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 6

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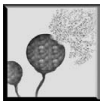
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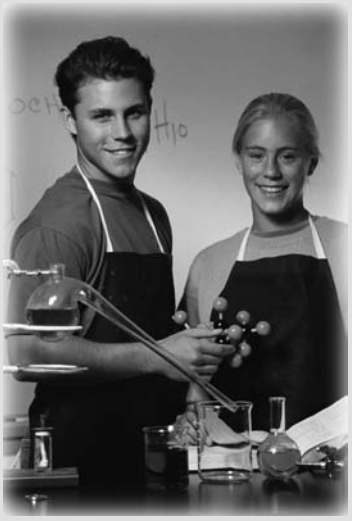
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"Biology is man's attempt to understand who he is, where he came from, why he is here, and where he is going."

—Ronald E. Johnson, C.Ph.D.



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Bacteria

Lesson 1

Chapter 6

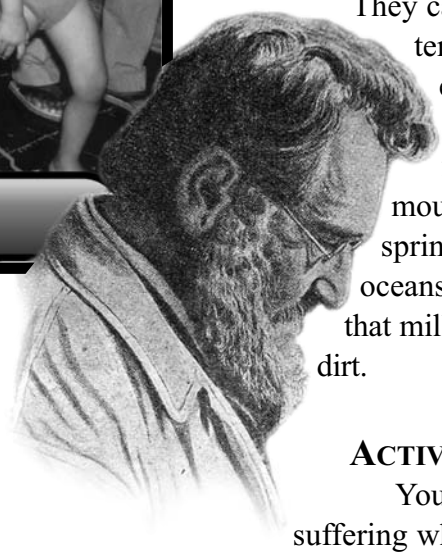
THE MYSTERIOUS WORLD OF BACTERIA

Section 1

Lessons 1-5



Bacteria are not well understood by biologists. Several facets of bacterial structure and function are still unknown. Some bacteria can survive in habitats that are deadly to other organisms. They can live on dust particles floating 20,000 feet above the surface of the earth. They can thrive and multiply in temperatures that are too extreme for any other organism. Bacteria are found everywhere—from mountaintops, to sulfur springs, to the depths of great oceans. Bacteria are so small that millions can exist in a pinch of dirt.



VOCABULARY

Pathogen: an organism that causes disease
Saprophyte: an organism that feeds on dead matter
Heterotroph: organism that relies on other organisms for food
Parasite: an organism that feeds on a living host
Autotrophoph: organism that uses energy from sunlight to change simple, non-living chemical nutrients in its environment into living tissue
Photosynthesis: process by which green plants and some bacteria use the energy of sunlight to produce carbohydrates

ACTIVITIES OF BACTERIA

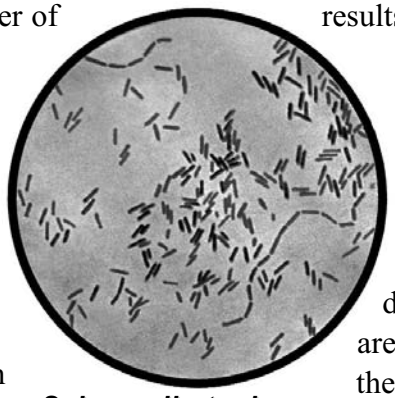
You may think of disease and suffering when you think of bacteria. Although bacteria called ***pathogens*** are responsible for numerous illnesses that plague humanity, many forms of bacteria exist that are beneficial to humans. Some species of bacteria live on the roots of legume plants and help assimilate nitrogen from the air to make it available to the plant. The plants then use nitrogen to make amino acids and proteins, providing them to animals which consume plants. Other bacteria are responsible for decay that occurs in landfills and other debris in the environment. These bacteria recycle essential elements in organic matter.

Billions of bacteria live in your own digestive system, helping you to digest and assimilate your food daily. Those bacteria in your digestive system help synthesize B vitamins and vitamin K, which your body needs to stay healthy. Other beneficial bacteria help us make cheese, sauerkraut, vinegar,

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butter, yogurt and buttermilk. In other industries, bacteria are used to produce antibiotics, chemicals, dyes, numerous vitamins and enzymes and a number of insecticides.

Unfortunately, many bacteria are *pathogenic*, meaning they cause disease. Diseases such as tuberculosis, gonorrhea, syphilis, scarlet fever, food poisoning, Lyme disease, plague, tetanus, typhoid fever and most pneumonias are due to bacteria. In conditions such as food poisoning and tetanus, the bacteria produce powerful toxins that interfere with normal body functions. In persons affected by tuberculosis and typhoid fever, bacteria grow aggressively in the tissues of the victim. The tissue is thereby destroyed and disease results.



Salmonella typhosus: **the bacteria that causes typhoid fever**

VOCABULARY

Chemosynthesis: the process by which bacteria use the energy of chemical reactions to produce food

Respiration: the process by which food is converted into useable energy for life functions

Aerobic respiration: respiration that requires oxygen

Anaerobic respiration: respiration that does not require oxygen

Gram staining: process by which bacteria are classified based on the characteristic staining of their cell walls

Cocci (singular, coccus): spherical bacteria

Bacilli (singular, bacillus): rod-shaped bacteria

Spirilla (singular, spirillum): spiral-shaped bacteria

Flagella (singular, flagellum): whiplike projections found on some cells; typically used for movement

METABOLISM OF BACTERIA

The vast majority of bacteria are decomposers. Since decomposers rely on dead organisms for food they are called ***saprophytes***; however, they can also be classified as ***heterotrophs***. Saprophytic bacteria are an integral part of nearly every aspect of nature. Since bacteria decompose dead organisms, the materials necessary for life are recycled back into nature so that they can be used to make new, living things. Without decomposers, all life-giving material would end up in the dead bodies of just a few generations.

Not all heterotrophic bacteria are saprophytic. Some bacteria are ***parasites*** from which diseases occur. Most parasitic bacteria lack the ability to digest nutrients, so they need to absorb nutrients that have already been digested. In addition, they often lack the ability to manufacture the complex chemicals necessary to sustain life, so they often must absorb these chemicals from their hosts.

Even though most bacteria are heterotrophic, many forms of ***autotrophic*** bacteria exist as well. In general, two different means exist by which autotrophic bacteria manufacture their own food: ***photosynthesis*** and ***chemosynthesis***. As you learned in a previous lesson, photosynthesis uses the energy from sunlight, along with certain chemicals, to make food for autotrophic organisms. In green plants, the

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byproduct of photosynthesis is oxygen. However, the photosynthesis that occurs in some bacteria does not produce oxygen as a byproduct, although other byproducts of their photosynthesis are quite useful to some organisms.

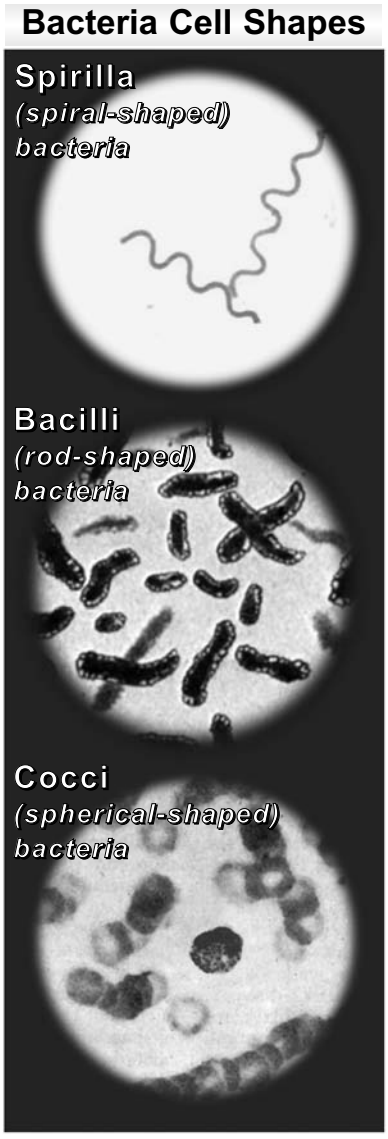
Chemosynthetic bacteria use a different process for manufacturing their food. The main difference between that process and photosynthesis is the source of energy. In chemosynthesis, the bacteria use energy from chemical reactions.

Once a bacterium or any living organism has food, some process must exist by which that food can be converted into energy to be used in the support of life. This part of the metabolic process is called ***respiration***. You have learned about respiration in a previous lesson. In human beings, we usually think of respiration as breathing; but breathing is only one stop in a long process that converts food into useful energy.

Two types of respiration exist in nature: aerobic and anaerobic. ***Aerobic respiration*** requires oxygen; ***anaerobic respiration*** does not require oxygen. Aerobic respiration is by far the most common form of respiration, which is why the Earth must have a plentiful supply of oxygen in order to support life.

Characteristics of Bacteria

Bacteria are *prokaryotes*—cells without nuclei—having no distinct, membrane-bound organelles. Bacteria have a relatively simple structure. Genetic information in bacterial cells is found on a single, circular DNA molecule (a chromosome) found in the cytoplasm. The cytoplasm is surrounded by a cell membrane made of lipids and proteins.



Bacterial Cell Walls

In most cases, a bacterium has a cell wall that surrounds the cell membrane and is composed of complex carbohydrates. The cell wall protects the bacterium from injury and helps to regulate the movement of molecules into and out of the cell.

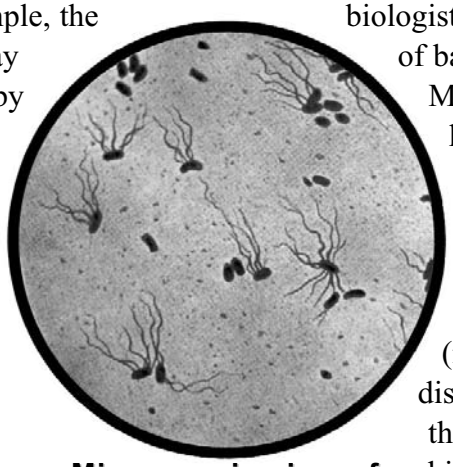
A bacterium is often identified according to its type of cell wall. Biologists determine the type of a cell wall by using a technique known as ***Gram staining***, named after its inventor, Hans Christian Gram, a Danish physician. Bacteria that absorb Gram's purple stain are known to be "gram-positive". Those that do not absorb the stain are called "gram-negative". Gram-negative bacteria each have an extra lipid layer around their cell walls. This layer helps the bacteria keep out the stain, as well as many drugs used to fight bacterial infections. For this reason, many gram-negative bacteria infections are very serious.

Usually, a bacterium with a cell wall will also have a capsule that surrounds the

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cell wall. This capsule is usually made up of a sticky substance which helps the bacterium adhere to surfaces. For example, the bacteria that cause tooth decay are able to cling to the teeth by using their sticky capsules.



Microscopic view of bacteria showing *flagella*

Cell Shape

Most bacteria can be divided into three groups according to their shapes. The spherical bacteria are referred to as ***cocci***; the rod-shaped bacteria are called ***bacilli***; and spiral bacteria are called ***spirilla***.

Cell Movement

Bacteria may also be described by how they move. Only a very small number of bacteria have no means of movement. Most can move, and some can move very quickly. Some can change their shapes to wriggle forward—almost like snakes—and others glide slowly along the surfaces of solid objects. Many bacteria have whiplike ***flagella*** that propel them through liquids with great speed.

Classifying Bacteria

Biologists have struggled for years to find the best way to classify different types of bacteria. Many bacteria look similar, but are actually very different in other respects, and no simple way exists to determine which characteristics are the most important. From textbook to textbook, opinions will vary.

In recent years, scientists have discovered how to determine the DNA sequences of bacteria. By this means, scientists have also learned how to determine which bacteria are more alike. The DNA sequencing techniques have led many biologists to agree to split the kingdom of bacteria (once called Kingdom Monera) into two separate kingdoms: *Archaebacteria* and *Eubacteria*.

Archaebacteria

The *Archaebacteria* (meaning "ancient bacteria") display striking differences in their cell membranes, biochemical pathways and ribosomes. This group includes organisms that live in very harsh environments and are generally anaerobic. Typically, they are found in areas devoid of oxygen, such as in deep lakes and oceans, in the mud at the bottom of swamps or in the digestive tracts of animals. These bacteria are essential to life because they either decompose dead organisms or convert unuseable chemicals into useable forms that can be utilized by other organisims.

Eubacteria

Eubacteria (meaning "true bacteria") are the largest and most diverse group of bacteria. They are found everywhere on Earth. These bacteria require oxygen for respiration.

Before you leave this lesson, stop a moment to think about what you have learned. Bacteria have many different shapes, forms and metabolisms. All of them, however, in some way, promote life on earth. Without the *saprophytic bacteria*, the chemicals necessary for life would not be recycled from the dead organisms to live ones. As a result, in just a few generations, life could not exist on this planet. Without

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certain parasitic bacteria, many forms of life would not be able to digest their food. *Photosynthetic bacteria* produce certain useful chemicals that no other process on Earth can produce. Chemosynthetic bacteria are able to convert chemicals that are useless to living organisms into substances which are essential for life. Even *pathogenic bacteria* have a role in supporting life. Often, a group of organisms gets too large and could destroy the balance of nature. Typically, disease caused by pathogenic bacteria will kill off a large number of the organisms, making sure that the balance of nature remains intact.

These kinds of processes need to occur everywhere on Earth. For example, when organisms die in a swamp they usually sink to the bottom of the swamp and are slowly engulfed by the muck at the bottom. If no anaerobic decomposing bacteria existed in that muck, then chemicals in the dead organisms would never be recycled back into nature. The diverse types of bacteria are everywhere in our world, each performing its own designated, important task.

In the next lesson, we will examine reproduction in bacteria.

WATCH VIDEO: Bacteria

LIFE PRINCIPLE

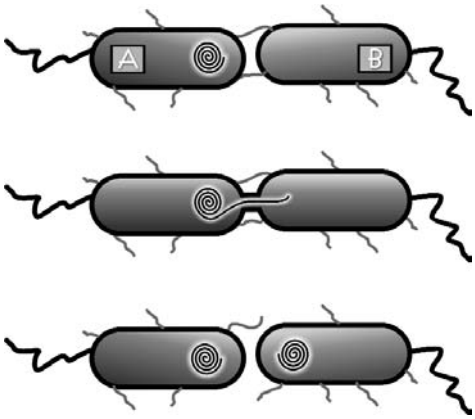


"Controversy is only dreaded by the advocates of error.""

—Benjamin Rush (1745-1813)
Medical doctor and signer of the Declaration of Independence

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Bacteria

Lesson 2

Chapter 6

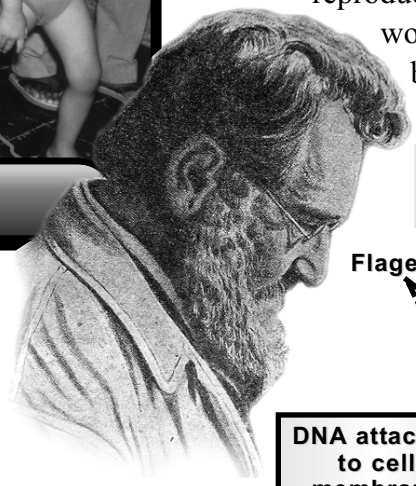
BACTERIA: REPRODUCTION MECHANISMS AND COLONIZATION

Section 1

Lessons 1-5



Under proper conditions, bacteria can grow at astonishing rates. Some can reproduce themselves in as little as 20 minutes. This means that in the course of a single day, one cell can go through 72 generations—or 3 generations every hour. A single cell reproducing that quickly for a full day would give rise to more than 4 billion cells!

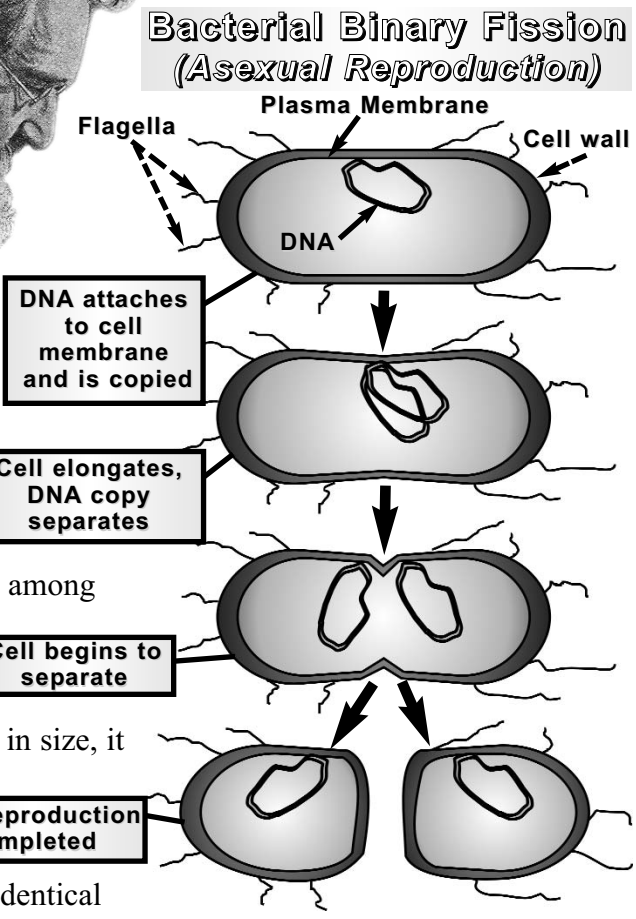


VOCABULARY

Binary fission: asexual form of reproduction in which a cell divides in half to produce two identical daughter cells
Steady state: a state in which members of a population die as quickly as new members are born
Conjugation: form of sexual reproduction that results in new combinations of genes
Plasmid: small, circular DNA molecule in some bacteria that can be used in cell reproduction
Transformation: process of reproduction in which genetic material is added to, or replaces, portions of a bacterium's DNA

ASEXUAL REPRODUCTION

Asexual reproduction is the most common form of reproduction among bacteria. When a bacterium has grown to the point where it has doubled in size, it replicates its chromosomes and divides in half, producing two identical daughter cells. This is known as ***binary fission***. Because binary fission does not involve



During asexual reproduction, a bacterium copies its DNA and the cell divides into two identical cells, all in a matter of minutes.

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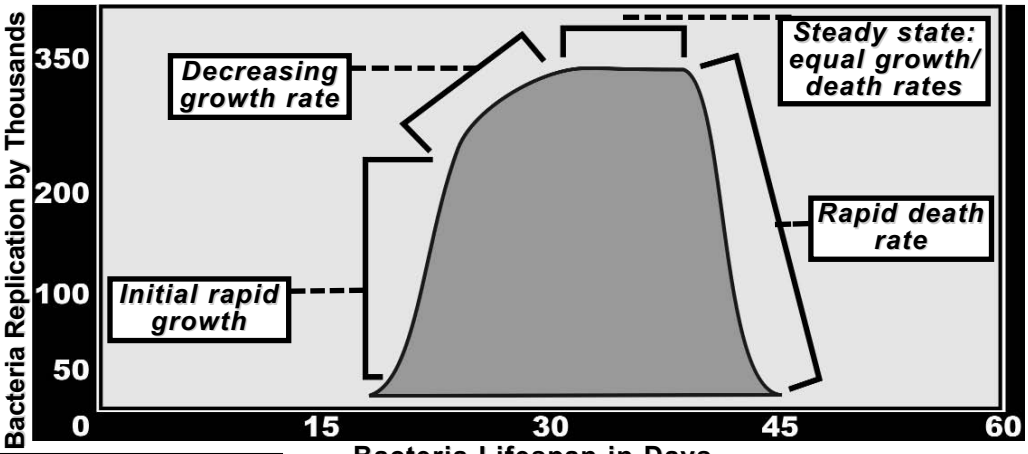
the exchange of genetic information, it is an asexual form of reproduction.

As you can see from the illustration, reproduction begins when the DNA forms a loop attached to the plasma membrane. The DNA then copies itself in order to give the same genetic information to the next generation. Once this is accomplished, the copy attaches to the plasma membrane close to the original. The cell wall and plasma membrane then elongate, separating the copy from the original. Once they are separated, the cell wall and plasma membrane begin to grow in between the two strands of DNA, eventually closing off one organism from the other. At that point, two bacteria exist. Asexual reproduction usually results in offspring that are identical to the parents, since each has the identical DNA. However, if a mistake were made while the DNA was being copied, then a marked difference between the offspring and the parent would result. This is called a *mutation* as we have studied in previous lessons.

As we read in the first paragraph of this lesson, the speed with which bacteria reproduce is quite amazing. Scientists have estimated that if all bacteria were allowed to grow unrestrained, for even a week at the rate we discussed, the total number of bacteria would have a combined weight that is greater than the entire planet! Thankfully, this does not happen. Several factors are at work to counteract bacterial overgrowth.

For example, when a saprophytic bacterium finds a dead cow, the bacterium begins to feed on that cow and immediately begins to reproduce. In just a day or so, billions and billions of these bacteria are produced. They begin to spread out across the remains of the cow. Soon they have access to the entire animal. Then, some bacteria are cut off from their food supply and die, thereby decreasing the population of the bacteria. Some bacteria try to eat other bacteria which further decreases the bacterial population. While this is happening, bacteria are still reproducing. Therefore, some are dying and some reproducing. For a while, the bacterial population maintains a point at which the number of new bacteria equals the number of bacteria that are dying. This is called the ***steady state*** of a population.

