromere: the point on a chromosome by which it is drawn to the pole during mitosis
Microtubule: cytoskeleton component that provides a tough, flexible framework of support for the cell; composes structures like cilia and flagella
Mitotic: having to do with mitosis
Vesicle: a tiny sac or cavity

MITOSIS

After interphase, the cell is ready for *mitosis*, or cell division. Mitosis is divided into four phases: *prophase*, *metaphase*, *anaphase*, and *telophase.* (For review, see page 51.)

The first phase of mitosis is called *prophase* and is generally the longest of the four phases, taking as much as 50 percent of the total time required to complete mitosis. Often, the first clue that prophase has started is the appearance of chromosomes into organized, tidy structures. This is a most impressive process. The cell nucleus changes dramatically in prophase, as the chromosomes come together to form thick, threadlike structures that are quite visible with the light microscope. At this point, each chromosome has been duplicated (during the *S phase* in interphase) and consists of two identical strands called ***chromatids***. Because the chromatids are identical copies of the same chromosome, they are often called *sister chromatids*. The chromatids are attached at an area called the ***centromere***.

In animal cells, the *centrioles*—tiny structures that help to organize ***microtubules***—separate from each other and move to opposite sides of the nucleus. Each pair of centrioles

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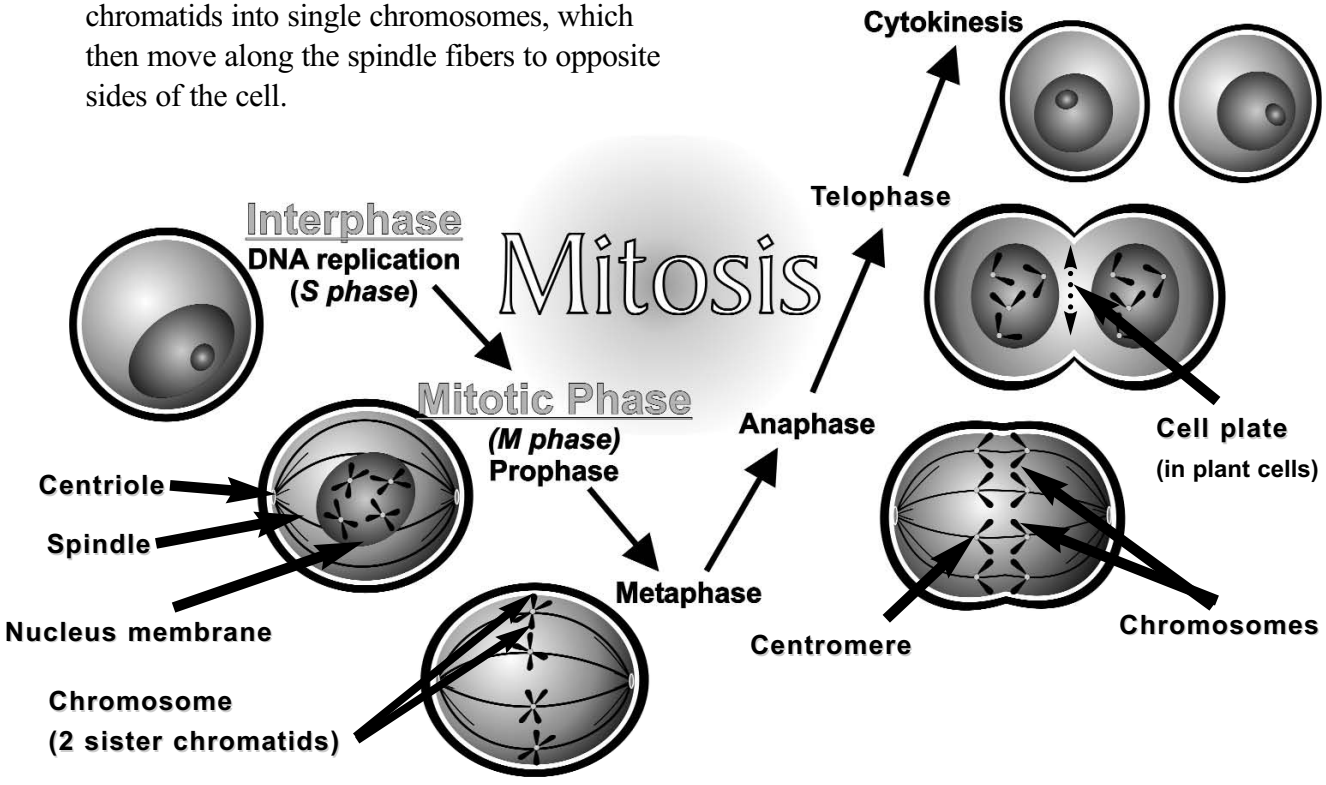
appears to be the origin for the growth of a cluster of microtubules that span the nucleus. This cluster of microtubules is called the *spindle*. The spindle spans the cell in the shape of a football to help split the chromosomes into two identical groups. As the spindle forms, the nuclear membrane breaks down into tiny sacs or vesicles that are dispersed into the cytoplasm. Final disintegration of the membrane marks the beginning of the next phase of mitosis called *metaphase*.

Metaphase, the second phase of mitosis, is the shortest phase and may last only a few minutes. During metaphase, the spindle fibers attach to the chromatids near the centromeres to line up neatly across the center of the cell. Like two individuals standing back to back at the equator, one chromatid faces one pole of the cell, and its linked partner faces the opposite pole. This precise orientation is necessary for the next ***mitotic*** step to occur.

Anaphase begins when the centromeres split, separating the identical chromatids into single chromosomes, which then move along the spindle fibers to opposite sides of the cell. In a matter of a few minutes, the chromosomes move apart and are concentrated into two groups—one at each pole of the spindle.

As these two identical groups of single chromosomes gather at opposite poles of the cell, *telophase* begins. The spindle fibers break down and the newly formed chromosomes begin to unwind. A nuclear membrane forms around each new cluster of chromosomes and two distinct nuclei gradually form within the cell. These two daughter nuclei will each go to one of the cells produced by the division, so that each of these new cells contains a nucleus.

In the past, some scientists thought that the original parent cell nuclear membrane literally dissolved during prophase. Peter Helper, a scientist at the University of Massachusetts at Amherst, discovered that nuclear membranes do not dissolve at all. Instead, the material of the envelope is rearranged into a series of tiny ***vesicles*** during prophase, and those vesicles are reassembled



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as membranes during telophase. Thus, although the membranes seem to disappear, they are actually broken apart and stored until the cell needs them again during telophase.

Cytokinesis

The final phase of the cell cycle is known as *cytokinesis*, in which the cytoplasm itself divides. The timing of cytokinesis varies with the cell type. It can begin in anaphase and finish in telophase or it can follow telophase. In cytokinesis, the cell's cytoplasm separates in half with each half containing one nucleus. Animals and plants accomplish cytokinesis in slightly different ways. In animals, the cell membrane is pulled inward by a ring of filaments. This continues until the cytoplasm is pinched into two equal parts, each containing its own nucleus and cytoplasmic organelles.

In plant cells, a structure called the *cell plate* forms midway between the two nuclei. The cell plate grows gradually outward until a new cell wall appears between the daughter cells.

After cytokinesis is complete, the new cells enter interphase and the cell cycle begins again.

More About Chromatids

Once a chromosome has completed the *S phase* of the cell cycle, it is consistently referred to as being composed of two chromatids. This reference is part of an attempt by biologists to reduce confusion, especially about the number of chromosomes a cell contains. Human cells, for example, contain 46 chromosomes. Then, at the end of the *S phase*, each chromosome has been duplicated. Biologists do not say, however, that the cell (now in G2) contains 92 chromosomes, because the information content of the cell has not changed. Biologists continue to say that the cell has 46 chromosomes, but where once a single DNA molecule existed, now two identical ones exist. This is why the term "chromatid" was coined. Each chromosome consists of one chromatid before the *S phase* and two chromatids after the *S phase*.

In the next lesson, we will examine the perfect mechanism of meiosis—the process by which life propagates new and unique organisms.

Life Principle

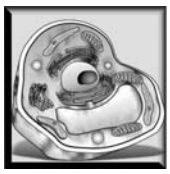


"Every day, do something that will inch you closer to a better tomorrow."

—Doug Firebaugh
Marketing trainer, speaker, author

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Cells

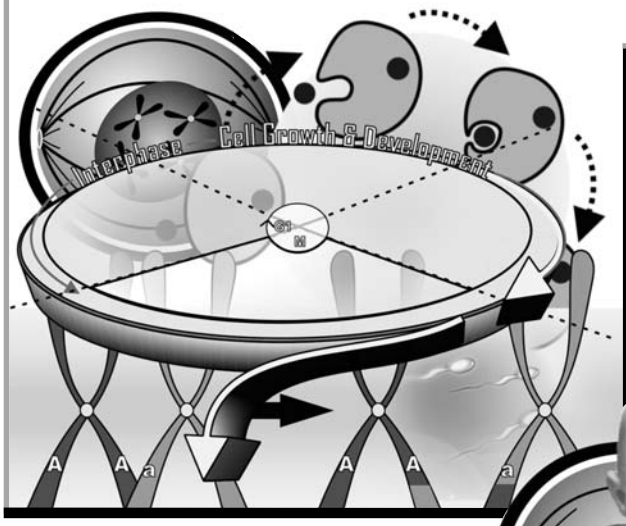
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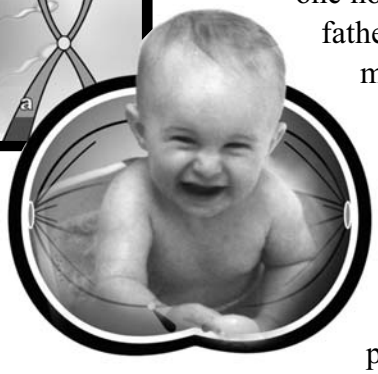
Chapter 2

MEIOSIS: THE PROPAGATION OF LIFE

Section 3

Lessons 11-15





Cell Reproduction and Specialization

Every normal cell in the body of an animal or plant contains the same number of chromosomes—usually an even number. This is because each chromosome has a double or twin called a ***homologue***—one homologue comes from the father and the other from the mother, giving an even number of chromosomes. The pairs are called ***homologous chromosomes*** because both members of the pair contain the same kind of genetic information at the same position on the chromosomes. For example, a certain human chromosome contains genes for the enzyme ***amylase*** and for an ***Rh blood factor***.

The reproductive cells—*gametes* (the egg and the sperm)—must each contain half the number of chromosomes present in normal body cells. Otherwise, with each generation the number of chromosomes per cell would double—a situation which could not continue or the cell would become too large very quickly.

The normal body cells of most plants and animals are said to be ***diploid***. This refers to the two sets of chromosomes, each donated by one parent cell. In human cells, forty-six chromosomes are organized into twenty-three pairs. Hence, we say that human cells are diploid in that they have two sets of twenty-three chromosomes, for a total of forty-six.