After a while, the bacteria consume the entire cow. The bacteria then begin to



VOCABULARY

Spores: small, typically single-celled structure capable of producing a new individual, either immediately or after a period of dormancy
Endospore: type of asexual spore formed inside a bacterial cell that develops a thick wall enclosing part of the cytoplasm and DNA; enables the bacteria to prolong life
Encapsulate: to enclose material in a kind of capsule

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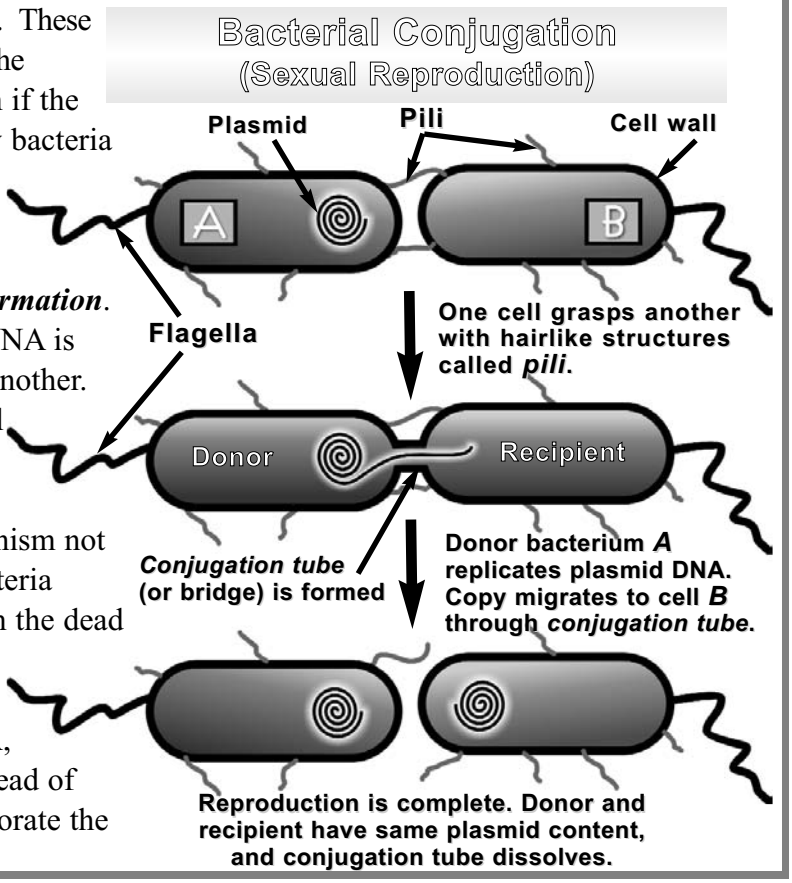
starve to death, increasing the incidence of bacteria eating bacteria. Thus, the population of bacteria dwindles, along with the remains of the dead cow. Eventually, all bacteria at the site die. This is illustrated in the accompanying graph.

Sexual Reproduction

A few bacteria are able to reproduce by ***conjugation***. During conjugation, a bridge of protein called a *conjugation tube* forms between two bacteria, allowing some DNA to be transferred from one cell to another and a small, circular copy of DNA called a ***plasmid*** is transferred. When the conjugation process is over, the connection between the cells is broken. As a result of conjugation, some bacterial cells receive new genetic information and have different sets of genes. Biologists consider conjugation to be a form of sexual reproduction because it results in new combinations of genes. These new combinations may be useful to the bacteria. They help ensure that even if the environment changes, at least a few bacteria will have the combinations of genes needed to survive.

Another method by which bacteria reproduce is called ***transformation***. Transformation takes place when DNA is transferred from one bacterium to another. When a bacterium dies, its cell wall falls apart and the components of the cell (including the DNA) flow into the surroundings. By a mechanism not understood by scientists, living bacteria seem to "sense" that this DNA from the dead bacterium contains traits that the living ones could use. The living bacteria then absorb the loose DNA, as if ingesting food. However, instead of using it as food, the bacteria incorporate the new DNA into their own DNA. Transformation is considered a reproductive mechanism because traits have been passed from one bacterium to another.

The last mechanism of reproduction is really more of a survival technique for bacteria. When faced with difficult conditions, many bacteria are designed to form tough structures called ***spores***. One type of spore, called an ***endospore***, is formed inside a bacterial cell. The endospore develops a thick wall that encloses part of the cytoplasm and a DNA molecule. Endospores are resistant to heat, drying, radiation, and even to chemical disinfectants. The endospores of some bacteria can survive for years in a state of suspended animation; then, when conditions are right, bacteria can become activated and begin to grow. Endospores enable bacteria to survive harsh conditions that might otherwise kill them. Such defense



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mechanisms make the complete elimination of bacteria difficult.

COLONIZATION

Although the discussion has been limited to bacteria as individuals, many bacteria exist in colonies. In a bacterial colony, the individual organisms group together, but they still live as individuals. Since strength exists in numbers, the bacterium's ability to survive is usually enhanced as a member of a colony.

Some colonies secrete a substance that ***encapsulates***, or surrounds and protects, the entire colony. This substance gives the bacterial colony a slimy feel and holds it together. Bacterial colonies encapsulated in this manner often look like bluish-green mats floating on top of certain bodies of water. Stagnant ponds are common places to find such colonies. Other bacterial colonies work together to capture and eat their prey. For example, a *Myxococcus xanthus* colony moves as a unit in search of prey which is, typically, other bacterial colonies. When a prey is found, it is engulfed. The agressor group then secretes a substance that digests the prey. The entire colony proceeds to "share the spoils" and feeds on the nutrients.

In the next lesson, we will examine in more detail the activities and roles that bacteria play in our lives.

LIFE PRINCIPLE



"When we try to pick out anything in the universe, we find it is tied to everything else in the universe."

—John Muir (1838-1914)
American naturalist and explorer

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Bacteria

Lesson 3

Chapter 6

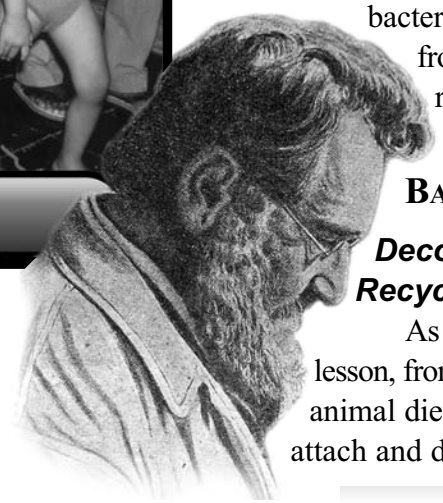
BACTERIA: THE ROLES THEY PLAY

Section 1

Lessons 1-5



Careful estimates of the numbers of bacteria in the soil, the ocean and deep within the earth suggest that the mass of living bacteria is greater than that of all other organisms combined! Given their tremendous population, we would expect bacteria to play many roles in nature. As we have seen, bacteria do a little of everything, from photosynthesis to recycling nutrients.

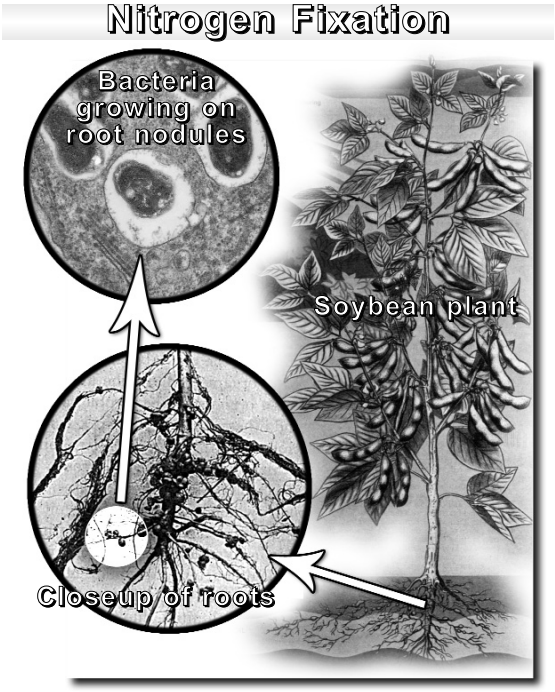


BACTERIA AND ECOLOGY

Decomposers and Recyclers

As we discussed in the previous lesson, from the moment a plant or animal dies, thousands of bacteria attach and digest the dead tissues, breaking them down for nourishment and energy. As these armies of bacteria do their work, the body tissues of the organism gradually fall apart and crumble into the soil. The raw materials are returned to the earth, and the cycle of life can begin again. Although the bacteria are

Roots of plants contain large amounts of bacteria designed to convert nitrogen into forms plants can use.



VOCABULARY

Copper Ore: rock bearing the element, copper
Metallurgist: a specialist in the science and technology of metals
Antibiotic: powerful drug which kills certain bacteria by interfering with critical cell processes
Probiotics: the "friendly" bacteria found inside the digestive system of many organisms

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not the only organisms involved in this process, they are certainly one of the most significant.

Fertilizers

Nearly all organisms require a supply of nitrogen in order to survive. Although the Earth's atmosphere contains plenty of nitrogen gas, plants and other organisms cannot use nitrogen gas directly. Fortunately, many bacteria can carry out a process called *nitrogen fixation*, in which nitrogen gas is converted to a chemical form that plants can use. In this way, bacteria manufacture a natural fertilizer.

INDUSTRIAL USES

Bacteria have been used for industrial purposes for many thousands of years. As you might expect, humans have made use of the very things that bacteria do best—the breaking down of material for nourishment.

Food Processing

Bacteria are used to prepare a wide variety of foods. Some cheeses, sour cream, buttermilk and yogurt are made by allowing certain types of bacteria to be grown in milk products. Other forms of bacteria are used to make pickles, sauerkraut and vinegar.

Sewage Treatment

Sewage water contains human wastes, discarded foods and various chemical wastes. Certain types of bacteria can break down each of these materials naturally. Tons of bacteria are added to sewage at water treatment plants. As the bacteria grow, they break down waste compounds into simpler materials. Carefully administered, bacterial sewage treatment produces purified water, plus nitrogen and carbon dioxide, leaving a sludge that can be used as crop fertilizer.

Mining

Bacteria also play a role in the mining industry. Most of the ***copper ore*** in the United States is a relatively low grade, which means it contains only a small amount of copper. Extracting copper would be a difficult job without a little bacterial friend named *Thiobacillus ferroxidans*.



Louis Pasteur

This bacterium grows naturally in copper-containing ore, producing sulfuric acid which reacts with copper to form copper sulfate. Copper sulfate is water soluble, so ***metallurgists*** simply allow this bacterium to grow in the ore, then the copper sulfate is washed out as it forms. Later, metallurgists retrieve the copper from the copper sulfate solution.

Interior of sewage/ water treatment facility



Sewage waste

BACTERIA AND HEALTH

French chemist and bacteriologist Louis Pasteur was the first person to show, convincingly, that certain bacteria cause disease. Pasteur established what has come to be known as the *germ theory of disease* when he showed that bacteria were responsible for a number of animal and plant diseases.

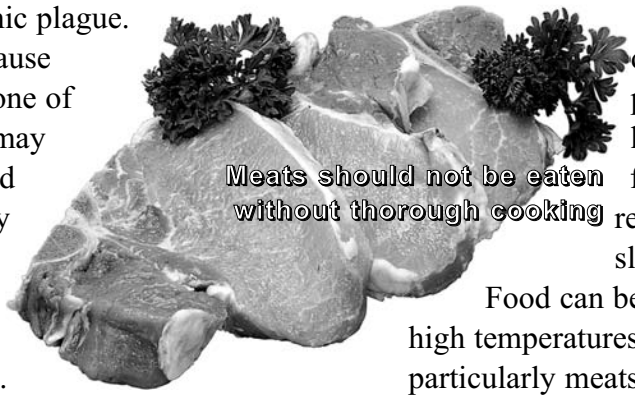
You may have encountered one of the most widespread, disease-causing bacteria called *Streptococcus*

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pyrogenes, responsible for the severe sore throat condition called "strep throat". Other diseases caused by bacteria include diphtheria, tuberculosis, typhoid fever, tetanus, syphilis, gonorrhea, cholera, Lyme disease and bubonic plague.

Bacteria cause these diseases in one of two ways. They may attack the cells and tissues of the body directly, breaking them down and using their materials for food. Or, they may release toxins that travel throughout the body, interfering with normal body functions.


Meats should not be eaten without thorough cooking

For example, *Salmonella* is a bacterium that grows in foods such as meat and poultry, and on eggs. If these foods are not properly handled and cooked, *Salmonella* may get to the dinner table before you do, releasing poisons into the food. The symptoms of food poisoning range from a mild stomach upset to severe pain, vomiting and diarrhea.

An effective way to combat bacterial infections is by the use of ***antibiotics***. Antibiotics are drugs which are powerful weapons that can kill bacteria by interfering with cell processes. For example, penicillin interferes with the cell wall synthesis. If cell walls cannot be formed, the bacteria die one by one because they cannot complete the process of division that produces new daughter cells.

Although most bacteria are not harmful, researchers and scientists try to learn how to control the growth of bacteria in certain situations. Sterilization—the killing of bacteria with heat or chemicals—is the simplest way to control the majority of bacteria. Most bacteria cannot survive high temperatures, so hospital instruments are sterilized with high-pressure steam. A hospital room is sterilized by the use of disinfectants which are chemicals that kill bacteria.

The control of dangerous bacteria is of particular importance while handling and processing food. Low temperatures in refrigerators or freezers can slow the growth of bacteria. Food can be sterilized by cooking it at high temperatures, and many foods—particularly meats—should not be eaten without thorough cooking to kill harmful bacteria. Pork is particularly susceptible to bacterial and parasitic growth. Experiments with pork reveal that bacteria can survive in pork that is cooked at 600ºF for several hours.

One of the most exciting new areas of bacterial research is in the field of ***probiotics***—the friendly bacteria that inhabit your digestive system. Billions of these organisms live in your intestinal track and are responsible for many healthy benefits. These bacteria help to produce vitamins and also assist in digesting your food.

In the next lesson, we will examine the role of these very important organisms—probiotics—in your body.

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LIFE PRINCIPLE



". . .the only form of life we have created so far is purely destructive."

—Stephen W. Hawking
Noted British physicist (speaking of computer viruses)

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Bacteria

Lesson 4

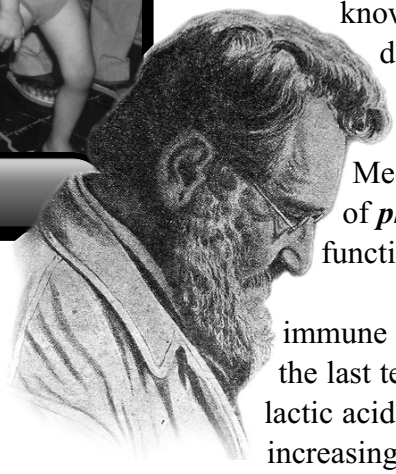
Chapter 6

BACTERIA: PROBIOTICS, YOUR PERSONAL PHARMACY

Section 1

Lessons 1-5





The health benefits of friendly bacteria, called *probiotics* (meaning "for life"), first came to the attention of the general public in 1908 when Dr. Elie Metchnikoff, a Russian biologist, wrote *The Prolongation of Life*. This book recognized that certain white blood cells, known as *phagocytes*, ingest and destroy dangerous bacteria. Dr. Metchnikoff shared the 1908 Nobel Prize in Physiology and Medicine for identifying the process of ***phagocytosis***, an important function of the immune system.

Concurrent with this work on the immune system, Dr. Metchnikoff devoted the last ten years of his life to the study of lactic acid-producing bacteria as a means of increasing life span. After much research, he was convinced that he had discovered why so many Bulgarians lived noticeably longer than most other people. He believed this phenomenon was due to their consumption of large quantities of cultured foods, especially yogurt, which he believed helped to maintain the friendly bacteria that live in the gastrointestinal tract.

Today, researchers have learned that these friendly bacteria are responsible for a number of important body functions.

VOCABULARY

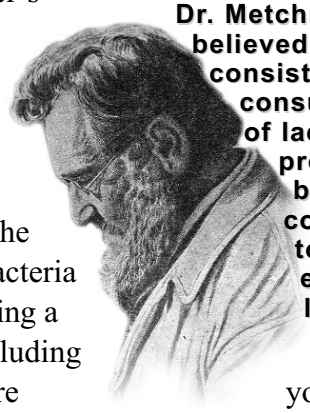
Phagocytosis: the process by which white blood cells engulf and destroy bacteria
Mother's milk: produced by mammory glands in female humans and mammals for nourishment of their young
Exacerbate: to make a condition worse
Autointoxication: an abnormal state of body poisoning stemming from the intestines
Bioprospector: scientist who searches nature for compounds or organisms that fight disease or assist with everyday jobs

PROBIOTICS AND GENERAL HEALTH

As a baby is born and passes through the birth canal, the baby's body makes contact with a host of beneficial bacterial microorganisms. These beneficial bacteria, which are absolutely essential to proper human function, enter the body through the mouth as the baby passes through the birth canal. From the mouth, bacteria rapidly make their way into the intestinal tract where they establish themselves in large

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colonies. Additionally, ***mother's milk*** contains just the right ingredients to nourish these friendly bacteria once they become established in the intestines. On the other hand, babies delivered by caesarean section, and not allowed to nurse on mother's milk, are more susceptible to disease and allergies than are babies born through the birth canal and allowed to nurse immediately after birth.



Dr. Metchnikoff believed that consistent consumption of lactic acid-producing bacteria contributed to an extended lifespan

Once established through the birth and nursing processes, the bacteria go to work performing or stimulating a number of important functions, including enhancing the function of the entire gastrointestinal tract, protecting the body against pathogenic or otherwise harmful foreign invaders, maintaining the vital chemical balance of the entire gastrointestinal system, producing needed vitamins and hormones and regulating their levels. Beneficial bacteria also compete with undesirable organisms for nutrients, thereby helping to keep their spread in check, as well as perform a large array of other essential tasks necessary to achieve and maintain proper human growth, function and immune response. Researchers have discovered the existence of more than 400 different species of microorganisms, consisting of approximately two to four pounds of body weight, living in the human digestive system.

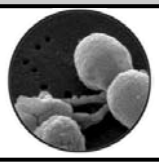
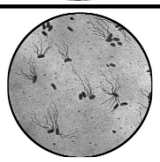
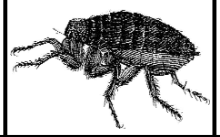
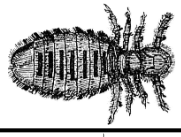
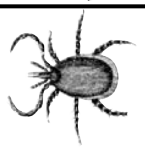
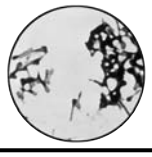
These beneficial microorganisms inhabiting the intestines play a vital role in keeping the body healthy and strong. Nonetheless, they live a precarious existence. Their balance in the body can be completely disrupted by such common things as a diet that is high in sugar, or one that is low in natural fermented milk products like yogurt, cottage cheese, whey and buttermilk. Excessive alcohol intake, as well as drinking contaminated or chemically treated water, can also disrupt the body's balance of much-needed microbes. Also dangerous to this important microbial balance are radiation therapy and the use of non-steroidal anti-inflammatory drugs. Prescription antibiotics can wipe out virtually every beneficial microorganism in the body. The antibiotics cannot distinguish between harmful bacteria and beneficial bacteria. They kill virtually all bacteria, producing a condition commonly referred to as "sterile gut." Unfortunately, once the beneficial microorganisms are wiped out, harmful microorganisms can establish large colonies in the intestines and contribute to a number of ill-health conditions.

Healthy individuals usually have a balance of about 85 percent good to 15 percent harmful organisms in the intestinal tract. Scientists estimate that today many Americans have the opposite ratio, creating a chronically unhealthy condition. Nutritional researchers are convinced that as much as 90 percent of known diseases may be caused or ***exacerbated*** by these gastrointestinal

VOCABULARY

Intestinal flora: the microorganisms inhabiting the intestinal tract
Scour: to search for something rapidly, but with great attention to detail
Dysentary: a condition of severe diarrhea, accompanied by passage of blood and mucus; usually caused by infection

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Disease	Bacteria Involved	Bacteria, Carrier or Symptom	Symptoms/ Comments	Mode of Transmission
Pneumonia	Pneumococcus		Inflamed, infected, weakened lungs, persistent cough; can be fatal	Airborne water droplets
Tuberculosis	Tubercle bacillus		Fatigue, persistent cough, bleeding in lungs; can be fatal	Airborne water droplets
Cholera	Vibrio cholerae		Severe vomiting, diarrhea; often fatal	Contaminated water
Typhoid fever	Samonella typhi or typhosa		Fever, headaches, rash, diarrhea; often fatal	Contaminated food or water
Bubonic plague	Pasteurella pestis or yersinia (from infected rats)		Swollen glands, bleeding under skin; often fatal; killed nearly one third the population of Europe in the mid 1300's	Flea bites
Typhus	Rickettsia prowazekii		Chills, fever, rash; can be fatal	Lice bites (especially from body lice)
Lyme disease	Borrelia burgdorferi (from infected animals)		Often a large "bull's eye" rash, pain, swelling in joints	Tick bites, embedding
Syphilis	Treponema pallidum		Lesions, damages Central Nervous System if left untreated	Sexual contact
Tetanus	Clostridium tetani		Severe, prolonged muscle spasm; "lock-jaw"	Wounds, broken skin
Leprosy	Mycobacterium leprae		Skin lesions, tissue degeneration, nerve damage	Personal contact

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imbalances. When toxins are dispersed through the bloodstream, poisoning may occur by harmful intestinal bacteria. As far back as 1928, Dr. H.H. Booker remarked:

> *It is now universally conceded that **autointoxication** is the underlying cause of an exceptionally large group of symptom complexes.*

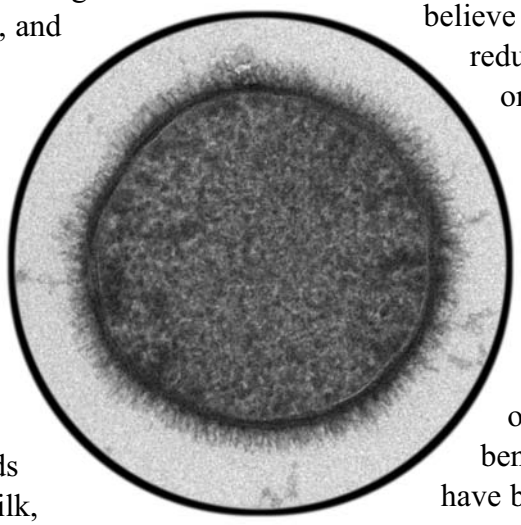
Generally, this imbalance of bacteria will contribute to or manifest as one or more of the following: fatigue, nervousness, gastrointestinal upset, impaired nutrition, skin problems, hormonal problems, circulatory problems, headaches, arthritis, low back pain, allergy, asthma, heart irregularities, appendicitis, diverticulitis, irritable bowel syndrome, ulcerative colitis, Crohn's disease, diabetes, psoriasis, high blood pressure, high cholesterol, obesity, pathological changes in the breasts, and/or eye, ear, nose, and throat diseases.