The gametes of human cells are ***haploid***. This term refers to the single set of chromosomes, or twenty-three chromosomes in humans. When the human gametes unite with one another during sexual reproduction, the normal diploid condition of forty-six chromosomes is reestablished.

VOCABULARY

Homologue: one set in a pair of homologous chromosomes

Homologous chromosomes: chromosome pairs of the same length and centromere position, containing the same kind of genetic information; one homologue is inherited from each parent

Amylase: a starch-digesting enzyme found in human saliva and digestive juices

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Mitosis is the process that takes over from this point to bring about the full development of the organism.

Meiosis is the process by which the chromosomes in gametes are reduced by half so that each daughter cell receives only one homologue twin of each chromosome, therefore becoming *haploid* cells. In meiosis, a cell containing the diploid number of chromosomes is converted into four cells, each having the haploid number of chromosomes. Meiosis occurs by a series of phases that resemble the phases of mitosis. Two major subdivisions of meiosis occur: *Meiosis I* and *Meiosis II*. Each of these major subdivisions is divided into the same phases characteristic of mitosis: *Prophase I*, *Metaphase I*, *Anaphase I*, and *Telophase I*.

VOCABULARY

Rh blood factor: one or more genetically determined substances in red blood cells capable of inducing an intense immune system reaction; lacking in Rh negative persons

Diploid: from the Greek word "diplos", meaning *double* or *two*; having two of each type of chromosome

Haploid: from the Greek word "haplos", meaning *single*; having one of each type of chromosome

Meiosis: process of nuclear division in which the number of chromosomes is reduced in half; the process by which gametes are produced

Synapsis: forming pairs or aligning side by side

Crossing over: exchange of parts of two homologous chromosomes during meiosis

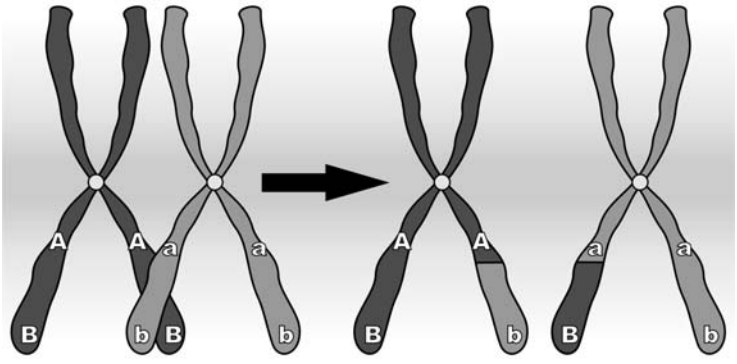
MEIOSIS I

As the cell prepares to enter meiosis, each of the chromosomes has duplicated, as in mitosis. Therefore, at the beginning of meiosis, each chromosome consists of two chromatids attached at the centromere. (In the case of a human, this translates to forty-six chromosomes or ninety-two chromatids). Recall that this is exactly the case just before mitosis.

Many of the events in *Prophase I* of meiosis resemble those in the prophase of mitosis. The individual chromatids shorten and thicken and become visible under the light microscope. The nucleoli slowly fade from view and the nuclear membrane begins to disappear as the spindle begins to form. The chief difference between the prophase of meiosis and mitosis is that in meiosis, each pair of homologous chromosomes move together and come to lie side by side. Therefore, four chromatids align next to one another. This combination of four chromatids is called a *tetrad* and the process of aligning is called ***synapsis***.

Once synapsis has taken place, the process of ***crossing over*** occurs. In this process, segments of DNA from one chromatid in the tetrad pass to another chromatid in the tetrad. Human chromatids will have about 50 areas of crossing over.

Crossing Over



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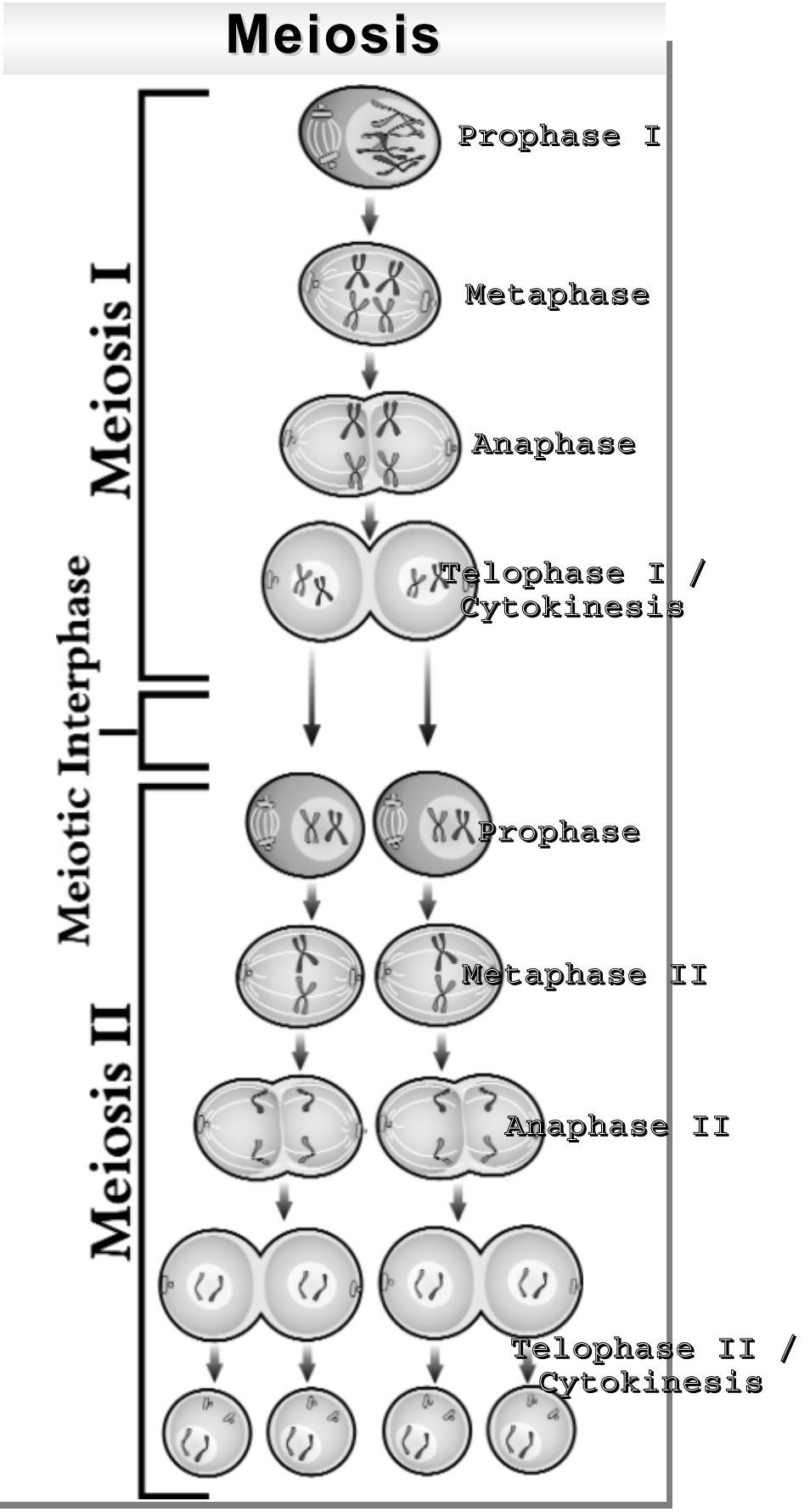
Crossing over mixes up the chromosomes obtained from the parents and produces a wide variety of combinations of gametes.

In *Metaphase I* of meiosis, the tetrads align on the spindle as in mitosis. The centromeres attach to the spindle fibers which extend from the poles of the cell.

In *Anaphase I*, the homologous chromosomes separate. One homologous chromosome (consisting of two chromatids attached by a centromere) moves to one side of the cell, while the other homologous chromosome (consisting of two chromatids attached by a centromere) moves to the other side of the cell. The result is that twenty-three chromosomes (each consisting of two chromatids attached by a centromere) move to one pole, and twenty-three chromosomes (each consisting of two chromatids attached by a centromere) move to the other pole.

In *mitosis*, the goal is to produce cells that are genetically identical to each another. During that process, the chromosomes divide at the centromere, which accomplishes the purpose of giving each cell a matching set of chromosomes, or 46 single-stranded chromosomes.

In *meiosis*, however, the goal is to produce cells that are



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genetically different from one another. During meiosis, the chromosomes do not divide at the centromere. Rather, the pairs of homologous chromosomes, which have been through the process of crossing over, simply separate. This pairing helps to accomplish the purpose of producing a wide variety of gene combinations.

Telophase I of mitosis and meiosis are essentially the same, except that each of the two new nuclei formed in mitosis has the same number of chromosomes as the parent nucleus: 46 single stranded chromosomes. Each of the nuclei formed in meiosis has half the chromosomes that were present in the parent cell: 23 double-stranded chromosomes. Please note that the number of chromatids (46) is identical for mitosis and meiosis. The difference is in the pairing during meiosis. Just as in mitosis, the telophase I occurs differently in plant and animal cells.

During meiotic interphase (between *Meiosis I* and *Meiosis II*), DNA does not duplicate. The interphase period may be very brief or very long, depending on the species of organism.

Meiosis II

The second division of meiosis, which follows interphase, occurs essentially the same way as in mitosis. In meiosis II, a cell containing forty-six chromatids will undergo division into two cells, each with 23 single-stranded chromosomes.

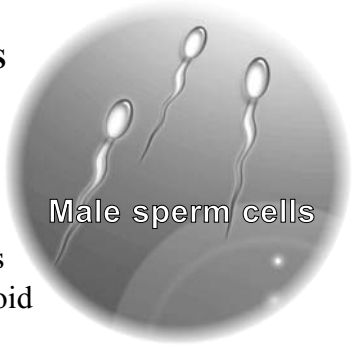
Prophase II is similar to the prophase of mitosis. The chromatin material condenses, and each chromosome contains two chromatids, attached by the centromere. The chromosomes do not synapse during this division of meiosis. The 23 chromatid pairs (a total of 46 chromatids) then move to the spindle. During *Metaphase II*, the spindle fibers attach to the chromatids near the centromeres to line up neatly across the center of the cell. During *Anaphase II*, the centromeres divide and the 46 chromatids separate from one another. Spindle fibers move one chromosome from each pair to one pole of the cell and the other member of the pair to the other pole. In all, twenty-three single-stranded chromosomes move to each pole. The forces that operate in mitosis also operate during this phase of meiosis. During *Telophase II*, the chromosomes gather at the poles of the cells and become indistinct. Once again, they form a mass of chromatin. The nuclear envelope develops, the nucleoli reappear, and the cells undergo cytokinesis as in mitosis.