Medical researchers are developing ways of introducing friendly bacteria into the body in order to re-establish the proper balance. If caused by an imbalance of the natural ***intestinal flora***, adverse health conditions can often be reversed or prevented by simply supplementing the diet with foods such as cultured yogurt, buttermilk, cottage cheese and other fermented milk food products that are rich in beneficial intestinal microorganisms. Supplements are also available in the form of powders and capsules which contain different strains of these "friendly" bacteria, the *probiotics*. Probiotics are also showing great promise with livestock, especially in preventing disease in chickens and cattle.

PAY DIRT

Bioprospectors are scientists who ***scour*** nature for compounds or organisms that fight disease or perform everyday jobs, such as removing fabric stains and keeping bread fresh. Bioprospectors probe plants and animals for novel substances. Some even prospect in dirt. As you can imagine, dirt holds an unlimited supply of living organisms.

One of the most promising and exciting areas of probiotics is in the area of soil-based organisms (SBO's). These are bacteria that normally live in soil, but have proven very helpful when introduced into the digestive tracks of both humans and livestock. SBO's appear to be more aggressive at crowding out pathogens, and are better at colonization than the standard probiotic bacteria in cultured food. Some scientists believe that we have greatly reduced soil-based organisms in our diet due to our quest to reduce unwanted disease-causing pathogens. With the introduction of chemicals, pesticides and the chlorination of water, many beneficial soil bacteria have been eliminated along with the harmful ones.



Cross-section of the beneficial *Bacillus subtilis* bacteria

An example of a beneficial soil bacteria is *Bacillus subtilis*. During World War II, the Germans determined that this soil-based bacterium was effective in eliminating ***dysentery*** and other intestinal problems. Dysentery is caused by pathogenic bacteria from local food and water sources and is often a problem for

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soldiers in foreign territories. When the Germans administered these bacteria orally to their troops, dysentery would disappear. For many years afterwards, cultures of *Bacillus subtilis* were sold worldwide as a medicinal product. However, this product began to lose favor in the late 1950's and 1960's with the advent of synthetic antibiotics. *Bacillus subtilis* is still used today in Germany, France and Israel.

Bacillus subtilis is one of many soil-based bacteria that has also been discovered to benefit livestock health. As disease-causing bacteria are becoming more and more resistant to man-made antibiotics, this area of medicine holds great promise for new discoveries.

In the next lesson, we will examine a most strange and interesting phenomenon—the viruses.

LIFE PRINCIPLE

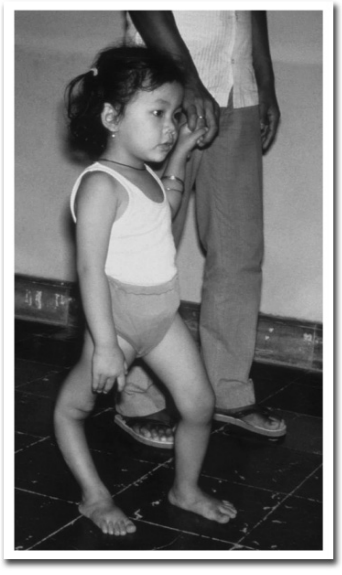


"The saddest aspect of life right now is that science gathers knowledge faster than society gathers wisdom."

—Isaac Asimov
Russian-born American novelist and scientist

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Viruses

Lesson 5

Chapter 6

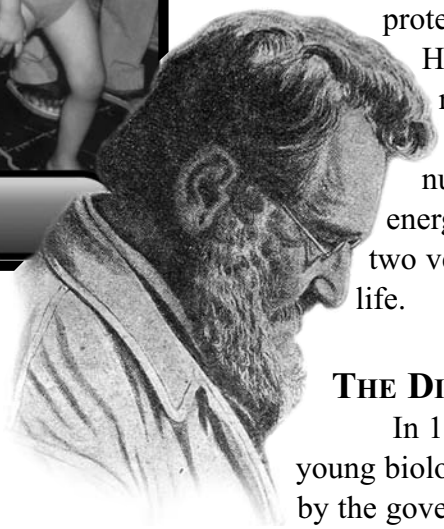
VIRUSES: A VERY STRANGE PHENOMENON

Section 1

Lessons 1-5



Bacteria are certainly a major contributor to disease. However, the most common agent of disease is the virus. Viruses are not classified into any kingdom or phylum because viruses are not considered to be living organisms. A virus does have genetic material inside a protective protein coat. However, a virus cannot reproduce itself and has no means of converting nutrients into useable energy. Thus, it fails to meet two very important criteria for life.



VOCABULARY

Virus: nonliving particle containing DNA or RNA and can infect a living cell

Lytic infection: process in which viral enzymes destroy a host cell's DNA, ribosomes and resources in order to reproduce

Lysogenic infection: process in which viral genes combine with the host cell's DNA, produce viral mRNA, and gradually make new viruses

Messenger RNA (mRNA): form of RNA that carries genetic information from DNA in the nucleus to ribosomes in the cytoplasm

THE DISCOVERY OF VIRUSES

In 1892, Dimitri Ivanovsky, a young biologist in Russia, was asked by the government to help solve a large agricultural problem. Tens of thousands of acres were planted with tobacco in the region of the Ukraine, and many Russians depended on this crop for their livelihood. However, much of the crop was being lost to a very strange disease.

Ivanovsky observed once-healthy tobacco leaves develop yellow spots. The entire plant would then wither and die. Ivanovsky suspected a disease, and he performed a simple experiment to test his idea. He crushed some leaves from a diseased plant and collected the juice. Then he placed a few drops of juice on the leaves of a healthy plant. In a few days, yellow spots appeared on the leaves precisely where the drops had been placed. This proved to the young biologist that this disease—now known as the *Tobacco Mosaic Virus*—could be passed from one plant to another.

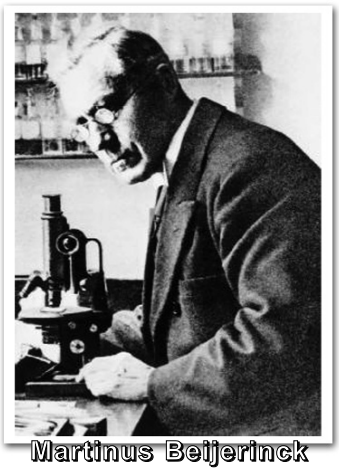
Ivanovsky thought that a bacterium might be causing the disease, so he examined the juice under a microscope.

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Surprisingly, he found no bacterium. In fact, he found no cells at all. Ivanovksy then concluded correctly that the infected plants must contain an invisible infectious particle.

A few years later, Dutch scientist Martinus Beijerinck confirmed Ivanovsky's experiments. Beijerinck showed that not only were these particles invisible under a microscope, they were so small that they could pass through the pores of very fine filters. Because the Latin word for "poison" is *virus*, Beijerinck wrote that the tobacco disease was caused by a "terrible virus."


Martinus Beijerinck

A ***virus*** is a non-living particle consisting only of genetic information—DNA or RNA—surrounded by a protein coat called a *cupsid*, which, in turn, is composed of a series of repeating subunits called *capsomeres*. Viruses are much smaller than cells; in fact, viruses are the smallest known entities affecting life: 10 to 100 times smaller than the average bacterium. Not until 1939 were researchers actually able to see a virus by means of an early electron microscope.

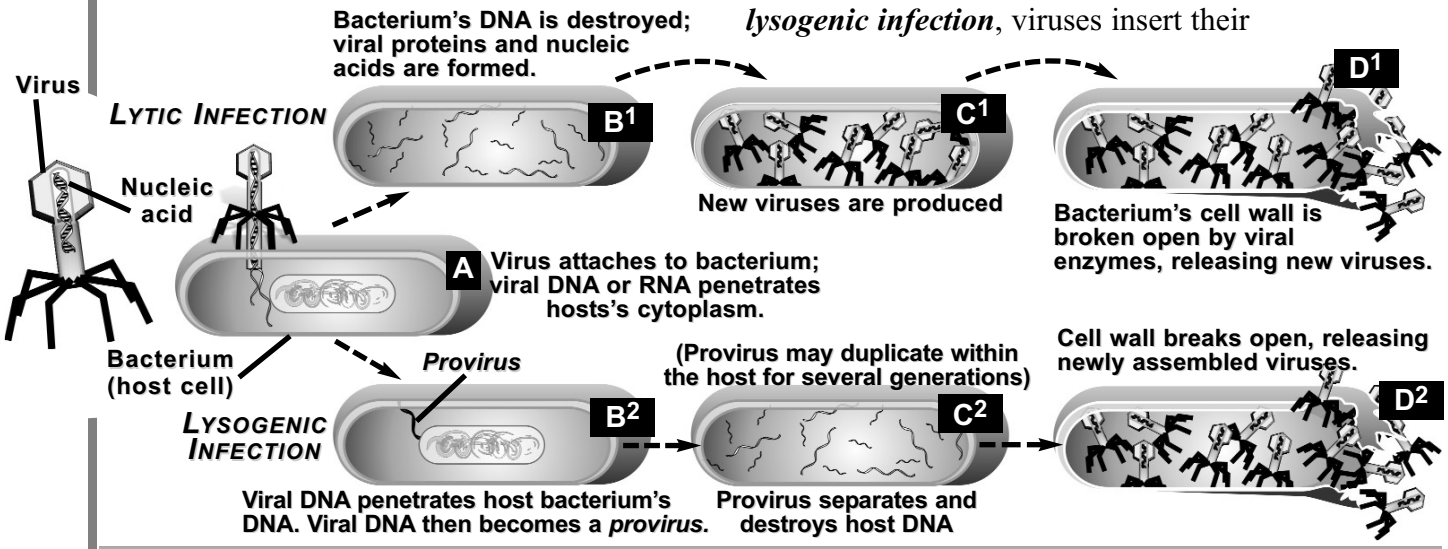
Although some viruses contain other materials, such as lipid membranes and enzymes, viruses cannot operate outside of living cells.

How a Virus Infects a Cell

Once a virus makes contact with a cell that it can infect, the virus goes to work. A bacterial virus infects a cell by attaching to the membrane of the cell. It then penetrates or fuses with the cell's membrane, releasing its own genetic material into the cell's cytoplasm. Once inside the host cell, viruses express their genes so that the host reproduces the virus. The host cell then makes copies of the virus. These new viruses, in turn, can infect other cells.

Some viruses take over and destroy the host cell. They produce enzymes that slice the host cell's DNA into pieces and take control of its ribosomes to make viral proteins. In this way, the virus uses up all the host cell's resources in order to make more viruses. This process is known as ***lytic infection***.

Other viruses are more subtle. In a ***lysogenic infection***, viruses insert their



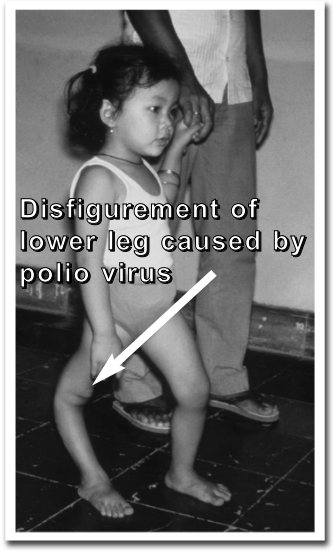
Lytic Infection and Lysogenic Infection: two ways by which a virus infects a bacterial cell.

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genetic material into the DNA of a host cell. The viral genes then begin making ***messenger RNA (mRNA)*** like the genes of the host cell. However, these viral mRNA's will direct the synthesis of viral proteins, gradually converting the cell into a living factory for making new viruses.

An example of a lysogenic infection is the *lambda virus*, called a ***bacteriophage***—a virus that infects the bacteria. When a lambda virus infects a host cell, the virus inserts its double-stranded DNA molecule into the bacterium. In most cases (as is characteristic of a lysogenic infection), this DNA is then inserted into the host cell DNA. The viral genes—now part of the bacterium's own chromosomes—are known as a ***provirus***. The provirus may remain part of the cell's own DNA for many generations, passed on from one cell to the next.



The provirus state, however, is not permanent. Any one of a number of factors, including radiation or chemicals that damage DNA, may cause their activation. *Lambda* DNA then emerges from the host chromosomes, produces copies of *viral* DNA, assembles scores of new viruses and then proceeds to destroy the host cell.

VOCABULARY

Bacteriophage: any virus that infects bacteria
Provirus: viral DNA that has become part of the host cell's DNA
Retroviruses: virus containing an enzyme that copies its genetic information from RNA to DNA

Viruses and Disease

All viruses are parasitic. A parasite depends entirely upon another living organism for its existence in a way that harms the host organism. Because viruses infect living cells, they often harm those cells, producing sickness and disease. Warts, chicken pox, the common cold, influenza (flu), several forms of cancer, mumps, measles, AIDS and many other diseases are caused by viruses. Viruses affect other organisms, as well as humans. As we saw earlier, plants can be killed by viral infections.

Polio Virus

Poliovirus is an example of a devastating virus. Poliovirus contains a single RNA strand which is enclosed in a protein coat that has a highly regular structure resembling the surface of a soccer ball. When a poliovirus enters the human body, it usually attaches to the surface of a cell in the throat or the nose. Sometimes the virus travels through the body and attacks cells in the nervous system. When this happens, the nerve cells that control muscles are destroyed, producing paralysis and sometimes even impairing the ability to breathe.

Polio was once a serious infectious disease that killed or paralyzed thousands of people in the United States each year. Fortunately, highly effective vaccines have almost completely eliminated polio.

Retroviruses

Retroviruses are a class of viruses that, like polio, contain RNA as their genetic material. Retroviruses receive their name from the fact that their genetic material is copied backwards—from RNA to DNA,

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instead of from DNA to RNA. (The prefix *retro* means backward.) Retroviruses are responsible for some types of cancer in humans and animals. AIDS is one type of retrovirus.

Each virus is spread from organism to organism in a specific way. For example, the smallpox virus is spread through personal contact; the cold virus is spread through the air; and the yellow fever virus is spread by mosquitoes. Once the virus enters the body, it infects only certain cells because of the shape and composition of the virus particle. A cell membrane contains protein molecules that act as receptors. A virus particle of a certain shape may match a certain receptor; in a sense, it fools the cell membrane into thinking it is something else. Once the virus particle attaches to the receptor, the virus can enter the cell and take over its reproduction apparatus. Thus, a cold virus infects cells of the nose and throat, and the hepatitis virus infects cells of the liver.

In the next lesson, we will begin an examination of the Kingdom Protista.

WATCH VIDEO: Viruses

WATCH VIDEO: Ebola Virus

LIFE PRINCIPLE



"Bad friends are like viruses—they infect and destroy your character."

—Ronald E. Johnson, PhD
Educator and author

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Protista

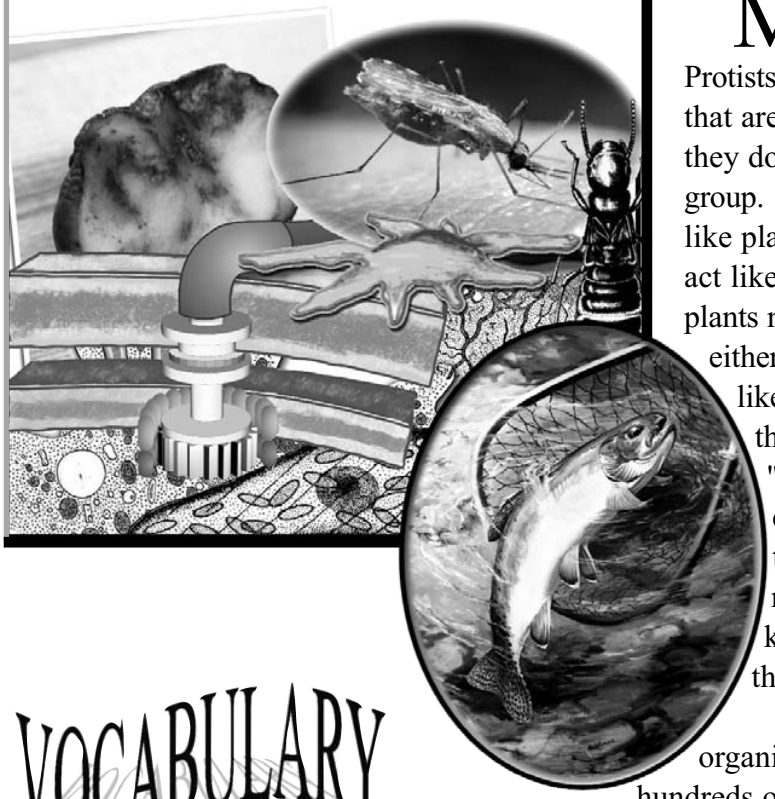
Lesson 6

Chapter 6

PROTISTA: A WORLD OF ANIMAL-LIKE WONDERS

Section 2

Lessons 6-10



Members of the Kingdom Protista are the simplest of the eukaryotes. Protists are an unusual group of organisms that are grouped together simply because they do not seem to belong to any other group. Some protists perform photosynthesis like plants, while others move around and act like animals, but protists are neither plants nor animals. They are not fungi either, even though some protists might like to "think" they are! In some ways, the Kingdom Protista is home for the "leftover" organisms that cannot be classified elsewhere. You might not think a tiny, one-celled amoeba has much in common with a giant sea kelp, but they are both members of the Kingdom Protista.

Most members are single-celled organisms, although quite a few consist of hundreds of thousands of cells. The Kingdom Protista may contain as many as 200,000 species. Some protists produce the oxygen that you breathe, and some cause especially deadly diseases.

VOCABULARY

Mutualism: reciprocal relationship in which two organisms benefit each other.

Pseudopod: temporary projection from an amoeba-type cell; used for movement and feeding; cytoplasm streams into the pseudopod and the rest of the cell follows.

Spore: small, typically single-celled structure capable of producing a new individual, either immediately or after a period of dormancy

SINGLE-CELLED EUKARYOTES

Biologists have argued for many years over the best way to classify single-cell eukaryotes, and the issue will probably never be settled. The disagreement lies in the fact that many of these organisms have more in common with some of the multicellular kingdoms, such as fungi, plants and animals, than they do with each other. However, these single-celled organisms do not have the specialized multicellular structures that are found in the other eukaryotic kingdoms. Thus, the Kingdom Protista has been used as a “default” kingdom for these strange organisms. Currently, the Kingdom

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Protista is defined in terms of what it is *not*. Any eukaryote that is not classified as a fungus, a plant or an animal is classified as a protist. This classification results in a most interesting and diverse group.

Biologists will often describe a protist by first noting to which of the three multicellular kingdoms it is most similar: animal, plant or fungi.

Animal-Like Protists

The animal-like protists are also called *protozoans*, which means "first animals." Four phyla of protozoans exist: Zoomastigina, Sarcodina, Ciliophora and Sporozoa. These classifications represent the way in which a protozoan moves.

VOCABULARY

Cilia (singular cilium): short, hairlike projections of some cells; in ciliates, used to pull the organism through water with a coordinated rowing movement

Contractile vacuole: specialized structure in some protists used to collect and expel water

Macronucleus: the larger of the two nuclei of a ciliate; stores multiple copies of commonly used genes

Micronucleus: the smaller of the two nuclei of a ciliate; stores copies of all the cell's genes

Gullet: depression on a paramecium used for the intake of food particles

Oral pore: the food intake end of a paramecium where the gullet is found

Anal pore: waste-discharging region on a paramecium

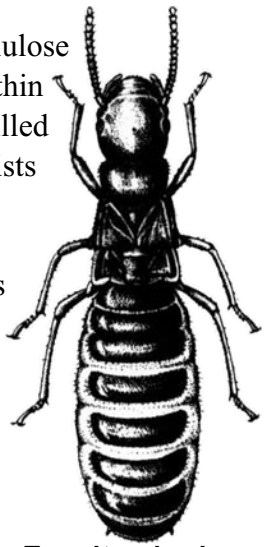
Trichocysts: tiny, bottle-shaped structures embedded in the paramecium and discharged in time of need of defense

Conjugation: form of sexual reproduction that results in new combinations of genes

Zoomastigina (Flagellates)

Organisms in the phylum *Zoomastigina* move through water using whip like structures called *flagella*. For this reason, the zoomastiginans are also called *flagellates*. Although most flagellates use their flagellum to swim freely in the water, some use their flagellum to attach to solid objects.

Flagellates absorb food directly through their cell membranes. Some flagellates live in ponds and streams in which they subsist on dead and decaying organic matter. Others, however, exist within the bodies of living animals. For example, the termite harbors large numbers of various flagellates in its digestive system. These flagellates help to digest the cellulose fibers in the wood, making the flagellates very useful to the termite. If these protozoa were not present, cellulose would continue to build up within the termite until toxic levels killed it. Instead, these resident protists prevent toxic substances from accumulating, and, in the process, feed themselves. This relationship is another example of ***mutualism***, a symbiotic relationship between two organisms that benefits both organisms.



Termites harbor flagellates in their digestive systems.

Other flagellates are parasites—organisms that harm the animals in which they live. A parasitic flagellate called *trypanosome* lives in the human bloodstream and causes African sleeping sickness.