Recall that resulting from meiosis I are two cells, each with 23 double-stranded chromosomes (46 chromatids). Therefore, two cells undergo meiosis II. The result is four cells, each with 23 single-stranded chromosomes. Each of the four cells is haploid.

Also recall that the 23 chromosomes in the four cells from meiosis are not identical. This is because crossing over has taken place in *Prophase I*. The purpose of crossing over is to yield genetically different cells. This variation in genes is what gives such diversity in nature. We will get a much better picture of genetic variation in the next chapter.

Meiosis in Humans

In humans, meiosis is the process by which sperm cells and egg cells are produced. In the male, meiosis takes place after puberty. Diploid



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cells within the testes undergo meiosis to produce haploid sperm cells with 23 chromosomes. A single diploid cell yields four haploid sperm cells through meiosis.

In females, meiosis begins during the fetal stage when a series of diploid cells enter *Meiosis I*. At the conclusion of *Meiosis I*, the process stops and the cells are stored in the ovaries. At puberty, meiosis resumes. One cell at the end of *Meiosis I* enters *Meiosis II* each month. The result of *Meiosis II* is a single egg cell per cycle. The other three are called "polar bodies" which simply disintegrate. Each egg cell contains 23 single-stranded chromosomes and is, therefore, also haploid.

The union of the egg cell and the sperm cell leads to the formation of a fertilized egg with a full complement of 46 single-stranded chromosomes, or 23 pairs. Fertilization restores the diploid number of chromosomes. The diploid fertilized egg is called a *zygote* and eventually, through mitosis, will yield a complete human being.

In the next lesson, we will study the ways in which the cell regulates its cycle and the cellular aging process.



WATCH VIDEO:
The Miracle of Life

LIFE PRINCIPLE

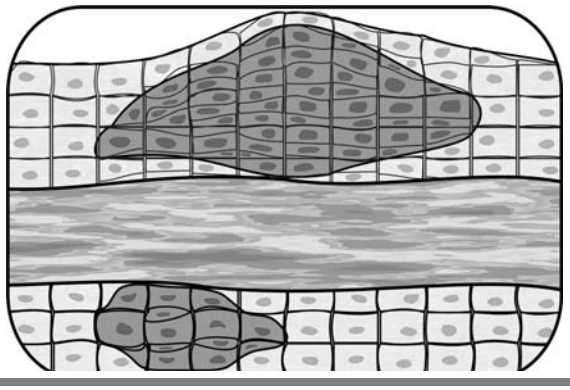


"Quality is never an accident; it is always the result of intelligent effort."

—John Ruskin (1819-1900)
British author and art critic

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Cycles

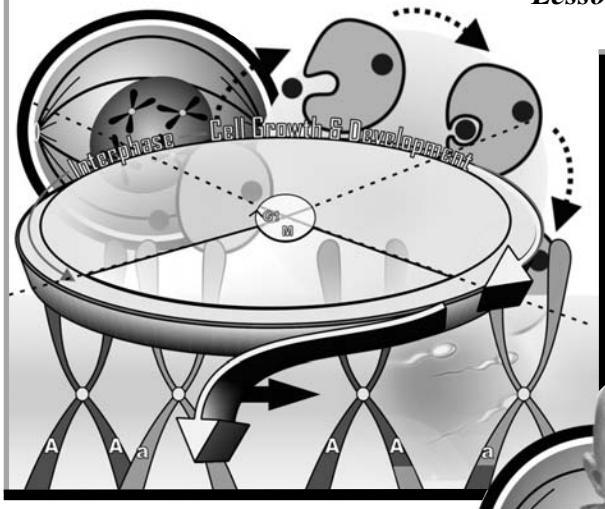
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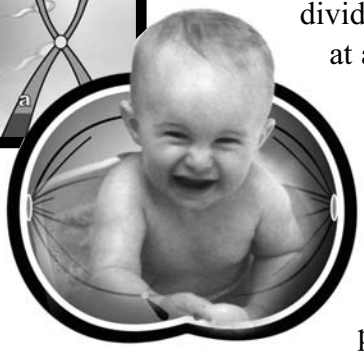
Chapter 2

CELL CYCLE AND THE AGING PROCESS

Section 3

Lessons 11-15





Cell Reproduction and Specialization

One of the most striking aspects of cell behavior in multicellular organisms such as human beings is how carefully cell division and cell growth are controlled. Cells in certain places of the body rarely divide—like brain and nerve cells—if at all. In contrast, cells of the skin and the digestive system divide rapidly and often throughout life, replacing cells that have broken down due to daily wear and tear.

Some cells are able to perform mitosis very quickly. Skin cells, for example, can complete mitosis in about ten minutes. This is important because your skin cells die at a very high rate. When you scratch your skin, you are actually destroying several hundred to several thousand skin cells, and those cells must be replaced quickly. Other cells take a much longer time to replenish. Bone cells are replaced very slowly, which is why a broken bone takes so long to heal.

Some cells do not divide at all. Brain cells grow in size over time to increase your thinking capacity. However, they cannot perform mitosis. Thus, if a brain cell dies, it cannot be replaced. This is one of the dangers of taking drugs such as alcohol, marijuana and cocaine which destroy brain cells. Because these cells cannot be replaced, brain damage is permanent.

Cell Cycle Regulation

The cell cycle in living organisms is controlled and regulated very carefully. One mistake in regulation may be

VOCABULARY

Cancer: a condition in which regulation of the cell cycle has been lost, resulting in an uncontrolled growth of cells

Proliferation: rapid growth or production

Cyclins: proteins which control cell division and regulate the timing of the cell cycle

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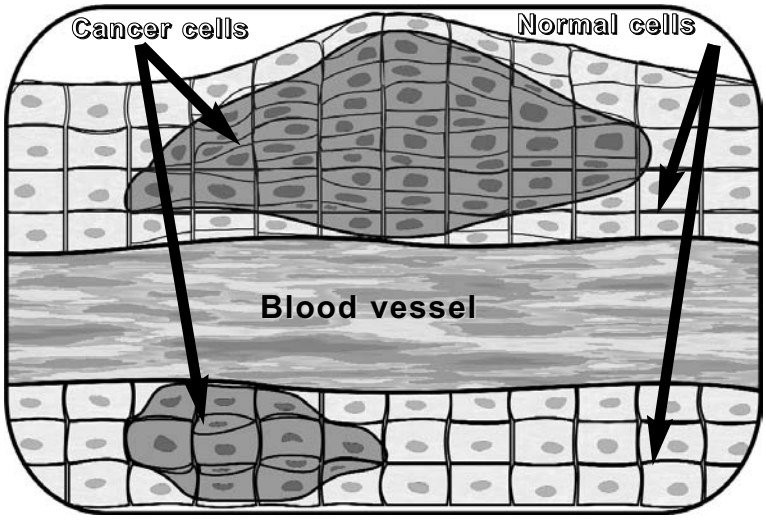
fatal. ***Cancer***, a disease in which some of the body's cells grow uncontrollably, causes thousands of deaths every year. The various types of cancer seem to have one thing in common. To one degree or another, cancer cells have lost their normal ability to regulate the cell cycle, which leads to a state of uncontrolled ***proliferation***. Cancer cells do not respond to the usual instructions that a cell receives. Very often, the reason they don't respond to the instructions is because of a defect in cell cycle regulation.

For years, biologists had wondered what controlled the cell's cycle and what determined when or if the cell would divide. Within the past few decades, however, scientists have discovered that a dividing cell contains a protein which causes a spindle to form if it is injected into a non-dividing egg cell. Scientists then discovered that the amount of this protein in the cell rose and fell in timing with the cell cycle. Scientists called this protein ***cyclin*** because of its effect on the cell cycle. Cyclins regulate the timing of the cell cycle in all eukaryotic cells that have been studied—from tiny yeast cells to human cells. Many kinds of cyclins occur, including those that regulate different phases of the cell cycle. For example, the cyclin that was first discovered is called *M-phase cyclin* because it regulates the entry of the cell into mitosis.

As a cell goes through the cell cycle, cyclin is made at a fairly constant rate and gradually builds up inside the cell. When the cyclin level reaches a critical point, it triggers the cell to enter mitosis. Then, remarkably, once the cell has entered mitosis, the cell destroys nearly all the cyclin. This means that the cell must manufacture new cyclin before it can enter mitosis again. The time required for a cell to make sufficient cyclin determines the length of time required for the cell to move through the cell cycle.

The duties of cyclins range from direct control of specific aspects of the cell cycle to reporting environmental conditions. In addition to initiating cell mitosis, the job of some cyclins is to delay or prevent cell divisions. Cyclins and interacting proteins seem to be the master proteins in regulating the cell cycle. Because of the important role of cyclin in cell growth and division, scientists are hopeful that more cyclin research will play an important role in the prevention of cancer.

Uncontrolled Cell Growth



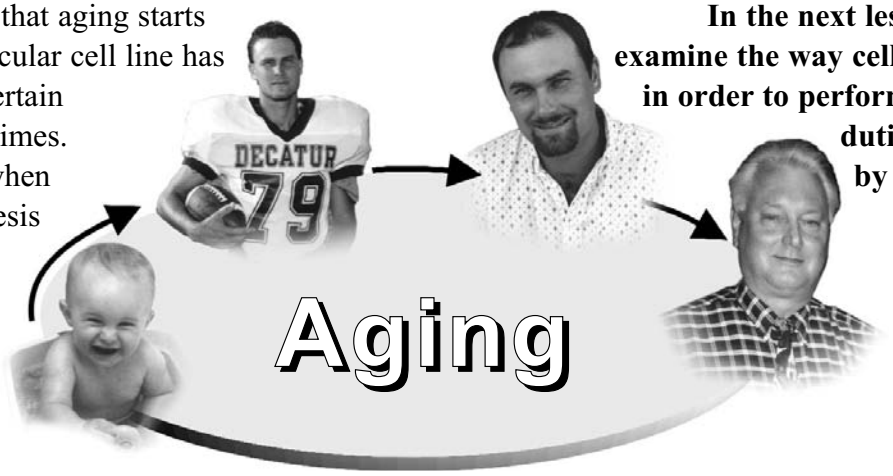
AGING

Aging is the sum of changes that accumulate with time and eventually bring the organism to death. It begins even before an organism completes development. Slower healing, for example, is one of the cellular signs of aging; even a human teenager's bones heal less rapidly than those of a younger child.

Aging and death seem to be genetically programmed. Species have

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characteristic life spans. An elephant dies of old age at about 200 years, a human at about 80 to 100 years and some insects at a few days or weeks. We do not know fully how aging occurs, but scientists have proposed at least 20 different theories. One suggestion is often made that aging starts after a particular cell line has divided a certain number of times. However, when this hypothesis has been tested in detail for any particular type, it has usually been disproved. When cells removed from the bodies of very old animals are kept in appropriate environments, they may live and divide without any signs of aging for generations beyond the animals' own time of death. This suggests that the environment of a cell can be a major factor in determining the rate of aging.