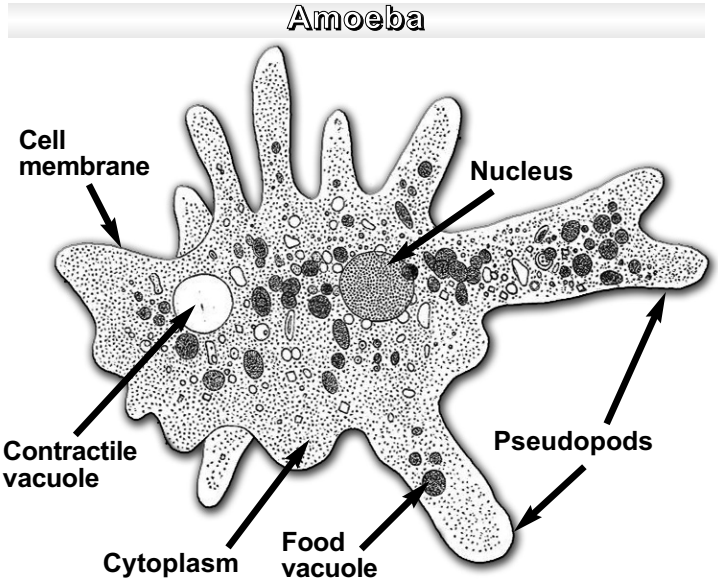
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Flagellates reproduce asexually by cell division. However, many also have a sexual phase to their life cycles.

SARCODINA (SARCODINES)

The most striking feature of the organisms in this phylum is that they have no standard body shape. Sarcodines are enclosed in a flexible plasma membrane which allows a shape change at will. When resting, sarcodines are usually spherical. However, when they need to move, they form extensions of their bodies called ***pseudopods***, or "false feet."



The best known sarcodines are the amoebas. Amoebas have neither cilia, nor flagella, nor cell walls, and they lack a definite shape. (The word *amoeba* comes from a Greek word meaning "change".) An amoeba moves by extending its pseudopods as illustrated below. Cytoplasm streams into the pseudopod and the rest of the cell follows. Amoebas also use pseudopods to capture and take in food particles.

Although thousands of different species of amoebas exist, they are greatly outnumbered by another class of sarcodines called the *Foraminifera*. Members in this group are so common that they have produced huge deposits of microscopic shells on the bottom of the ocean floor. The sarcodines also include a remarkable group of organisms known as the *heliozoans*, which means "sun animals". Heliozoans produce thin shells of silica which is the substance used to make glass.

SPOROZOA

The sporozoans do not have structures for movement. All sporozoans are parasites that reproduce by forming small, single-celled structures called ***spores***. A spore can survive for a while even in unfavorable conditions. In this form of reproduction, the nucleus divides while still inside the cell. This may happen several times, resulting in several different nuclei in one cell. Cytoplasm gathers around each nucleus, and then the cell disintegrates. The nuclei that are surrounded by cytoplasm then form hard, protective layers, making spores. The spores can then pass from one host to the next.

Sporozoans can infect fishes, worms, insects, birds and humans. In fact, a sporozoan causes malaria, one of the most serious infections known to scientists. Sporazoans often have complex life cycles involving more than one host. For example, the sporazoan that causes malaria lives part of its life in mosquitos.



This member of a mosquito species is commonly responsible for the spread of drug-resistant malaria.

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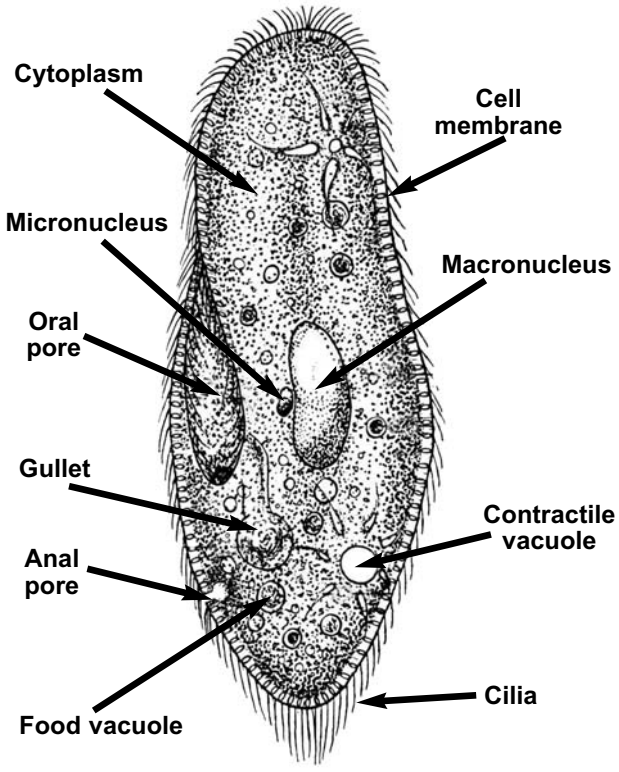
CILIOPHORA (CILIATES)

The phylum *Ciliophora* consists of protozoa that use ***cilia*** to move. As a result, these organisms are called ciliates. Cilia are short, hairlike projections that are similar to flagella. The cilia beat rhythmically to move the organism from place to place. The coordinated beating of cilia pulls the ciliate quickly through the water, just as the rowing of hundreds of oars pulled boats in ancient times.

Ciliates can be quite large, with some species attaining lengths of about one-tenth of an inch (about three millimeters). They vary in shape, ranging from bell-shaped to cone-shaped to foot-shaped. Members of the ciliate group live in fresh water, preferring stagnant lakes and ponds.

One very complex and interesting ciliate is the *paramecium*, an organism which is common in freshwater ponds. As shown in the illustration, a paramecium contains a variety of structures that perform different tasks. For example, the ***contractile vacuole*** expels the water that diffuses into the paramecium by osmosis. Another very prominent feature is the ***macronucleus***. This large nucleus controls metabolism. The paramecium, and most ciliates, require a large amount of energy to live, mainly because of the rapid movement of the many cilia. As a result, the metabolic control center must be large. In fact, the metabolic demand on the macronucleus is so large that a smaller micronucleus exists which controls reproduction so that the macronucleus can spend all of its resources controlling metabolism. Evidence also indicates that the paramecium uses the macronucleus as a "working library" of genetic information—a site to keep multiple copies of the genes that it uses everyday. The ***micronucleus*** contains *backup* copies of all the cell genes.

Paramecium



A paramecium is shaped like the sole of a shoe with a ***gullet*** at the end of its ***oral pore***, through which food particles enter and are then processed into food vacuoles. Waste products are discharged when a discarded food vacuole fuses with the cell membrane at a region known as the ***anal pore***. Embedded in the cell membrane are tiny, bottle-shaped structures called ***trichocysts***. Trichocysts are discharged when the cell is damaged or shocked. These structures can also produce barbed projections that are able to inflict damage on predators.

In addition to the asexual reproduction that is typical among the protozoa, paramecia can also engage in a form of sexual reproduction called ***conjugation***. In this process, two paramecia attach to one another at the openings of their oral grooves. Then they exchange DNA with each other. The result is two paramecia that are genetically identical, but different from the way they were before this conjugation process began.

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While looking at pond water under a microscope, you may see another important ciliate from the genus *Stentor*. This ciliate can grow as large as one-tenth of an inch. Common in fresh-water habitats, members of the genus are shaped like trumpets and have cilia surrounding their gullets. As the cilia beat back and forth, a micro-current is created in the water. This current sweeps food into the gullet, sometimes at the rate of a hundred "prey" each minute. *Stentor* eat all kinds of protozoa and bacteria.

Most ciliates are not pathogenic. One particular species, however, called *Balantidium coli* is a parasite found in many animal species including pigs, rats and guinea pigs. These ciliates can form cysts that survive in the fecal matter of their host. If an individual eats food or drinks water contaminated with such infected fecal material, the individual will become infected as well. In humans, infection by *B. coli* can result in severe dysentery. *B. coli* infection in humans is not common in the United States, but it is common in tropical regions of the world where malnutrition occurs and where pigs and humans live in close proximity to one another.

In the next lesson, we will examine the plant-like protists.

WATCH VIDEO: Protists

LIFE PRINCIPLE

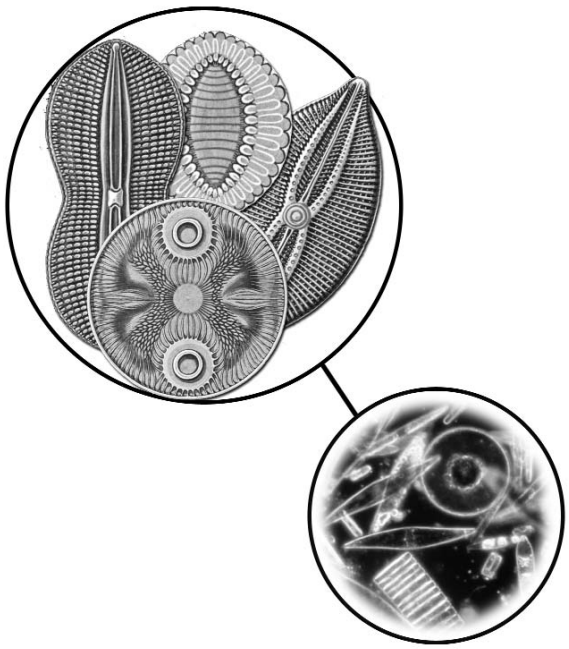


"Happy is he who gets to know the reason for things."

—Virgil (70-19 B.C.)
Roman poet

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Protista

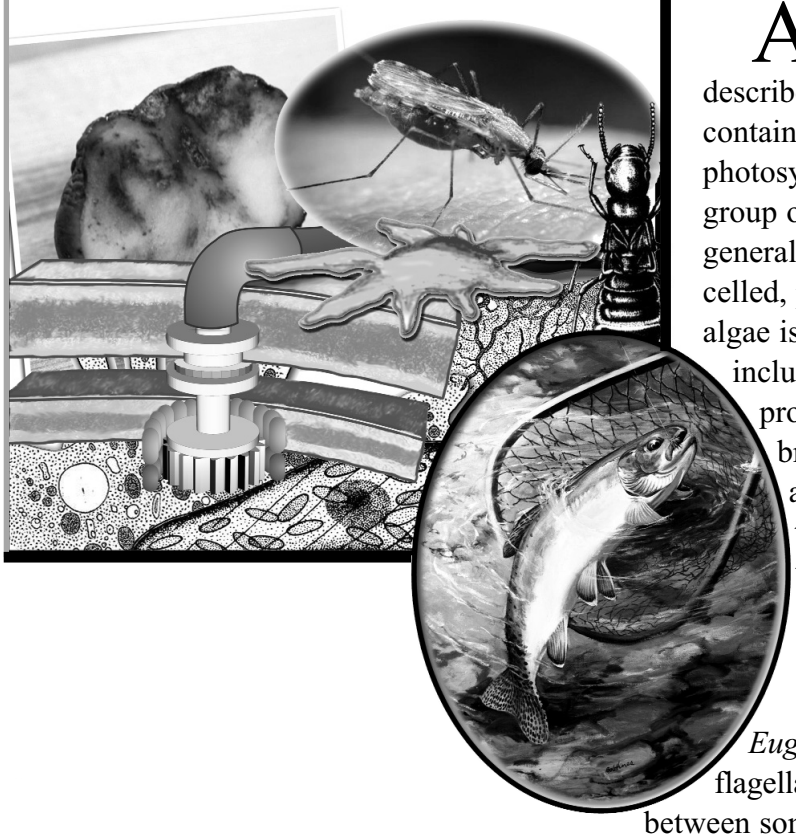
Lesson 7

Chapter 6

PROTISTA: A WORLD OF PLANT-LIKE WONDERS

Section 2

Lessons 6-10



Although plant-like protists can move around, they are still described as plant-like because they contain ***chloroplasts*** and are capable of photosynthesis. Algae are included in the group of plant-like protists. ***Algae*** is a general term that describes all single-celled, photosynthetic organisms. Some algae is multicellular. Most biologists include three phyla of algae in plant-like protists—red algae, green algae and brown algae. However, since these algae are so similar to green plants they will be featured at the end of this chapter.

EUGLENOPHYTES

Members of the phylum, *Euglenophyta*, are very similar to the flagellates. The only real difference between some species is the presence or absence of chloroplasts.

The phylum is named after the genus *Euglena*. A typical euglena is about 50 micrometers in length and has two flagella. The longer of the two flagella spins in a way that pulls the cell rapidly through water, making euglenas excellent

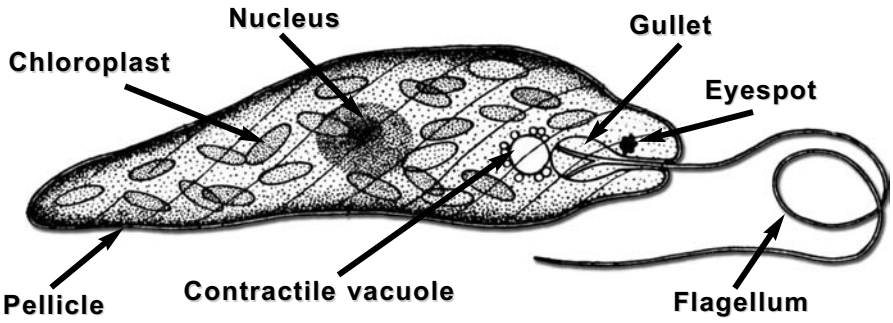
Chloroplasts: organelles found in plants and certain types of plant-like protists; contain chlorophyll, the principle pigment of green plants

Algae (singular, alga): single-celled photosynthetic organisms, classified as protists

Eyespot: a light-sensitive region in certain protozoa

Pellicle: a firm, flexible coating outside the plasma membrane of euglena

Euglena



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swimmers. Most euglenas are found in pools and lakes, although a few salt water varieties have been found. Euglenas reproduce asexually through binary fission.

Euglenas contain 10 to 20 oval-shaped chloroplasts that carry out photosynthesis. They also have a light-sensing structure, called an ***eyespot***, which is a cluster of red pigment near the flagella. Since the eyespot is light-sensitive, euglena use it to move towards regions of bright light, increasing their photosynthesis ability. Although the structure is called an "eyespot", the euglena does not actually see with it. The eyespot simply allows the euglena to locate sufficient light. When light is not available, euglenas absorb food from the water around them. If their surroundings become dim for several days or more, the euglena's photosynthetic capability degenerates. In this case, the euglena can never produce their own food again by photosynthesis regardless of how bright their surroundings might become later.

While euglenas do not have cell walls, they each do have an intricate cell membrane that is a firm, flexible coating called a ***pellicle***. The pellicle is folded into a series of ribbon like ridges, each supported by microtubules. Pellicles are tough, as well as flexible, allowing euglenas to squirm and crawl along surfaces where insufficient water does not allow them to swim.

VOCABULARY

Algal bloom: the phenomenon occurs when algae reproduce so rapidly that they take over their aquatic habitats

Red tides: the phenomenon caused by a group of dinoflagellates in which the sea appears to be red; a very toxic condition to most marine life

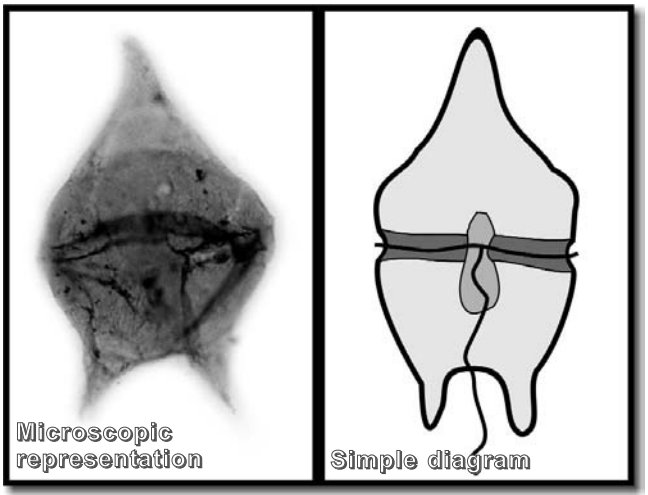
Diatoms: microscopic, plankton-like, single-celled creatures whose cell walls are made of silicon dioxide; the most abundant organisms on Earth

PYRROPHYTES

Phylum *Pyrrophyta* contains a group of single-celled algae that are often referred to as the *dinoflagellates*. This name is derived from the fact that most in the group have two flagella of unequal length. Some of these organisms are heterotrophic, some are photosynthetic and most of them inhabit marine waters. Dinoflagellates, which are photosynthetic, are an important source of food for many aquatic animals.

When agitated by a sudden movement in the water, many dinoflagellates undergo a chemical reaction that produces light. In the ocean on a dark night, this light is a remarkable, eerie light. The light also gives the phylum its name—*Pyrrophyta* which means "fire plants."

When conditions are ideal, algae will reproduce so rapidly in their aquatic environments that they make the water appear the same color as the algae itself.

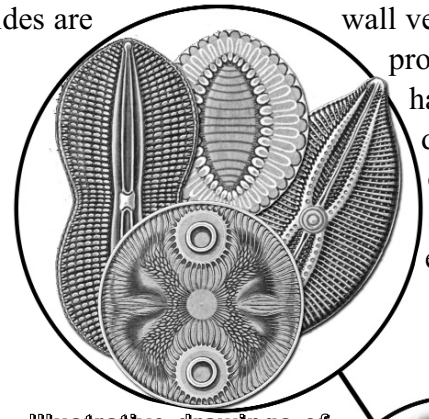


A *Dinoflagellate* possesses two *flagella*, perpendicular to each other within the organism.

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This is known as ***algal bloom***. The dinoflagellates are reddish-brown in color; therefore their bloom tends to turn the sea red. As a result, these "blooms" are often called ***red tides***. Red tides are deadly to other marine creatures. Hundreds of thousands of fish may be killed in a bloom because these organisms emit a toxin in the water. Although red tides are deadly to most other marine life, shellfish such as clams, oysters and mollusks are immune. However, toxins emitted by dinoflagellates do build up in the bodies of shellfish. As a result, heterotrophs that consume toxic shellfish can become poisoned. Many human deaths can be attributed to eating clams, oysters or mollusks that have been contaminated by a red tide.



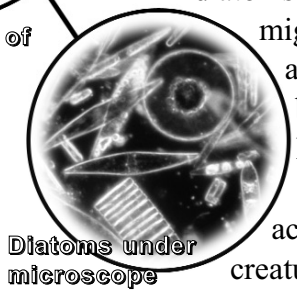
Illustrative drawings of diatom patterns

CHRYSOPHYTES

The phylum *Chrysophyta* includes species commonly known as the yellow-green algae, golden algae and diatoms. The chloroplasts of these organisms contain bright-yellow pigments that give the phylum its name which means "golden plants."

Like plants, chrysophytes contain cell walls. However, the chrysophytes' cell walls contain the carbohydrate, pectin, rather than cellulose. ***Diatoms*** are a unique group within this phylum.

Diatom means "to cut". The name was assigned because their cell walls are made of silicon dioxide which is the principal component of glass. This makes their cell wall very hard, providing excellent protection. In fact, the cell wall is so hard that it remains intact long after the diatom dies. The typical diatom shell contains two parts that fit together snugly. Some of these shells are etched with fine lines and markings that give diatoms a jewel-like brilliance. If you were to study diatoms under a microscope, you might conclude that diatoms are among the most beautiful creatures on Earth.



Diatoms under microscope

Diatoms are actually the most abundant creatures on Earth. When the cell wall remains of many dead diatoms clump together, they form a crumbly, abrasive substance called *diatomaceous earth*. Huge deposits of this substance exist in most regions of the world. Diatomaceous earth is a useful resource for people. Large amounts of diatomaceous earth are used by industry as a means of filtering liquids and as an abrasive. For example, most toothpaste contains an abrasive that helps clean and polish teeth. Often, diatomaceous earth is used for this purpose. It is also useful as a non-toxic deterrent for insects such as fleas, roaches and ants when sprinkled in areas they frequently travel.

In the next lesson, we will examine fungus-like protists.

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LIFE PRINCIPLE

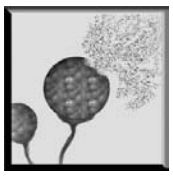


"Man is not the creature of circumstances. Circumstances are the creatures of men."

—Benjamin Disraeli (1804-1881)
First Jewish Prime Minister of England

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Molds

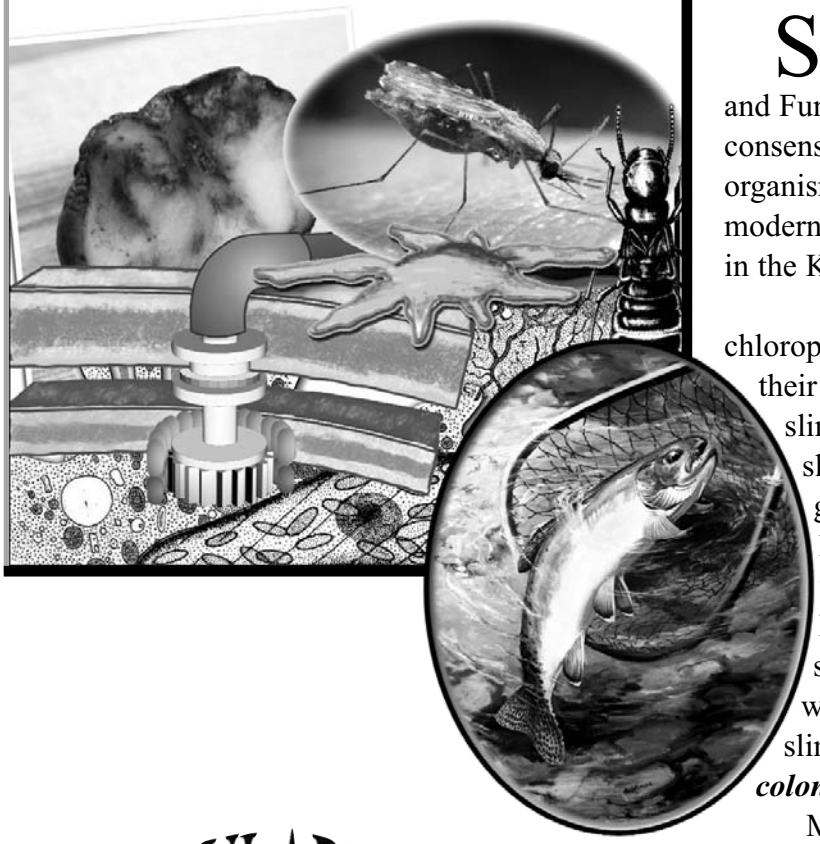
Lesson 8

Chapter 6

SLIME MOLDS AND WATER MOLDS: PROTISTA OR FUNGI?

Section 2

Lessons 6-10



Slime molds are organisms which seem to fit into both the Protista and Fungi Kingdoms. No clear consensus seems to exist as to how these organisms should be classified. Most modern textbooks place the slime molds in the Kingdom Protista.

Like fungi, slime molds lack chlorophyll and absorb food through their cell walls. The reproduction of slime molds is similar to fungi, and slime molds are found in the same general habitat as fungi. Fungi have cell walls made of chitin, which slime molds do not have. Like other protists, however, slime molds contain centrioles, which true fungi lack. Also, when slime molds feed, they behave like ***colonial protists***.

Most of the time, slime molds are in their feeding stage in colonies. They usually can be found on the bark of decaying logs, or between the layers of leaves on the floor of a forest. If tree bark or dead leaves are used as mulch in a garden, some of the mulch will produce slime mold in the middle of the growing season. Slime molds are usually white, red, orange or yellow. They exist in their feeding stage as a mass of living matter called a ***plasmodium***. As their name implies, they are slimy to the touch. Despite the fact that their name and appearance are rather disgusting, most slime molds are not harmful to plants or animals.

VOCABULARY

Colonial protists: protists that live in large groups, or colonies

Plasmodium: feeding stage mass of slime mold; also, any of a group of parasitic protists such as the organism (plasmodium) that causes malaria

Fruiting body: reproductive, stalk-like structure that produces spores

ACRASIOMYCOTA (CELLULAR SLIME MOLDS)

Members of the phylum, *Acrasiomycota*, are commonly called cellular slime molds. These organisms begin

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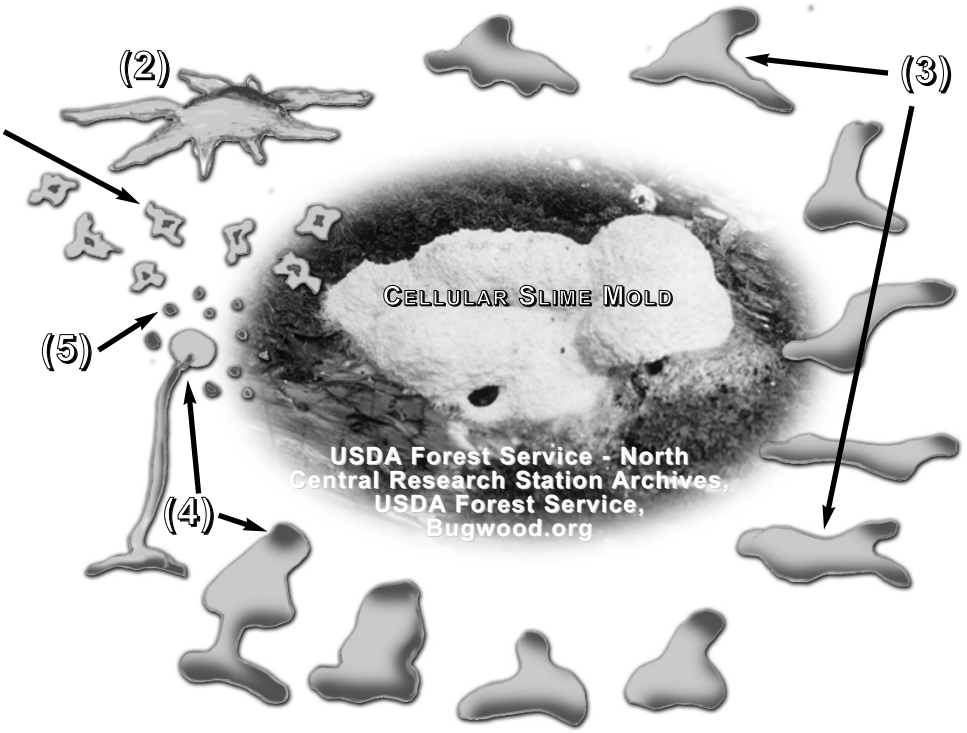
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their life cycles as individual, amoeba-like, cells. In fact, they look so much like amoebas that only an expert microbiologist can tell them apart. However, as these slime molds grow, the resemblance between amoebas and slime molds disappears.

When an individual cell begins to run low on food or water, it sends out chemical signals that attract other cells of the same species. Within a few days, thousands of cells will aggregate into a large, slug-like mass. This mass will migrate for a little while, and then stop to form a ***fruiting body***—a reproductive structure that produces spores. When the spores are scattered, each can give rise to a single amoeba-like cell that begins the cycle again.

Biologists are investigating how these individual, free-living cells signal each other first to aggregate, then to form a specialized structure like the fruiting body. Scientists are very interested in knowing the mechanism which organizes these functions.

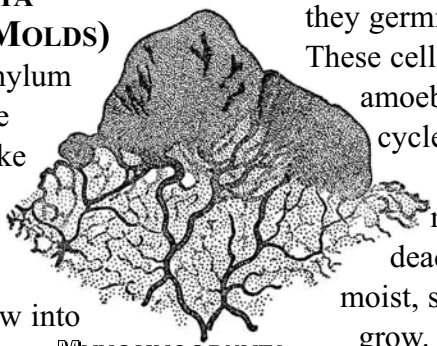
Plasmodial Slime Mold on the Move: Stages of growth



1: **Individual amoeba-like cell member of the plasmodium**
2: **Aggregated cells form a slug-like mass**
3: **"Slug" feeds on bacteria and grows, taking various shapes**
4: **Cells transform into a "fruiting body" a stalk-like structure that will produce spores**
5: **Spores disseminate, germinate and reproduce**

Myxomycota (Acellular Slime Molds)

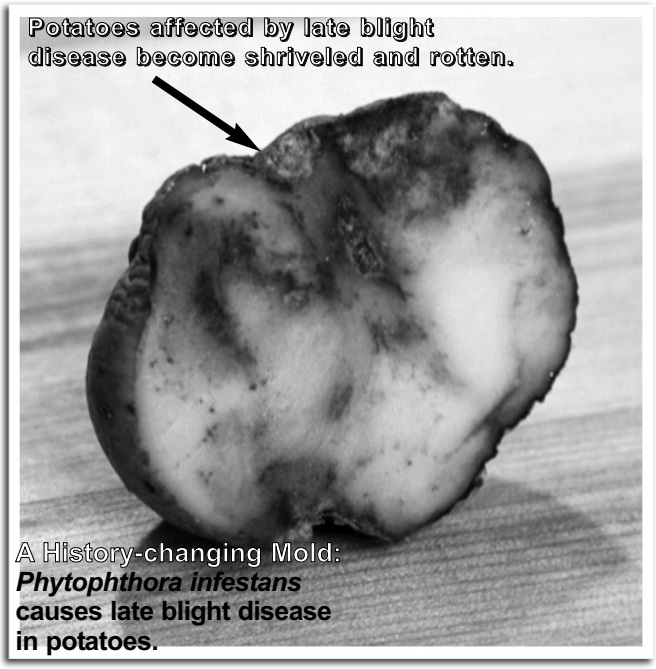
Members of the phylum *Myxomycota* are called the *acellular slime molds.* Like the cellular slime molds, the acellular slime molds begin their life cycles as amoeba-like cells that grow into large masses. In the acellular type, however, the mass is actually a single cell with thousands of nuclei. Acellular slime molds stream across leaves and twigs, gobbling up bacteria and other organic matter along the way. Eventually, they form fruiting bodies that form haploid (n) spores. When spores contact moist soil, they germinate to produce flagellated cells. These cells fuse to produce diploid (2n), amoeba-like cells. In this manner, the cycle starts all over again.



Myxomycophyta (Acellular Slime Mold)

The main feature of a slime mold's habitat is water. Wherever dead trees, bark or leaves are kept moist, slime molds are almost certain to grow. To rid the area of slime mold, the area must simply become dry. Gardeners

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A History-changing Mold: ***Phytophthora infestans*** **causes late blight disease in potatoes.**

often dislike slime molds because of their appearance. To rid gardens of these molds, gardeners need only to rake the ground surface daily. This will bring the moist mulch to the top, allowing the area to dry.

Oomycetes (Water Molds)

Some water molds (and other members of this phylum) are decomposers of dead plants and animals in a fresh water medium. Some oomycetes are parasites. Some, like *Phytophthora infestans*, are plant pathogens. This particular pathogen causes "late blight" in potatoes and was responsible for the Great Irish Potato Famine of the mid 1800's, during which an estimated one million people died. The potato had been Ireland's staple crop on which the rural populace depended. Repeatedly failed crops caused widespread havoc and starvation—all due to a devastating, then unknown agent—a water mold.

However, because a controversy exists as to whether water molds are protistan molds or fungi in nature, more about *Phytophthora infestans* will be discussed under "fungal diseases" in lesson thirteen.

In the next lesson, we will examine diseases caused by protists.

Biology Careers

What is a Microbiologist?

Microbiologists investigate the fascinating world of organisms too small to be seen with the naked eye. Although known by many different titles, a microbiologist is a scientist who studies living organisms, infectious agents (many of which can be seen only with a microscope) and the interaction of microorganisms with people. Everyday microbiologists around the world explore, investigate and discover how microbes exist and affect our lives.

As a microbiologist, you would work with many other scientists and have a vast range of opportunities. Microbiologists work in almost every industry and have many, varied responsibilities. You would collaborate with many other scientists. Depending on your specific situation, you could perform more than one function or role.



Life Principle

"Wise people realize they don't know what they don't know."

–Ronald E. Johnson, Ph.D.
Educator and author

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Protist Diseases

Lesson 9

Chapter 6

PROTIST DISEASES

Section 2

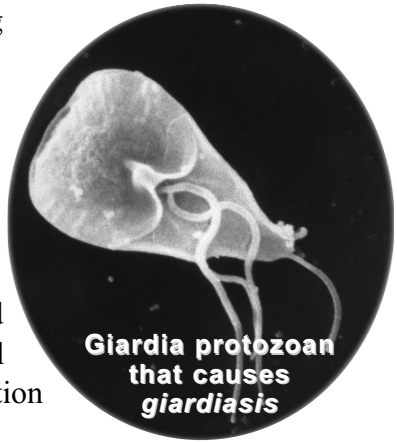
Lessons 6-10



We have seen a great diversity in the world of Protista. Many protists are some of nature's most useful organisms, while others are most troublesome and even deadly.

AFRICAN SLEEPING SICKNESS

In central Africa, flagellate protists of the genus *Trypanosoma* cause a disease called "sleeping sickness". These protists are passed from person to person through the bite of the ***tsetse fly***. Trypanosomes destroy blood cells, producing fever, chills and rashes. The disease may continue and damage the central nervous system. Affected individuals may lose consciousness and lapse into a deep, sometimes fatal sleep—which is why the disease is given the name sleeping sickness.



INTESTINAL DISEASES

Several protists can infect the human digestive system if an individual drinks contaminated water. These protists include *Entamoeba* and *Giardia*, both of which attack the wall of the intestine. An *Entamoeba* infection produces a disease called "amoebic dysentery", and a *Giardia* infection causes a disease called "giardiasis". Both infections cause diarrhea and severe abdominal pain.

VOCABULARY

Tsetse fly: a two-winged fly found in Africa, south of the Sahara Desert

Quinine: long-standing treatment for malaria; named for the *quina* tree (native name for the *cinchona* tree)

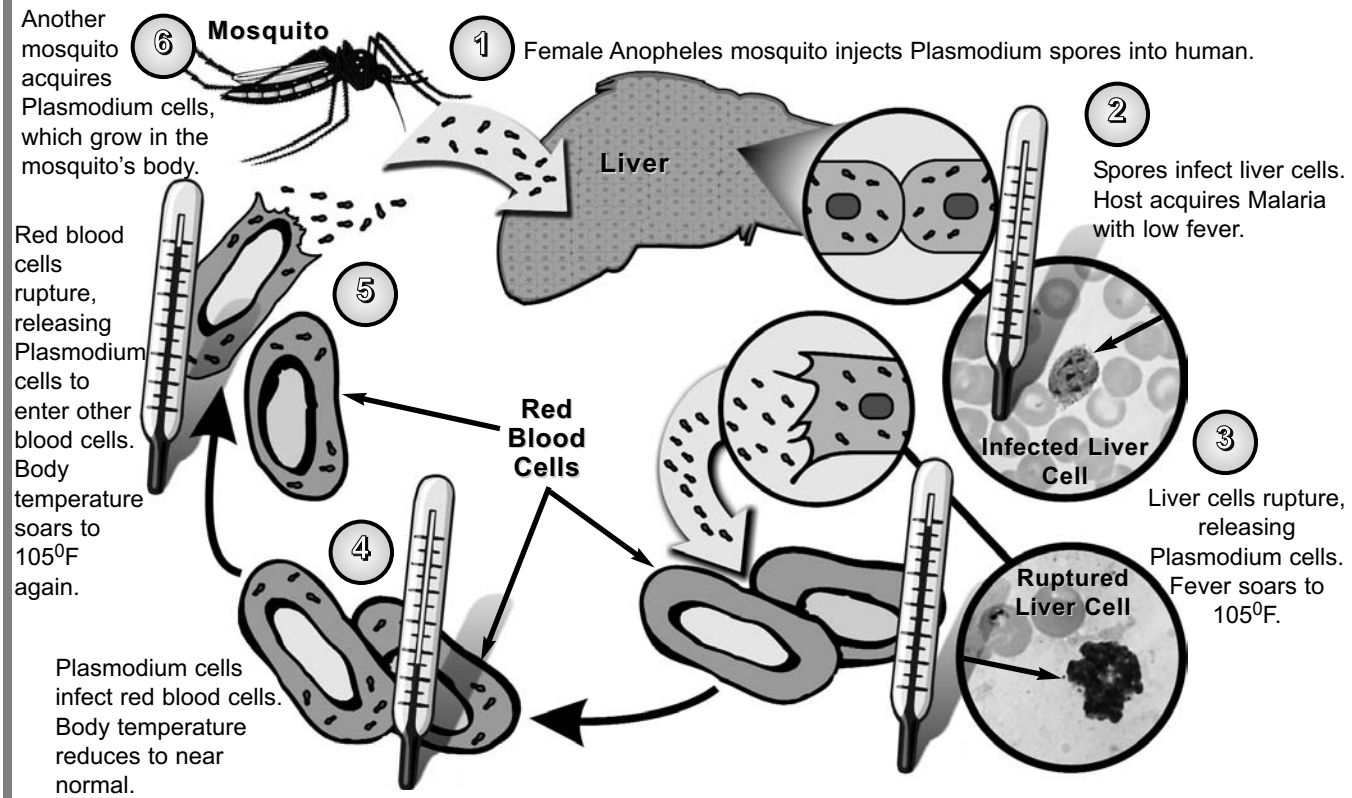
Chloroquine: a derivative of quinine; used in treatment of malaria

WHO (World Health Organization): a function of the United Nations

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Life Cycle of Malarial, Parasitic Plasmodium Spores



Amoebic dysentery is most common in areas with poor sanitation. On the other hand, even crystal-clear mountain streams may be contaminated with *Giardia*. Giardiasis (also known as "beaver fever") is frequently seen in day care centers and among campers. In acute cases, symptoms may include nausea, upper intestinal pain and explosive diarrhea. Fever and chills may be present, with symptoms that may mimic a peptic ulcer or gall bladder disease. *Giardia* produces tough microscopic cysts that can be killed only by thoroughly boiling the contaminated water. Hikers and campers are warned not to drink the waters of streams without first treating that water.

Malaria

By far the most serious disease that protists cause is malaria. More than 200 million people suffer from malaria, and as many as 2 million people die from it each year. Although largely eliminated from Europe and North America (only 1000 cases reported in the U.S. per year), it is still the most serious, infectious disease in tropical and subtropical regions of the world. Because malaria produces lethargy to total incapacitation, the disease has been blamed for impeding development of entire nations.

Malaria has had a significant impact on human history. This disease was one of the contributors to the fall of both the Greek and Roman empires. During the U.S. Civil war, more than twenty-five percent of hospital admissions were malaria patients. Malaria was also a problem in World War II. An estimated 500,000 American soldiers were hospitalized with malaria.

The name originated in Italy in the seventeenth century. *Mal-aria* meant "bad air" because the disease was associated with foul-smelling vapors from swamps.

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In the middle of the same century, ***Quinina***, a chemical derived from the *cinchona* tree in South America, was discovered to be a remedy for malaria and was the standard treatment for the next 300 years.

In 1902, Nobel Prize winner Dr. Ronald Ross discovered the protist *plasmodium* in the intestines of mosquitoes and established the major features of the life cycle of this protist. Researchers now know that Plasmodium is transmitted through the bite of the Anopheles mosquito. Plasmodium enters the bloodstream through the mosquito's saliva, and then infects liver cells and red blood cells. In a 48 to 72-hour cycle, infected cells burst open, dumping waste products and toxins into the bloodstream. This produces high fever and chills, the characteristic symptoms of malaria.


Rainbow trout caught in net

In 1955, ***WHO (World Health Organization)*** began a worldwide malaria eradication program by spraying DDT to kill mosquitoes. ***Chloroquine*** was used to treat people with malaria. Initially, this dual program was very successful and an estimated one billion people were spared from malarial infection. However, the program was abandoned during the late 1960's. DDT posed many health and biological problems. The most critical problem was the appearance of DDT-resistant strains of mosquitoes. Also, chloroquine resistant strains of *Plasmodium* appeared. The most lethal strain of malaria (*Plasmodium falciparum*) is now genetically resistant to chloroquine worldwide.

Medical scientists have developed a number of vaccines that seem to block the growth of the parasite. Unfortunately, these vaccines are only partially effective. For the immediate future, the best means of controlling malaria seems to be controlling the mosquitoes that carry it.

Whirling-Trout Disease

Fans of both fishing and dining value the rainbow trout, a colorful fish that is native to the northwestern United States. In recent years, however, many rainbow trout have been seen swimming in circles and chasing their own tails—and then dying soon thereafter. This strange behavior was named "whirling-trout disease."

Biologists discovered that this disease is caused by *Myxobolus cerebralis*, an animal-like protist that infects both the rainbow trout and the worms they eat. In trout, the protist attacks cartilage and the nervous system.

Hope for the rainbow trout may lie with another fish, the brown trout, which lives in the same streams as rainbow trout but is resistant to *Myxobolus cerebralis*. The brown trout is native to Europe, where *Myxobolus* is common. Scientists believe that since the brown trout apparently has developed a resistance to this disease, rainbow trout might do the same.

In the next lesson, we will explore the intricate design evident in the "simple" life forms.

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LIFE PRINCIPLE

"The important thing is not to stop questioning."

—Albert Einstein (1879-1955)
German-American mathematical physicist

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Discoveries

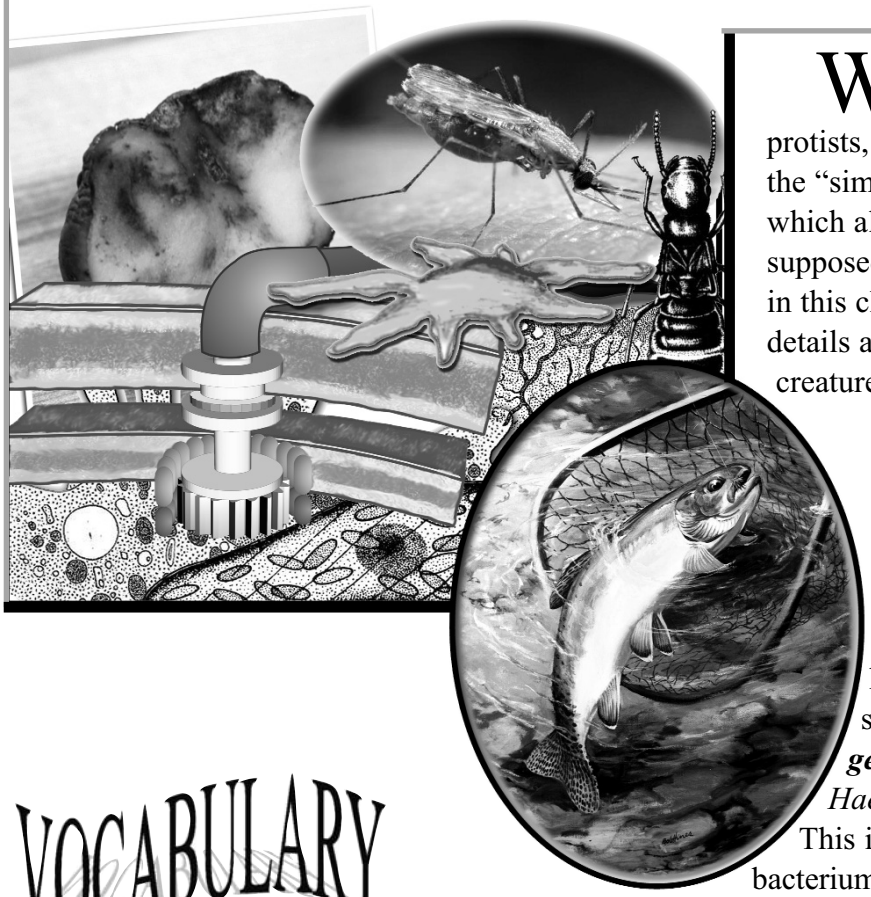
Lesson 10

Chapter 6

THE SIMPLE THINGS IN LIFE

Section 2

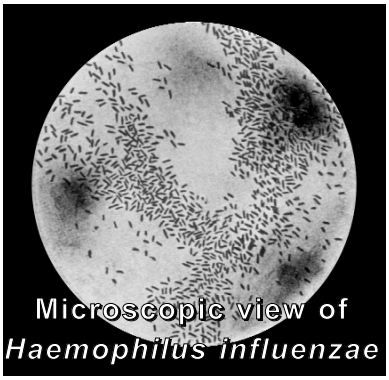
Lessons 6-10



We have examined the kingdoms of bacteria and protists, considered and taught to be the "simple" forms of life from which all life (including humans) supposedly evolved. We will pause in this chapter to examine a few more details about these "simple" creatures.