Searches for a single physical cause of aging have all ended in failure. Changes occur throughout the lifetime of an organism in many unrelated systems of the body (and mind, for humans) that eventually lead to death. All living things must eventually die.

In the next lesson, we will examine the way cells specialize in order to perform all the duties required by an organism.

Career Bound

Histologic technicians who prepare tissue samples for further study generally work in laboratories and hospitals.

Life Principle

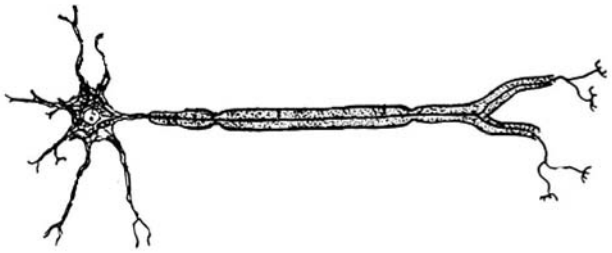


"Doing nothing for others is the undoing of one's self."

—Horace Mann, (1796-1859)
American educator

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Cells

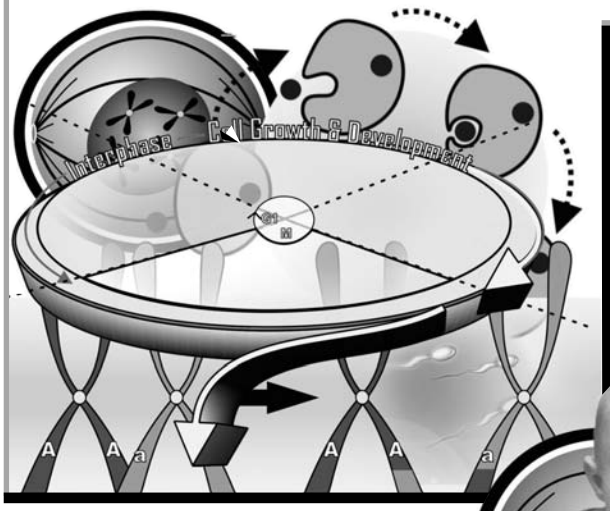
Lesson 15

Chapter 2

Section 3

Lessons 11-15

CELL ORDER



CELL REPRODUCTION, SPECIALIZATION & ORGANIZATION

Each of us began life at conception as the union of two haploid gametes—an egg and a sperm. By the time we were born, the union of those two cells had gone through millions of mitotic divisions. A multicellular organism, however, is much more than a large group of cells, in the same way that a society is much more than merely a large group of people. Just as society is made up of individuals, or groups of individuals, who have certain talents and specialties, so each cell, or group of cells in a multicellular organism, has a different specialty. These different specialties are what allows the organism to grow and to function.



VOCABULARY

Macrophage: an amoeba-like cell that moves through tissue fibers, engulfing bacteria and dead cells by phagocytosis

Phagocytosis: the process by which cells take in large substances by causing a part of the plasma membrane to surround the substance

Neurons: cells that carry impulses throughout the nervous system

CELL SPECIALIZATION

Cells in a multicellular organism tend to be specialized. *Cell specialization* means that specific cells are uniquely suited to carry out specific functions. Some cells may be designed to move, while other cells may specialize in responding differently to their environment. Still other cells may make products that the rest of the organism needs.

The cells of the body could be described in many different ways. Cells of the liver, the kidney and the intestines perform biochemical work in the body. Cells of the heart and other muscles do mechanical work. Cells of the nerve and brain control the body in both voluntary and involuntary ways. Some cells, such as the red cells of the blood and the keratin cells of the surface of the skin, consist almost entirely of one protein. In the case of red blood cells, the protein is

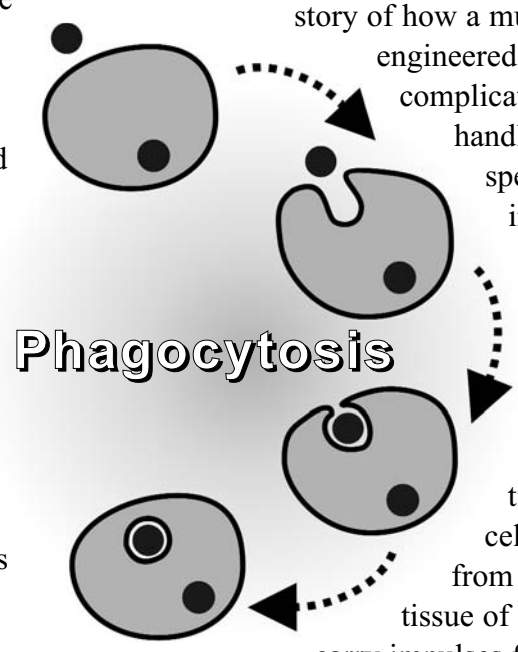
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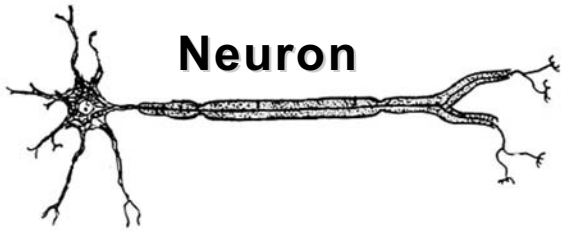
hemoglobin. In the case of skin cells, that protein is *keratin*. Other cells, such as those of the liver make a large number of different proteins, store carbohydrates and act as a general chemical factory.

Many hundreds of different types of cells comprise the human body. Let us examine just a few of the many "specialists".

Every large society needs law, order and protection. The trillions of cells in the "communities" of our bodies have similar needs, and one type of cell that provides this protection is the ***macrophage***. Macrophages travel throughout the body in the bloodstream, like National Guard troops that have been sent out to restore order in the wake of an emergency. At the site of a wound or an infection, macrophages appear in great numbers and begin to disarm the invaders—the bacteria and other foreign organisms. The cytoplasm of a macrophage is filled with specialized granules containing chemicals that attack the cell walls of bacteria. If these chemicals fail, the cell membrane of a macrophage may then surround the invader and completely engulf it. You may recall this process which is called ***phagocytosis***. Within a few minutes, the bacterium has been taken inside the macrophage and in a few hours it is completely destroyed.



Communication is important in any large group of individuals, and is just as important in a large group of cells. Without communication, one hand literally would not know what the other hand was doing. Nerve cells, or ***neurons***, transmit messages from the brain and spinal cord to all parts of the body. They are like electric cables, in that the live portion of the cable is on the inside, covered by an insulating sheath. However, nerves are much more complex than cables of domestic electricity which carry power to our households. Neurons carry messages by electrical impulses from one cell to another, relaying information to the muscle cells and controlling muscle activity. The impulses are all controlled and coordinated by the most complicated groups of cells in the human body—the human brain.



Levels of Organization

Cell specialization is only part of the story of how a multicellular organism is engineered. Many jobs are far too complicated for a single cell to handle on its own. Groups of specialized cells are necessary in many cases.

A tissue is a group of similar cells that perform similar functions. The two specialized cells that you have just read about are members of tissues. The macrophage cells that protect the body from infection are part of the tissue of blood. The nerve cells that carry impulses from one neuron to the next are part of the nervous tissue. *Epithelial*

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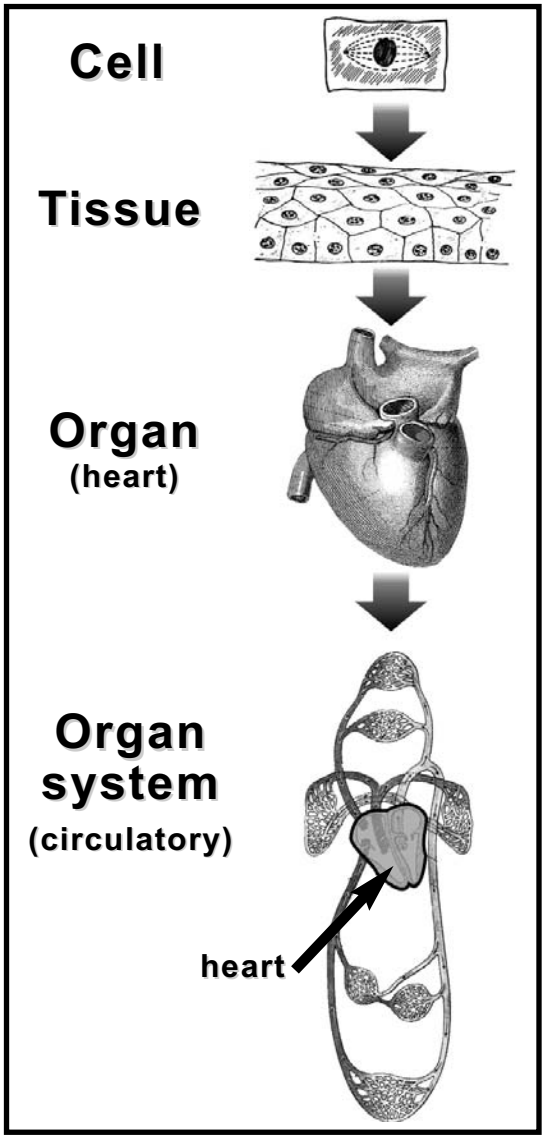
tissues are tissues of the skin and inner surfaces of the body such as the lungs, stomach and intestines. *Connective tissues* are those that support and hold parts of the body together. *Muscle tissues* are those which contract and relax within the body.

Some tasks are too complex to be carried out by just one type of tissue. Complex tasks require a specific *organ*, or a group of tissues, to work together. Each muscle in your body is an individual organ such as the kidneys, the lungs and the heart. Your eyes are very important organs. Organs contain many different tissues and cell types that work together to carry out essential tasks such as movement or vision.

Even a complex organ is not sufficient to carry out some series of specialized tasks. An *organ system*, or a group of organs, performs several closely related functions. For example, the organs of the digestive system all work together to digest the food that you eat. Eleven major organ systems operate in the human body, including the muscular system, the skeletal system, the nervous system, the digestive system and the circulatory system.

These four levels of organization—*cells*, *tissues*, *organs* and *organ systems*—are the same for nearly all multicellular organisms. The division of labor among the cells in these levels is one of the things that makes multicellular living possible. Specialized cells, such as nerve and muscle cells, are able to exist precisely because other cells are specialized to obtain the food and oxygen that these cells need. This overall specialization and interdependence is one of the remarkable characteristics of life.

In the next chapter, we will study the science of genetics.



LIFE PRINCIPLE

"Every part and tag of me is a miracle."

—Ralph Waldo Emerson, (1803-1882)
Prominent American author



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