HAEMOPHILUS INFLUENZAE GENOME MAP

A team of U.S. scientists recently achieved a landmark goal with the sequencing of the whole of the ***genome*** of the bacterium *Haemophilus influenzae* Rd. This is the first, free-living bacterium to be fully sequenced. *Haemophilus influenzae*, with a genome size of about 1.8 million bases, was chosen for sequencing because it was considered "typical among bacteria." The project involved an enormous amount of work and considerable computer analysis of the data generated by each of the laboratories involved. The resulting genome has 1,830,137 base pairs coding for an estimated 1,743 genes. The scientists involved in this project discovered that 87 genes code for proteins/enzymes involved in DNA replication alone. Many more genes exist which are involved in transcription and



Microscopic view of *Haemophilus influenzae*

VOCABULARY

Genome: literally means *gene mass*; the complete set of genes in an organism

Rpm: revolutions per minute

Albuminous: having the characteristics of a water-soluble, coaguable protein such as is found in milk, blood and egg white

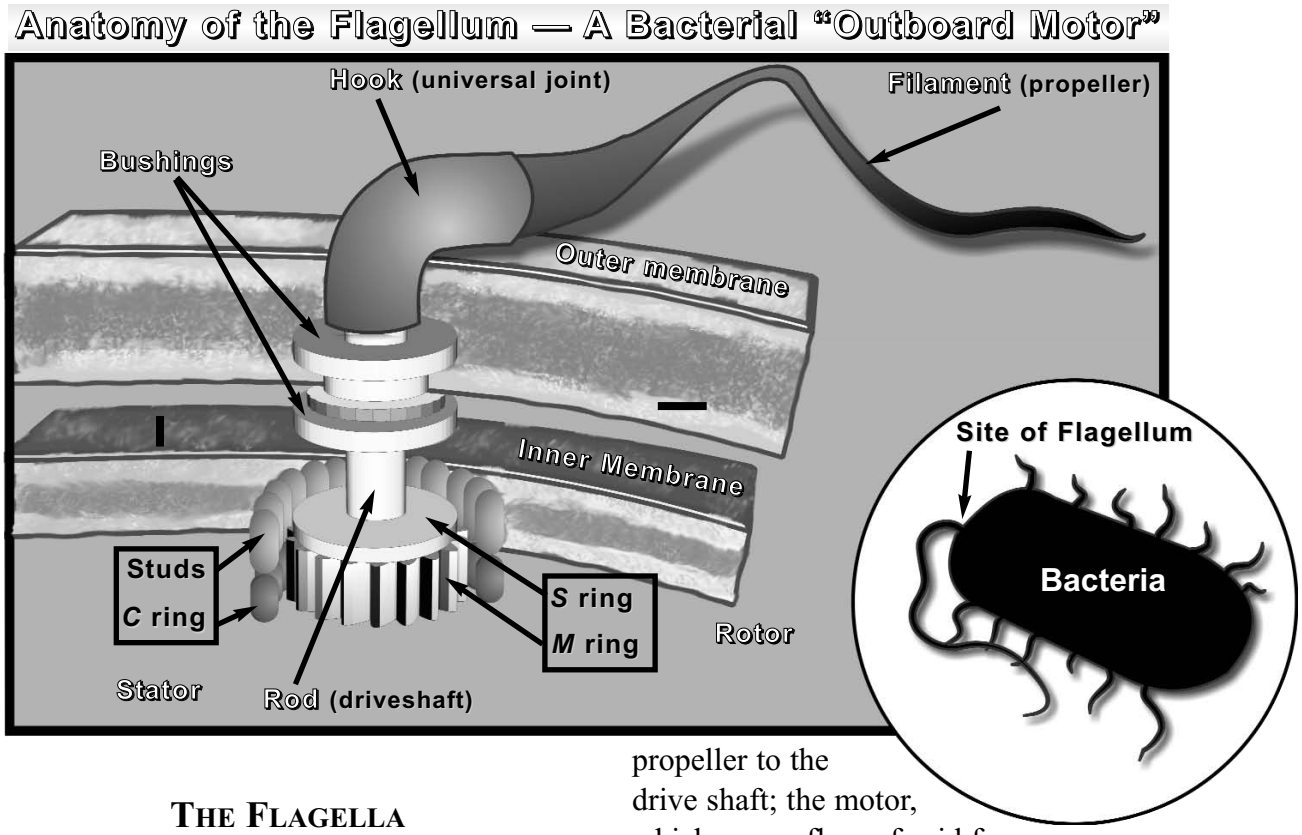
Molecular biologist: a biologist who studies life at the cell and molecule level

Ingenuity: creative genius

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translation, not to mention biosynthesis, energy metabolism, transport, etc. Although this bacterium is one of the least complex in life, it is by no means "simple." Furthermore, if a prokaryote such as *Haemophilus influenzae* were to be transformed into human life over some billions of years, it would have to have added to this information several million more genes because a human, reportedly, has upwards of ten million genes. As we have seen in previous lessons, this is mathematically an impossible task for mutations to achieve.



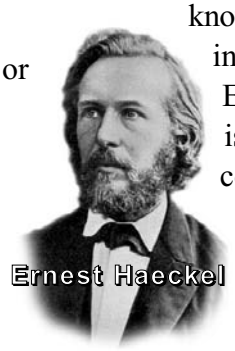
The Flagella

In a previous lesson, we studied an organism called a *Euglena* with two flagella which are whip-like organelles that the Euglena uses to move about in water. As we also studied, organisms in the phylum Zoomastigina (flagellates) also move through water using flagella. Although most flagellates use their flagella to swim freely in the water, some use the flagella to attach themselves to solid objects. Some bacteria have flagella.

The flagellum is a remarkable feat of engineering. The flagellum, is quite literally, an outboard motor which helps some bacteria to swim. It is a rotary device that, like a motorboat, turns a propeller to push against liquid, moving the bacterium forward in the process. It consists of a number of parts, including a long tail (called a filament) that acts as a propeller; the hook region, which serves as a univeral joint and attaches the propeller to the drive shaft; the motor, which uses a flow of acid from the outside of the bacterium to the inside to power the turning; a stator, which keeps the structure stationary in the plane of the membrane while the propeller turns; and bushing material to allow the drive shaft to poke up through the bacterial membrane. The rod and the hook fit together so

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smoothly that the hook can spin around the rod in circles. When the organism wants to move, a series of amazingly complex chemical reactions make the hook spin at 17,000 ***rpm***. Since the filament is attached to the hook, the filament begins to spin as well. The design of this incredible structure is so efficient as to be copied by engineers for industrial applications. In fact, some scientists have called the flagellum the "most efficient machine in the universe."


Ernest Haeckel

In the absence of the hook, or the motor, or the propeller, or the drive shaft, or most of the forty different types of proteins that genetic studies have shown to be necessary for the activity or construction of the flagellum, one does not get a flagellum that spins half as fast as it used to, or even a quarter as fast. Either the flagellum works fully, or it does not work at all. Like the mousetrap we studied previously, the flagellum is irreducibly complex. And again, like the mousetrap, its evolutionary development by "numerous, successive, slight modifications" is quite difficult to envision. In fact, if one examines the scientific literature, one quickly sees that no one has ever proposed a serious, detailed model for how the flagellum might have arisen in a Darwinian manner, let alone conducted experiments to test such a model. To complicate this matter further, at least 50 genes are needed to create a working flagellum. Each of those genes is as complex as a sentence with hundreds of letters. Furthermore, the requirements for a single flagellum are very specific. As microbiologist Scott Minnich of the University of Idaho states:

> *Mutations in any single gene knock out function or in lesser cases diminish function. So, to swim you have to have the full complement of genes. There are no intermediate steps.*

The "Simple" Cell

Ernest Haeckel, one of the nineteenth-century scientists who advanced the notion of spontaneous generation, called the single cell "a simple little lump of ***albuminous*** combination of carbon." Today, scientists know that the cell has machines more intricate than any machine made by man. Even the "simple" bacterial or protist cell is fantastically complex. A typical cell contains ten million atoms. If you were to build a scale model of a cell using tennis balls as atoms, and you placed one atom per minute into the model, 50 million years would elapse before the model could be assembled! Recall that noted scientist Carl Sagan stated:

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

This figure (10^{12}) is for just one cell. The numbers become even more staggering when considering a larger organism with many cells.

Molecular biologist Michael Denton, writing as a non-religious skeptic of Darwinian evolution, explains the complexity of a single cell in his book, *Evolution*: *A Theory in Crisis.*

> *Perhaps in no other area of modern biology is the challenge posed by the extreme complexity and **ingenuity** of biological adaptations more apparent than in the fascinating new molecular world of the cell…. To grasp the reality of life as it has been revealed by molecular biology, we must magnify a cell a thousand million times until it is twenty kilometers in diameter and*

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resembles a giant airship large enough to cover a great city like London or New York. What we would then see would be an object of unparalleled complexity and adaptive design. On the surface of the cell, we would see millions of openings, like the port holes of a vast space ship, opening and closing to allow a continual stream of materials to flow in and out. If we were to enter one of these openings we would find ourselves in a world of supreme technology and bewildering complexity.

Is it really credible that random processes could have constructed a reality, the smallest element of which—a functional protein or gene—is complex beyond our own creative capacities, a reality which is the very antithesis of chance, which excels in every sense anything produced by intelligence of man? Alongside the level of ingenuity and complexity exhibited by the molecular machinery of life, even our most advanced artifacts appear clumsy…

It would be an illusion to think that what we are aware of at present is any more than a fraction of the full extent of biological design. In practically every field of fundamental biological research ever-increasing levels of design and complexity are being revealed at an ever-accelerating rate.

As advancing research shows the awesome complexity of life at the cellular level, scientists like Michael Denton are beginning to believe that these sub-cellular processes could not have happened by random chance. Because of these discoveries, numerous modern scientists are favoring the theory of intelligent design simply because of obvious, observable design and the laws of probability. Earlier in the textbook, we quoted astronomer Sir Fred Hoyle. This may be an appropriate time to repeat Sir Hoyle's words. The magazine *Nature* quoted him, saying that the probability of higher life forms emerging from macromolecules by chance are comparable to the odds that a "tornado sweeping through a junkyard might assemble a Boeing 747 from the materials therein."

In the next lesson, we will examine the fascinating world of Kingdom Fungi.

LIFE PRINCIPLE



"The search for truth is the noblest occupation of man; its publication is a duty."

—Anne Louise Germaine de Stall (1766-1817)
Outspoken Swiss-French novelist, essayist

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Fungi

Lesson 11

Chapter 6

FUNGI— PART I

Section 3

Lessons 11-15



When you think of fungi, chances are the image you have is not a pretty one. To put it mildly, fungi have bad reputations. Some spoil food, others rot lumber or destroy trees, while still others can make us sick. The fungi have a well-deserved reputation as pesky and destructive organisms.

As we saw in a brief overview of fungi in the previous chapter, fungi fill a very important role in nature. They are the world's champions of decomposition. Without fungi to break down organic matter, the raw materials that go into each season of life would be lost and the earth would have long since become a barren place.

Fungi were listed in Kingdom Plantae for many years. Scientists decided that the design of fungi shows a closer similarity to animals, but are unique and separate life forms. Now, fungi are placed in their own kingdom. Fungi include a wide variety of organisms with different structures and different life cycles. However, all fungi have certain features in common.

VOCABULARY

Mycelium: mass of hyphae that grows in the food source and forms the body of the fungus

Hyphae (singular, hypha): threadlike, branching filaments that are the most basic structures in a fungus

Zygospore: a zygote (fertilized egg) surrounded by a protective covering

Ascus (pl: asci): tough sac of an ascomycete (fungus) that contains the spores produced by sexual reproduction

Ascospore: spore found within the ascus; from the Greek word *askos* meaning "skin bag"

General Features

Fungi are heterotrophs that obtain food by extracellular digestion and absorption. This means that they produce enzymes which break down food particles outside their bodies, then absorb the digested molecules. This process separates fungi from animals and plants, which obtain their energy in other ways.

The part of the fungus that we see is the "fruit" of the organism. The living body of the fungus is called the

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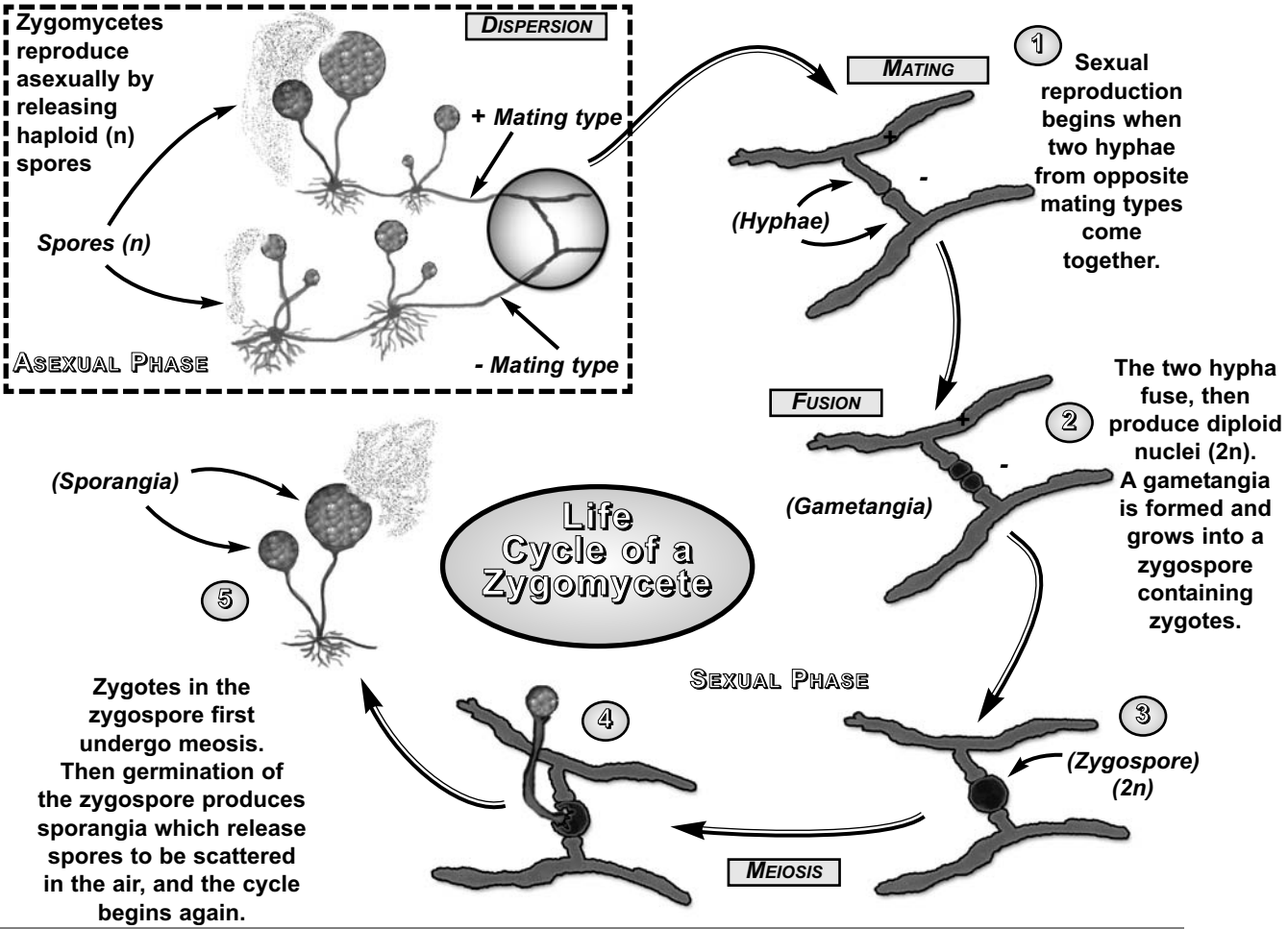
mycelium, which is made from a web of tiny filaments of the ***hyphae***. (Yeasts, which are unicellular fungi, do not have hyphae.). The mycelium is usually hidden in the soil, in wood, or another food source. A mycelium may be as small as a single ant, or cover many acres. The branching hyphae can add over one half mile (1 km) of total length to the mycelium each day. These webs live unseen until they develop mushrooms, puffballs, truffles, brackets, cups, "birds nests," "corals" or other fruiting bodies. If the mycelium produces microscopic fruiting bodies, the fungus may never be seen.

In most fungi, perforated cross walls separate individual cells. The holes in these cross walls join the cytoplasm of adjacent cells and this allows nutrients to move quickly through the hyphae.

All fungi reproduce asexually. They do so when cells or hyphae break off and begin to grow on their own. Some fungi also produce spores that can scatter a great distance.

In addition, many fungi have a sexual phase in their life cycles. Typically, these fungi have hyphae of two mating types called + (plus) and – (minus). When a + hypha fuses with a – hypha, the two nuclei come together in one cell. The two nuclei fuse to form a diploid (2n) nucleus, which eventually undergoes meiosis to produce haploid (n) spores.

Although fungi now have their own kingdom, much disagreement still occurs regarding their phylum and classification. Consequently, you may read about a very different classification system in other



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textbooks. For example, some textbooks will place the slime molds in the kingdom Fungi instead of the kingdom Protista. The writers of this textbook have chosen to use a very simplified classification system that is more easily understood and that is commonly accepted.

Fungi are classified into four different phyla according to their life cycles: *Zygomycota*, *Ascomycota*, *Basidiomycota* and *Deuteromycota*.

ZYGOMYCOTA

The zygomycetes are named for the thick-walled, diploid spore called a ***zygospore***. A zygospore is small and light enough to drift in the wind. Zygospores are quite resistant to damage.

Zygomycetes also produce spores asexually, which can help them to grow rapidly.

The most well known members of this phylum come from the genus *Rhizopus*, which contains most of the common bread molds. Because these fungi have several reproductive modes, their spores are in the air virtually everywhere. If you leave bread out in the open, bread mold spores will eventually land on it and, within a matter of days, the growing mold will be noticeable and probably distasteful. Most molds which grow on bread and other baked goods are harmless if consumed in small quantities. Recall that the drug penicillin is derived from bread mold. This does not mean, however, that bread mold should be eaten or used as an antibiotic.

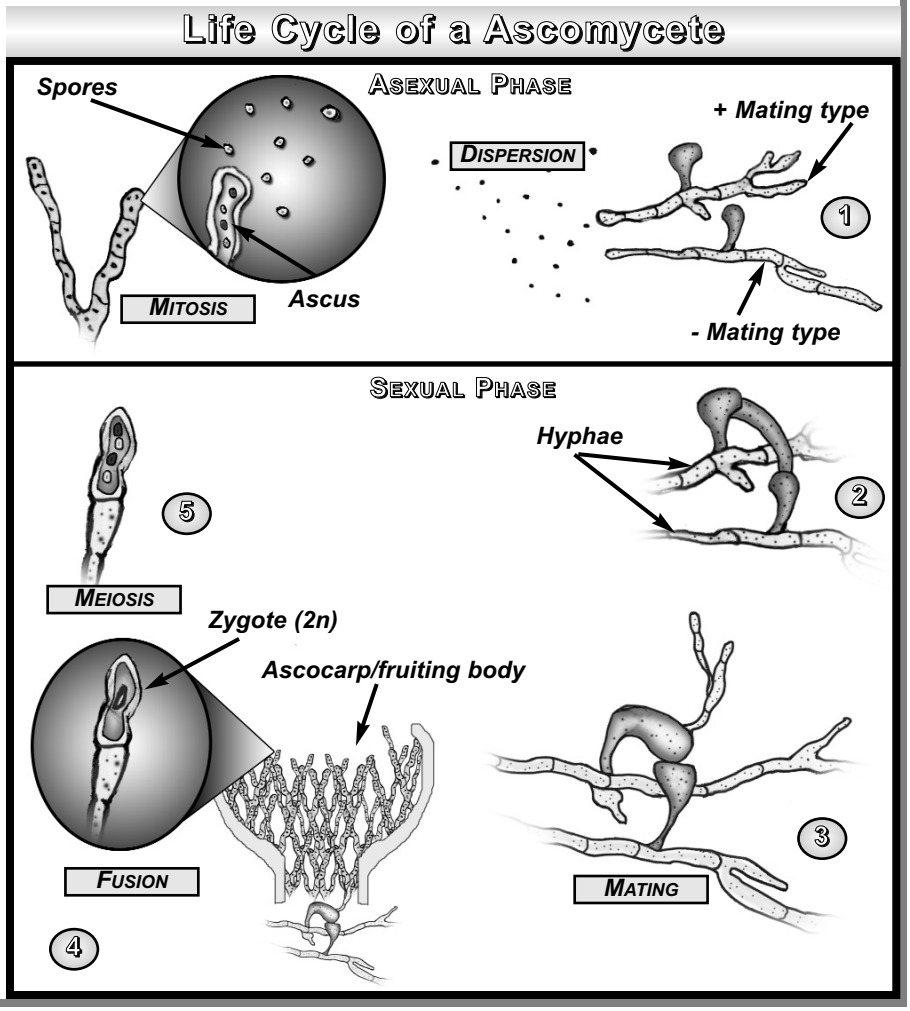
1. Ascomycetes reproduce asexually by releasing haploid spores called *conidia*.

2. In sexual reproduction, opposite mating types of hyphae join together to form a tube through which haploid nuclei from one mating type can unite with the other mating type.

3. Nuclei from both mating types pair up and begin to grow and weave tightly together to form a complex structure called an *ascocarp*, or fruiting body.

4. Some paired nuclei now fuse to form a diploid zygote, which immediately undergoes meiosis. Asci are also formed in ascocarp.

5. Four haploid nuclei are produced and undergo mitosis, producing eight hapoid nuclei. Nuclei develop into spores that are contained in asci which release mature spores, and the cycle repeats.

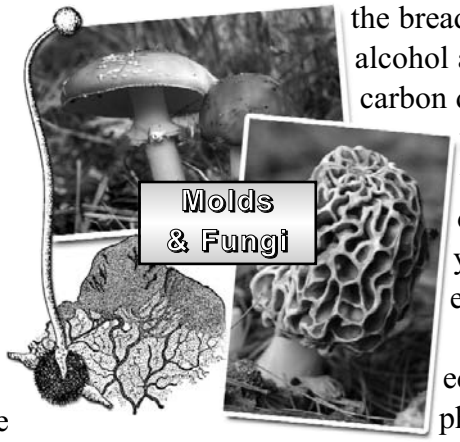


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ASCOMYCOTA

The phylum *Ascomycota* is named for the ***ascus***, a tough sac that contains the spores produced by sexual reproduction. These spores are called ***ascospores*** and they are produced by hyphae of opposite mating types. First, haploid nuclei from different hyphae fuse together, eventually forming a diploid nucleus. Then, the diploid nucleus enters meiosis and gives rise to 4 new haploid nuclei. In most ascomycetes, one or two rounds of mitosis follow meiosis, producing either 8 or 16 haploid ascospores.



The single-celled members of this class are generically called *yeasts*. The yeast that is used in cooking is an example of a single-celled member of the phylum, *Ascomycota*. Most yeasts are saprophytic, although parasitic yeasts exist as well. Yeasts are typically egg-shaped cells that are slightly larger than bacteria. Besides a nucleus, the only other organelle in a yeast cell is a vacuole that stores food substances. Certain species of yeasts use these vacuoles to store substances, such as vitamins, which are useful to humans. Some individuals eat these yeasts in ground-up powder form to obtain the vitamins.

Active dry baker's yeast, obtainable at grocery stores, contains *Saccharomyces cerevisiae* spores. When mixed with water, these spores mature into yeast cells which carry on the process of fermentation. Fermentation is responsible for making bread dough rise. The yeast, mixed in with the bread dough, begins to feed on the sugars in the bread, breaking them down into alcohol and carbon dioxide. Since carbon dioxide is a gas, it pushes its way out of the dough, causing the dough to rise. When the dough is put in the oven, the yeast is killed and the alcohol evaporates.

Many of the tasty, edible fungi belong to the phylum *Morels*, whose fruiting bodies resemble sponges, and are one of the most sought-after forms of edible fungi.

In the next lesson, we will examine the remaining two fungi phyla: Basidiomycota and Deuteromycota.

WATCH VIDEO: Fungi (Fungi Video #1)

WATCH VIDEO: Fungi (Fungi Video #2)



LIFE PRINCIPLE

"Nature never breaks her own laws."

—Leonardo DaVinci (1452-1519)
Master Italian artist, scientist, inventor, engineer

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Fungi

Lesson 12

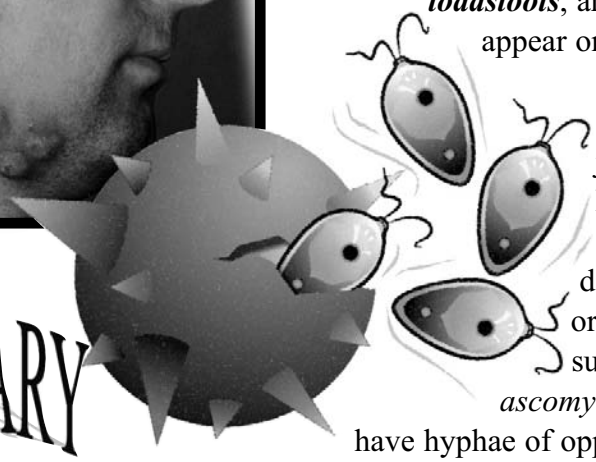
Chapter 6

Section 3

Lessons 11-15

FUNGI—PART II





VOCABULARY

Toadstools: poisonous mushroom "lookalikes"; from the German word *tod-stukl*, meaning "death stool"

Fairy ring: a circular formation of mushrooms associated with elves, fairies amd magic powers of mythical folklore

Athlete's foot: a contagious fungal infection of the skin, normally affecting warm, moist areas of the feet; characterized by tiny, itchy blisters that break open

Antibiotic: a chemical secreted by a living organism that kills or reduces the reproduction rates of other organisms

BASIDIOMYCOTA

Members of phylum *Basidiomycota* are often called the "club fungi" and include nearly all the organisms commonly called mushrooms. This phylum also includes puffballs, ***toadstools***, and the bracket fungi that appear on the trunks of trees.

The visible structure of a *basidiomycete* is actually just its fruiting body. Beneath the soil is mycelium that has slowly digested its way through organic matter to reach the surface. Just like the *ascomycetes*, the *basidiomycetes* have hyphae of opposite mating types. In *basidiomycetes*, however, the + and - hyphae donate nuclei to produce a structure called a secondary mycelium. A secondary mycelium can grow beneath the soil for many years. Some reach enormous sizes, often many meters in diameter. When conditions are right, the secondary mycelium produces a fruiting body, the mushroom, which forces its way upward through the soil.

Within the mushroom, haploid nuclei fuse and undergo meiosis, producing clusters of haploid spores called *basidiospores*. These spores appear in "gills" on the underside of the mushroom. A single mushroom can produce as many as a million spores, each with the potential of producing a new organism.

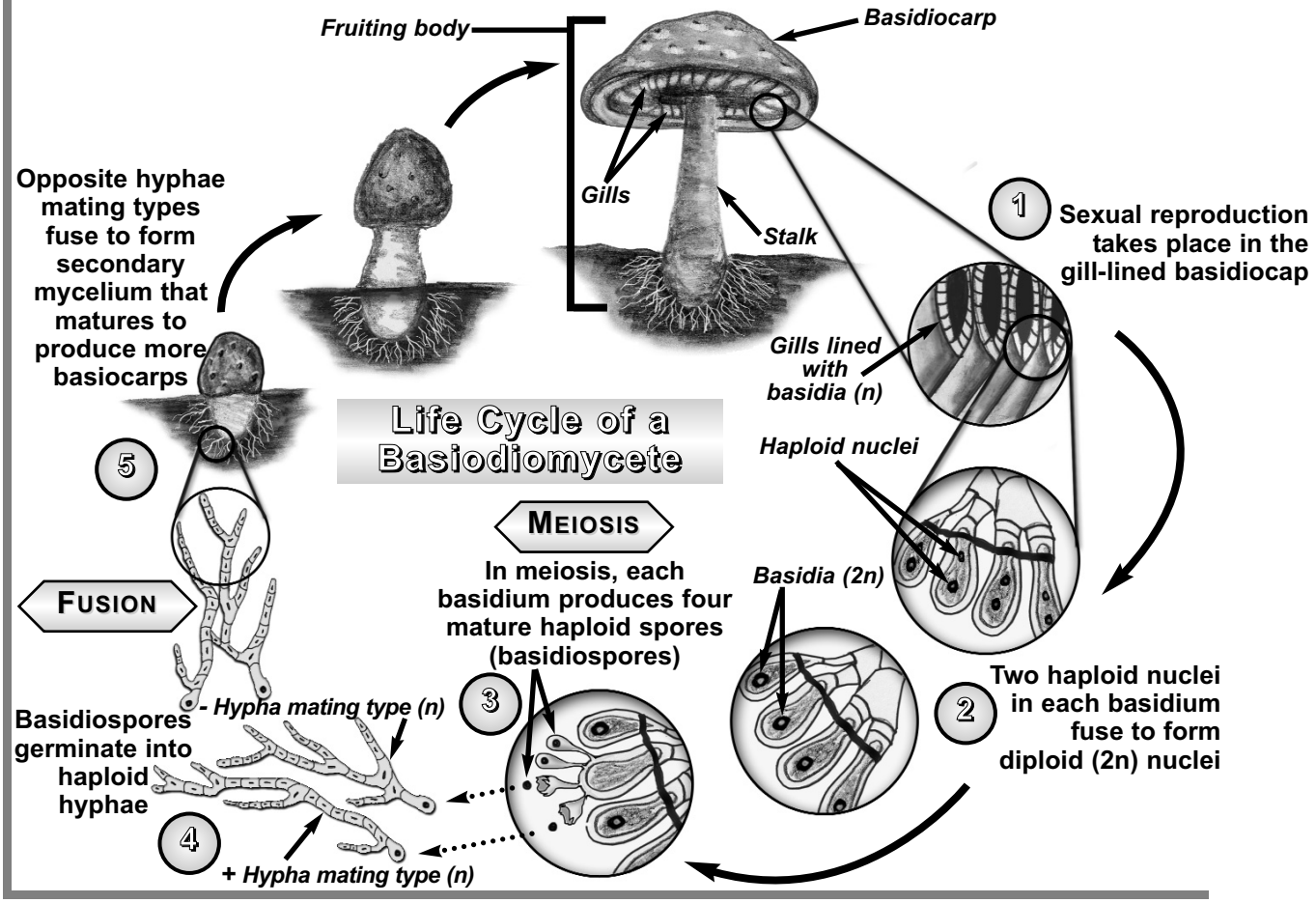
The fruiting body of the mushroom is the part that is edible. Although most mushrooms are tasty, and even nutritious, many are quite toxic. The genus *Amanita* contains mushrooms which are commonly called "destroying angel" mushrooms. These pure white mushrooms carry a poison that is deadly to humans. If you were to eat one of these

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mushrooms, it would taste quite normal. However, if this type of mushroom were ingested, the individual would die within 16 hours. Virtually nothing can be done to treat a person who has eaten these deadly mushrooms. Because no truly distinguishing marks exist that can separate poisonous mushrooms from non-poisonous ones, the only place that you should hunt for mushrooms is in the grocery store.

Mushrooms may be found growing in an almost perfect circle. Inside or outside of this ring of mushrooms, no other mushrooms grow. These rings, called ***fairy rings***, are believed by some to have magical properties because of their unique appearance. However, scientists know that this phenomenon is simply a result of the saprophytic nature of the fungus. When a fungal mycelium begins to grow in an area, it eats the remains of dead organisms. As it eats, it grows and reproduces. Eventually, the mycelium will spread out in all directions, making a relatively circular patch of hyphae. Once the hyphae in the center of the circle eat up all the remains of dead organisms, no food is left for them and they die. The hyphae at the edge of the mycelium, however, still have food because they haven't lived long enough to use up the food in their area. As a result, they continue to live and the mycelium becomes ring-shaped. When it is time to reproduce, the ring produces fruiting bodies, forming the so-called fairy ring. This happens year after year and the ring becomes larger each year. Some fairy rings have been found in which the ring of mushrooms was only a few inches wide, but the circle had a diameter of nearly 20 feet.



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DEUTEROMYCOTA

Members of phylum *Deuteromycota* are commonly called the "imperfect fungi" because they are believed to reproduce only through asexual spores. The deuteromycetes include a number of well-known organisms. Both ***athlete's foot*** and ***ringworm*** are produced by deuteromycetes.

One of the most useful, imperfect fungi is the genus *Penicillium*, from which we get the drug *penicillin*. In 1929, Alexander Fleming, an English physician, discovered this drug quite by accident. He had taken a short vacation, leaving a bacteria culture open to the air. When he returned, he saw that the culture was overrun by bacteria except in a certain place where a blue mold was forming. The blue mold seemed to be producing a substance that killed the bacteria. Fleming isolated the chemical and called it *penicillin*. With the help of two other scientists, he demonstrated that this substance, when ingested by sick persons, could kill the bacteria associated with many human sicknesses. Thus, the first ***antibiotic*** was discovered.

Other members of the genus *Penicillium* are useful to us because they flavor certain cheeses. Camembert and Roquefort cheeses are both flavored by the growth of *Penicillium* species.

Antibiotics can be very effective in killing many bacteria which cause disease. After a while, however, the medicines often lose their effectiveness. A colony of bacteria that is being destroyed by an antibiotic can, under certain conditions, produce offspring that are not at all affected by the antibiotic. Thus, the bacteria become immune to the effect of the antibiotic. As antibiotics are overused, more and more strains of bacteria develop immunity to the antibiotics. To counter this, medical scientists must find new antibiotics to which the bacteria are not resistant. This is a constant struggle. In fact, the more antibiotics are used to cure disease, the less effective they become because the very act of using an antibiotic can give rise to a strain of resistant bacteria!

Some scientists point to this process as an example of beneficial mutations during an evolutionary process. What has actually happened in these cases is that some bacteria *already* had the genes for resistance to the antibiotics. When antibiotics are applied to a population of bacteria, those lacking resistance are killed and any genetic information they carry is eliminated. By the process of natural selection, the survivors carry less information, but they are all resistant. Through natural selection, organisms without resistance are eliminated. Survival of the fittest is at work, but not evolution of a new species.

In the next lesson, we will examine the role of fungi in our health.

LIFE PRINCIPLE



"The whole history of science has been the gradual realization that events do not happen in an arbitrary manner, but that they reflect a certain underlying order. . . ."

—Stephen Hawking
Noted British physicist

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Fungi

Lesson 13

Chapter 6

FUNGI AND DISEASE

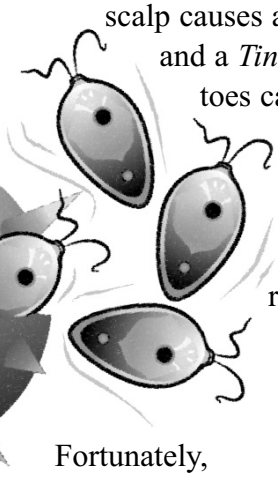
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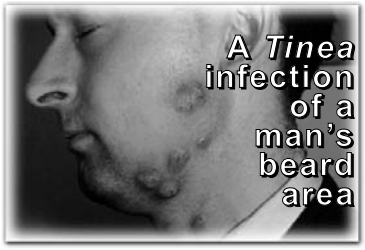
Lessons 11-15



Although fungi cause a few serious diseases, many common fungal diseases are relatively harmless and easy to treat.

A deuteromycete of the genus *Tinea*, for example, attacks human skin but does not invade the body any farther. A *Tinea* infection of the scalp causes a disease called ringworm, and a *Tinea* infection between the toes causes athlete's foot. In both diseases, *Tinea* spores produce hyphae that penetrate the skin's outer layers, causing a red, inflamed sore.





A *Tinea* infection of a man's beard area

Fortunately, applying antifungal medicines to the infected area can cure *Tinea* infections.

VOCABULARY

Oral thrush: a fungal disease of the mouth, seen mainly in infants; characterized by white patches in the oral cavity

Dimorphic: existing in two different shapes and forms

Rhizoid: root-like structure which anchors a candida albicans and absorbs water and nutrients from its environment

Antigenic: causing an allergic reaction

FUNGAL DISASTERS OF THE PAST

Claviceps purpurea, better known as "ergot of rye", can be deadly to humans. As its popular name implies, it feeds on rye grain. People who eat bread made with rye containing *Claviceps purpurea* often die. History tells us that Peter the Great was thwarted in his efforts to conquer the known world because his troops were fed rye bread contaminated with this fungus. In addition, many historians believe that certain calamities which plagued the early settlers in New England were caused by rye containing *Claviceps purpurea*. Unfortunately, the settlers had no knowledge about this fungus; so they blamed it on witches, which factored into the infamous Salem witch trials in colonial Massachusetts.

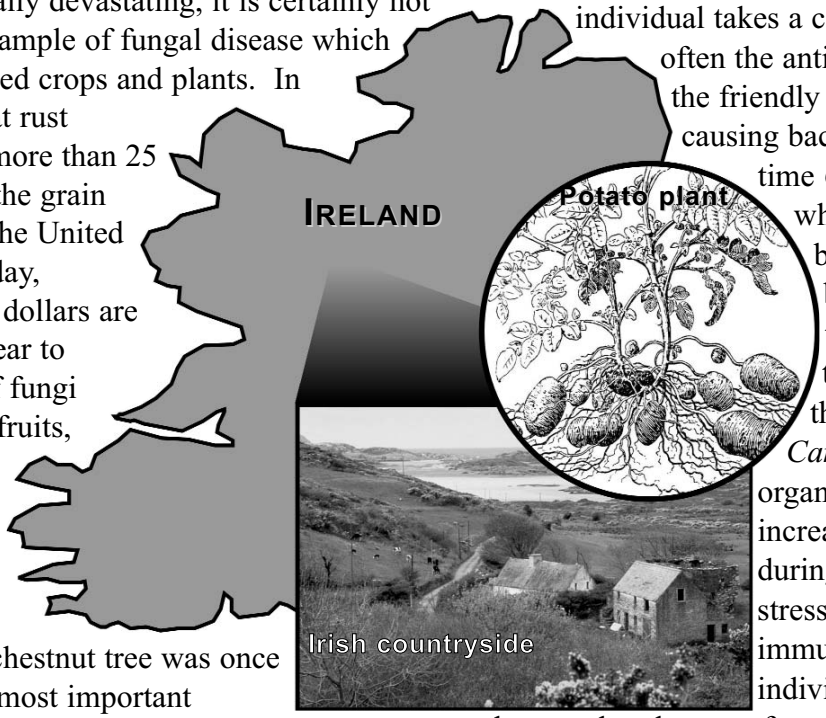
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In 1845, the potato was the major food crop of Ireland. Unfortunately, the summer of 1845 was unusually wet and cool, providing ideal conditions for the water mold, *Phytophthora infestans*. The threadlike hyphae of this mold invaded the roots, stems and leaves of potato plants, eventually killing them entirely.

Phytophthora destroyed almost 60 percent of Ireland's potato crop in 1845, and the damage was even worse the following year. Over a million people died from the Great Potato Famine, as the event has been called. It also led to the emigration of at least 2 million people from Ireland to the United States.

Although the Great Potato Famine was especially devastating, it is certainly not the only example of fungal disease which has destroyed crops and plants. In 1935, wheat rust destroyed more than 25 percent of the grain harvest in the United States. Today, millions of dollars are lost each year to fighting off fungi that attack fruits, grains, vegetables and other crops.



The American chestnut tree was once one of our most important sources of hardwood lumber. The fungus that causes chestnut blight, *Cryphonectria parasitica*, spread so quickly across America that the American chestnut tree was completely wiped out. Likewise, many regions have lost their elm trees due to the fungus that causes Dutch elm disease, *Ophiostoma ulmi*.

CANDIDA ALBICANS

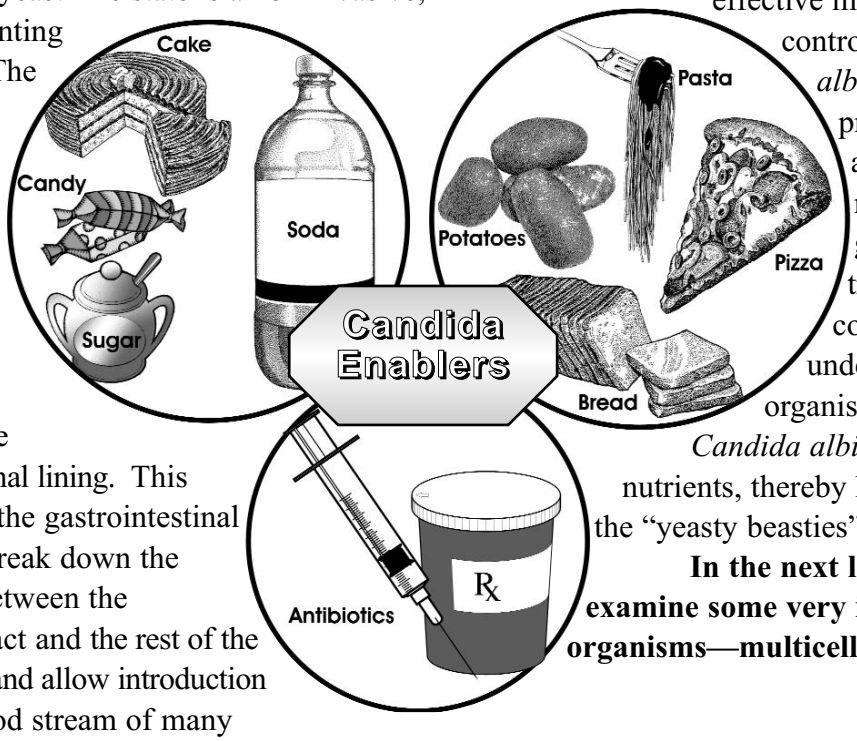
The yeast, *Candida albicans*, is a parasite present in all of us not long after birth. It lives in our intestinal tract and is one of the many organisms which make up our intestinal flora. Under normal conditions, *Candida albicans* does not cause any problems to an individual. As we studied in a previous lesson, some of the organisms living in this flora are helpful and healthy. The friendly organisms help maintain a balance and aid our immune system in keeping the "not-so-friendly" or unhealthful organisms under control. When the friendly intestinal flora are well entrenched, *Candida albicans* is kept in such small numbers it cannot be harmful However, when an individual takes a course of antibiotics, often the antibiotics kill off both the friendly and the disease-causing bacteria. At the same time *Candida albicans*, which is not affected by the antibiotics, begins to proliferate to take the place of the friendly flora that were killed. The *Candida albicans* organism may also increase its numbers during long periods of stress or lowered immune potential of the individual. It is well known that the use of steroids for a long period of time can increase the *Candida* population in the intestinal tract, as well as the regular use of oral contraceptive medications and high-sugar diets. Two of the common manifestations of *Candida albicans* are ***oral thrush*** and vaginitis. Another is diaper rash seen in infants. Researchers have recently

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discovered a number of other problems that may be caused by a *Candida albicans* overgrowth, including constipation, diarrhea, colitis, abdominal pain, headaches, bad breath, memory loss, mood swings, canker sores, persistent heartburn, muscle and joint pain, sore throat, congestion, nagging cough, night sweats, itching, clogged sinuses, pre-menstrual syndrome, fatigue, depression and a number of other varied symptoms.

As *Candida albicans* proliferates in the intestines, the organism's anatomy and physiology can change from its yeast-like form to a mycelial fungal form. *Candida albicans* is well recognized as a ***dimorphic*** organism and, as such, can exist in these two states. The yeast-like state is a non-invasive, sugar-fermenting organism. The fungal state produces ***rhizoids***, or very long root-like structures which can agressively penetrate the gastrointestinal lining. This invasion of the gastrointestinal lining can break down the boundary between the intestinal tract and the rest of the circulation, and allow introduction into the blood stream of many substances which may be ***antigenic***. Such things as incompletely digested dietary protein may be delivered to the blood through the portals of entry of the intestinal tract produced by the invasive mycelia of the fungal form of *Candida albicans*. This may explain why many individuals who have chronic *Candida* overgrowth, and a high percentage of the mycelial form of the organism, commonly show a wide variety of food and environmental allergies. These incompletely digested dietary proteins can then travel into the bloodstream and exert a powerful antigenic assault on the immune system, which is seen as allergies, even producing a wide variety of effects of mental dysfunction such as depression, mood swings, and irritability.

Medical researchers are finding that *Candida albicans* can be controlled through diet and anti-fungal supplementation. The use of probiotics, as we discussed in a previous lesson, is proving to be a very effective means of controlling *Candida albicans*. When the probiotic bacteria are in sufficient numbers in the gastrointestinal tract, they can compete with undesirable organisms, such as *Candida albicans* for nutrients, thereby helping to keep the "yeasty beasties" under control.



In the next lesson, we will examine some very interesting organisms—multicellular algae.

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LIFE PRINCIPLE



"It is possible to see the sacred in the science of life."

—Sharon Bagly
Wall Street Journal science editor

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Algae

Lesson 14

Chapter 6

Section 3

Lessons 11-15

ALGAE—PART I



General Characteristics

At high tide on a winter's day, the Maine coastline seems like a cold and barren place. Icy water crashes against gray rocks and little evidence of life exists. However, just six hours later at low tide, the scene is quite different. The pull of the Moon's gravity drops the waterline to reveal a damp forest of green and brown seaweeds clinging to the rocks. Even as waves beat against them, these persevering, underwater organisms hang onto the rocks. Coastal seaweeds are called *algae* and are hardy underwater organisms, bringing life to the cold salt water, providing food, and even shelter, for a myriad of animals. Coastal seaweeds are dramatic reminders of the way in which plant life has been placed into every corner of the planet, and the design by which plants continue to benefit the world in which we live. These are the algae—often called the "grass of the sea." In either salt water environments or freshwater environments, algae abound. In fact, the "fishy smell" and slimy feel of a body of water is usually due to the algae floating in it.

Algae are photosynthetic, aquatic organisms that are classified as protists. As we learned in a previous lesson, oxygen is generally the by-product of photosynthesis. The process of photosynthesis is responsible for replenishing Earth's oxygen. Virtually all of the organisms on Earth need to breathe oxygen in order to survive. Plenty of oxygen exists because photosynthetic organisms are always producing more oxygen. The vast majority of photosynthesis on Earth is accomplished by algae. In fact, biologists estimate that nearly

VOCABULARY

Carotenoids: yellow orange pigments found in brown algae; includes the xanthophylls and fucoxanthins (few-co-zan-thins)
Air bladder: an air-filled structure found in rockweed brown algae which gives the organism buoyancy in water
Alginic acid: a gelatinous substance extracted from brown algae and used as an emulsifier or stabilizer in foods
Phycoerythrin: bright red pigment giving red algae their color

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75% of all oxygen on Earth is produced by algae. Earth would quickly become uninhabitable if the waters of the planet became too polluted to support algae.

Algae are generally unicellular and comparatively simple organisms. We have already discussed three of the algae phyla in a previous lesson: *Euglenophyta*, *Pyrrophyta* and *Chrysophyta*. (Remember that these algae are unicellular.) However, the seaweed algae such as seen on rocky seashores at low tide are *multicellular*. Many of the algae in the remaining phyla are multicelluar, like plants, and also have reproductive cycles that are very similar to plants.

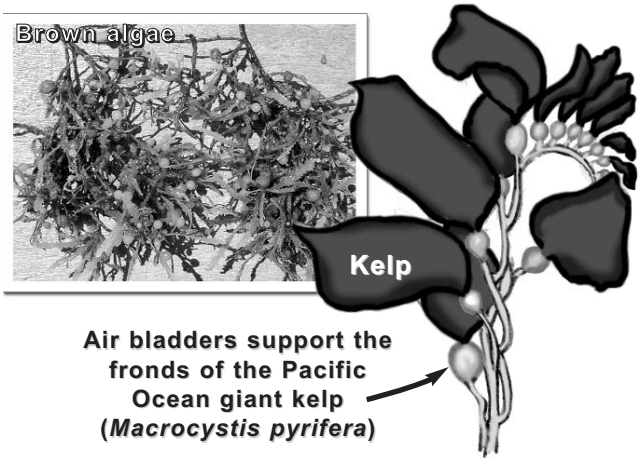
PHAEOPHYTA (BROWN ALGAE)



Atlantic Ocean brown algae "ribbon kelp" (most common)

Phylum *Phaeophyta* is comprised of multicellular organisms that inhabit cold ocean waters. The difference between a colony of single-celled organisms and multicellular organisms is quite simple. In a colony of single-celled organisms, each organism can exist on its own. Although they tend to group together for mutual protection and other such benefits, if a cell is split away from its colony it can survive. In addition, although the cells tend to live together, they generally perform life functions independently. In a multicellular creature, the individual cells are designed to specialize in individual tasks. The cells work together, each performing the tasks they are designed to accomplish. In the end, the organism survives because the cells work together. Since these cells are specialists in only one, or a few, of the tasks necessary for life, a single cell that is separated from a multicelluar creature usually cannot exist on its own.

Brown algae contain ***carotenoids*** or yellow-orange pigments that help them gather sunlight for photosynthesis. When these pigments are combined with the green pigment *chlorophyll*, the result is a dingy-brown color that explains the name of their phylum, *Phaeophyta*, which means "dusky plants" in Greek.



All brown algae are multicellular and some are very large. The brown algae known as giant kelp can be as long as 150 feet (46 meters). This kind of algae has a fascinating structure called an ***air bladder*** which can fill with air to allow the organism to float on top of the water. One of the most common forms of algae is *Fucus* (few-cus), often called "rockweed" because of the way in which it attaches to rocks. Such algae is found almost

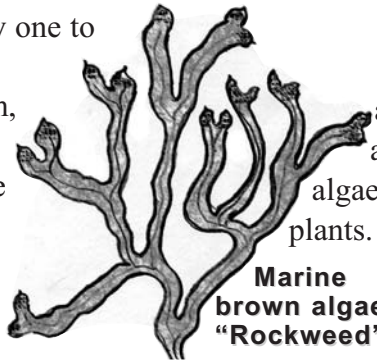
VOCABULARY

Agar: a gelatinous food source from red-algae; used as a culture media and thickening agent for foods such as pudding
Cellulose: a structural polysaccaride; the "woody" component of cell walls; from the Latin word *cellula*, meaning "small room"
Chlamydomonas: a unicellular green algae

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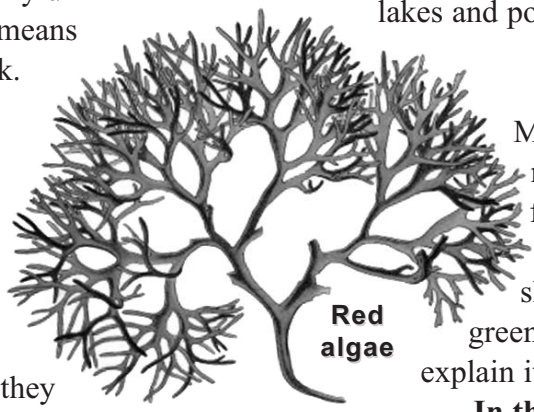
everywhere on the eastern coast of the United States and is generally one to two feet long.

If you enjoy ice cream, pudding, salad dressing or jelly beans, you can thank the members of the brown algae phylum. One of the unique characteristics of the organisms in this phylum is that their cell walls contain ***alginic acid,*** commonly called *algin*. This substance is extracted from brown algae and used as a thickening agent in foods. In addition, algin is often used in cough syrup, toothpaste, cosmetics, paper and floor polish.


Marine brown algae "Rockweed"

Rhodophyta (Red Algae)

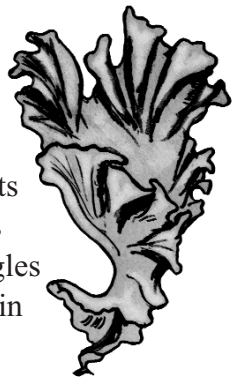
Red algae get their name from ***phycoerythrin***, a bright-red pigment used to supplement chlorophyll in photosynthesis. They belong to the phylum *Rhodophyta*, which means "red plants" in Greek. Despite this name, many red algae are green, purple or reddish-black, depending on the particular combination of additional pigments they contain. These extra pigments enable many red algae to live at great depths where little sunlight penetrates.


Red algae

Red algae are a source of ***agar***, which is often a food additive. Biologists also use agar to culture bacteria.

Chlorophyta (Green Algae)

While most brown and red algae are found in salt water, most green algae live in fresh water. Green algae are remarkably similar to green plants. *Chlorophyta* means "green plants" in Greek. Like plants, green algae have cell walls made of ***cellulose*** and store food in the form of starch. Although most green algae are aquatic, a few are found on land in wet soil or growing on moist tree trunks. Many green algae, such as ***Chlamydomonas***, live all or most of their lives as single cells. Some, however, form multicellular structures. *Spirogyra* consists of long filaments that produce tangles of greenish fuzz in lakes and ponds.


"Sea Lettuce" (*Ulva*)


Green algae

Members of *Spirogyra* get their name and unusual appearance from their spiral chloroplasts. *Ulva* is found along ocean shorelines and has large, bright-green, leaflike sheets that help to explain its common name—sea lettuce!

In the next lesson, we will examine reproduction in algae.

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LIFE PRINCIPLE



"The real voyage of discovery consists not in seeking new landscapes, but in having new eyes."

–Marcel Proust (1871-1922)
French novelist

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Algae

Lesson 15

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ALGAE— PART II

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Most photosynthetic algae have life cycles that involve both sexual and asexual stages. Their reproductive patterns are quite similar to plants.

Chlamydomonas cells have a single set of chromosomes, which means they are haploid (n). Under ordinary circumstances, *Chlamydomonas* undergoes asexual reproduction as illustrated. Notice that mature cells divide by mitosis to produce haploid cells, which are called *zoospores*. A zoospore is a reproductive cell that can produce a new individual simply by cell division.

If environmental conditions are unfavorable—especially when the cells are starved for nutrients—*Chlamydomonas* enters the sexual phase of its life cycle. The cells divide to produce haploid (n) ***gametes*** of two different

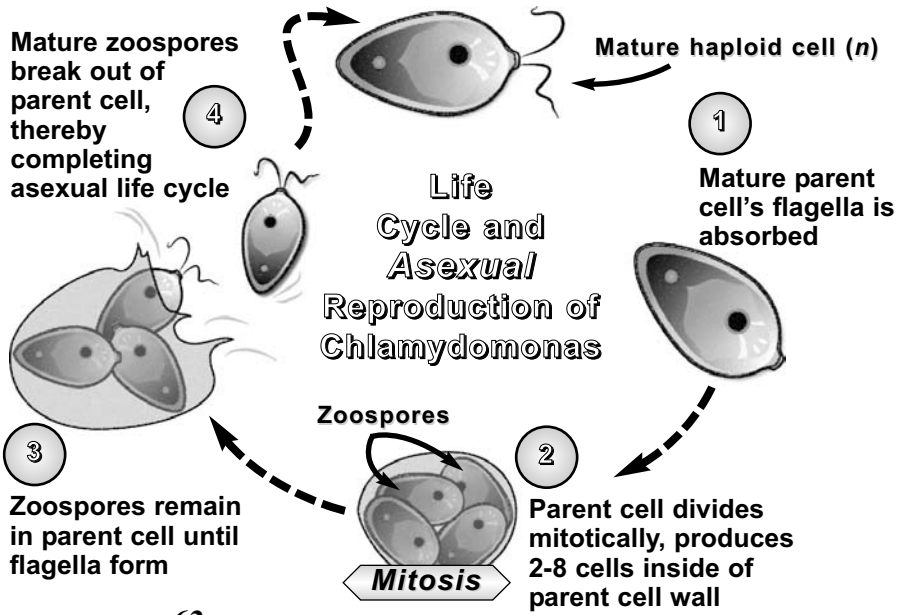
VOCABULARY

Gamete: a haploid reproductive cell that can unite with another haploid cell to form a new individual

Zygote: fertilized egg

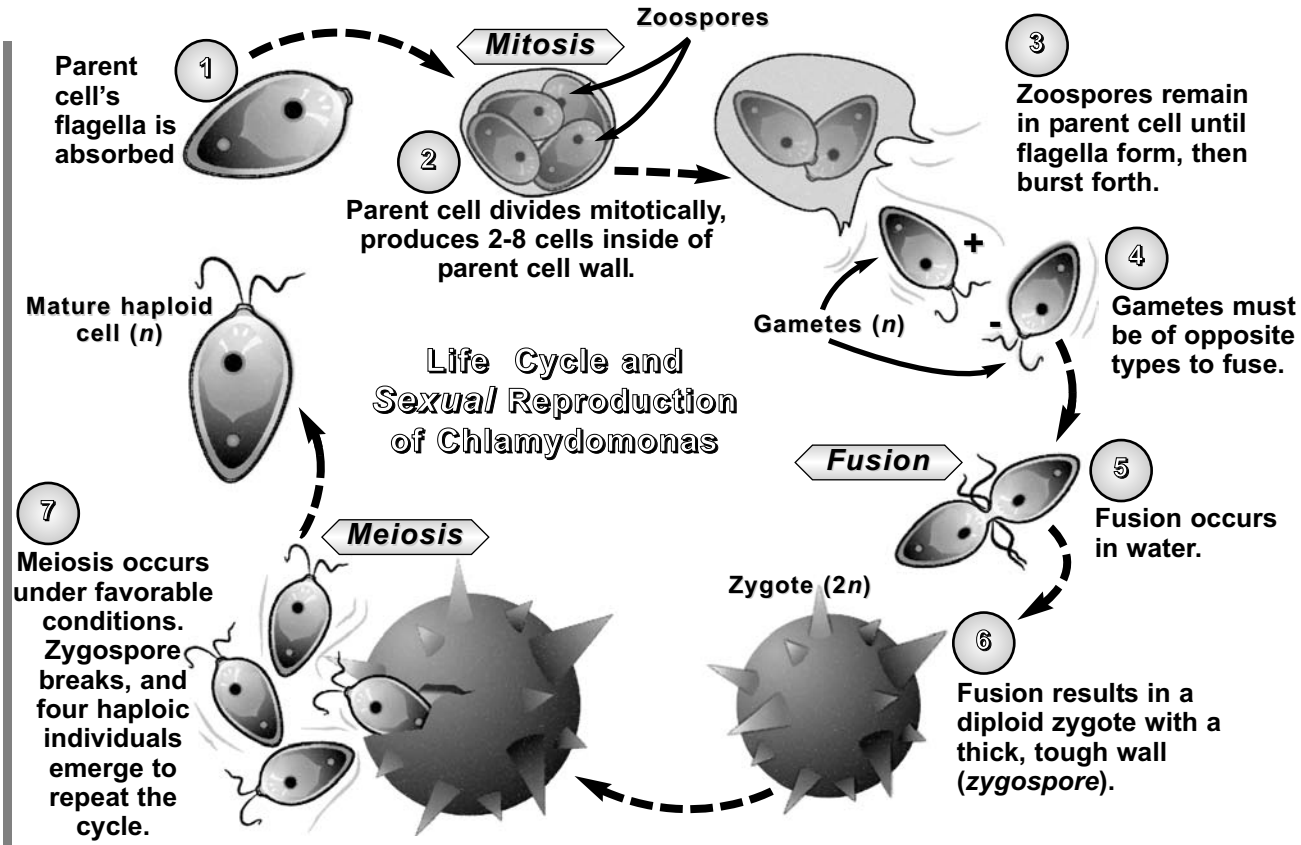
Sporophyte: in plants, the diploid spore-bearing generation that reproduces by spores

Gametophyte: in plants, the haploid gamete-bearing generation that reproduces by fertilization



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mating types. A *gamete* is a mature reproductive cell that can produce a new individual only after fusing with a gamete of the opposite mating type. Interestingly, in Greek, *gamete* means "husband", and in French it means "marriage".

The ***zygote*** resulting from the union of the gametes grows a thick, protective wall that enables it to survive under extremely harsh conditions, such as when a pond dries up or freezes over. When favorable conditions return, the zygote goes through meiosis and produces four haploid cells that break out of the protective wall and swim away. These cells begin the life cycle all over again.

The life cycle of *Ulva* ("sea lettuce") is somewhat similar to that of *Chlamydomonas*, but some important differences exist. As you can see from the illustration, the diploid and haploid phases of *Ulva's* life cycle are both multicellular. Even though the organisms of these two stages look almost identical, they produce completely different kinds of reproductive cells. The life cycle of *Ulva* contains a hint of the pattern that you will see in plants quite often. Notice that the cycle contains two separate generations: the ***sporophyte*** and the ***gametophyte***. Because the organism always

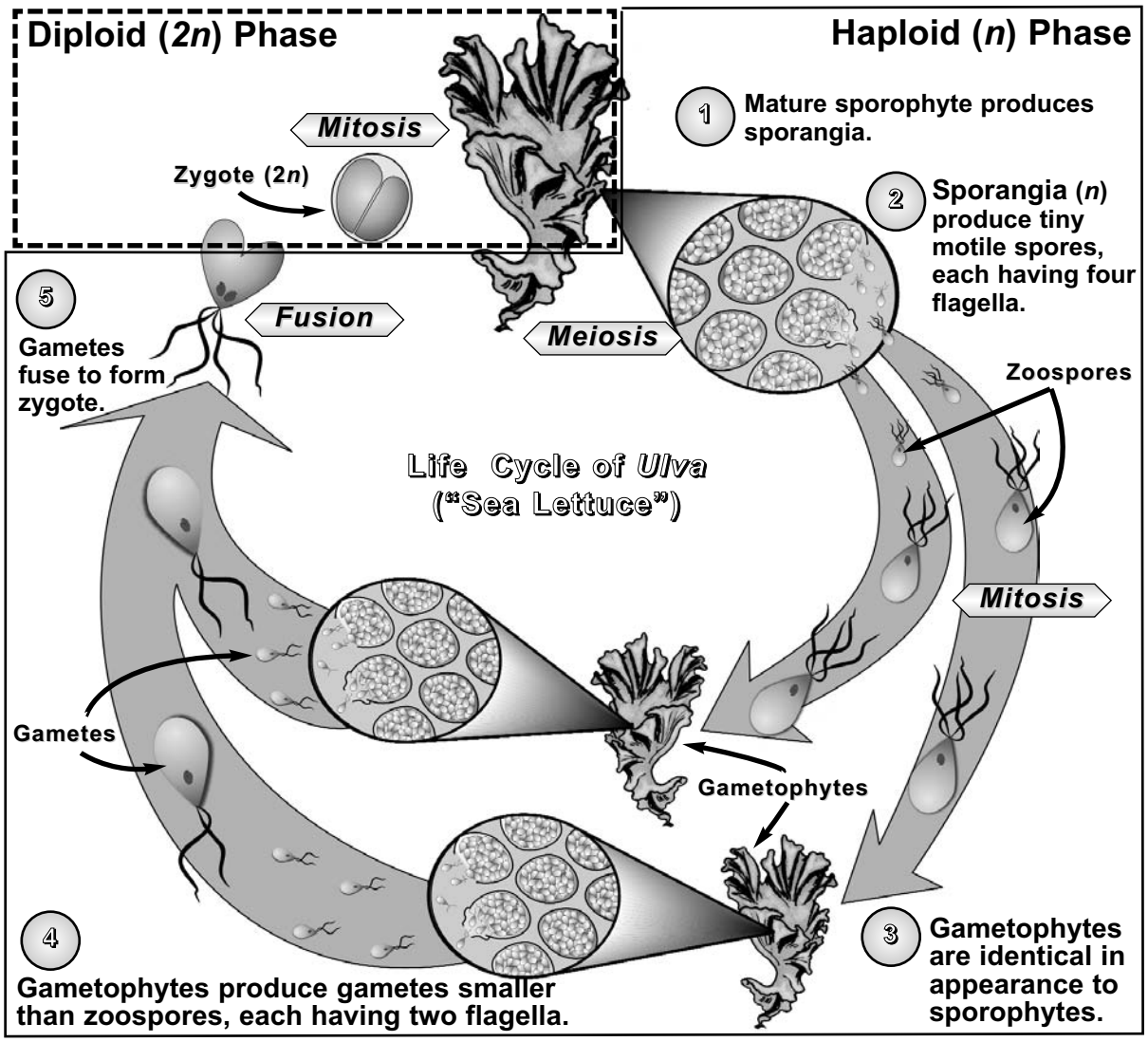
VOCABULARY

Alternation of generations: variation in a life cycle that switches back and forth between the phases of diploid (2n) and haploid (n) cells; in plants, pattern of reproduction in which the organism alternates between sporophyte and gametophyte

Sporangia: spore cases in which asexual spores are produced

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Alternation of Generations in the Life Cycle of *Ulva*

alternates between sporophyte and gametophyte phases, this pattern of reproduction is called the ***alternation of generations***. Nearly all plants also follow this pattern in their life cycles.

LIFE PRINCIPLE



"Everything is determined, the beginning as well as the end, by forces over which we have no control. It is determined for insects as well as for the stars. Human beings, vegetables or cosmic dust, we all dance to a mysterious tune. . . ."

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

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