Biological Characteristics of Water

Microorganisms and Disease

Today we know that disease-causing microorganisms can be carried in water and that their presence in drinking water is a serious hazard to human health. But that knowledge is relatively new. In 1676 a Dutch scientist was able to see bacteria using a very primitive microscope, but it wasn't until the mid and late 1800s that we began to understand that bacteria caused disease and that they can be carried in water. Microorganisms that cause disease by transmission through contaminated water are called **waterborne pathogens**[23].

[23] Waterborne Pathogens – Bacteria, virus, and protozoa that cause disease and are carried by water.

One of the main jobs of water system operators is to control potentially pathogenic microorganisms. So it is important that they are familiar with the different types of microorganisms and their characteristics.

Microbiology

Definition

Microbiology is the study of microorganisms, of small living things. Although some forms of organisms studied by microbiologists can be seen with the naked eye, most of the things that microbiologists are interested in require the use of a microscope to see clearly. Microorganisms of interest to the water industry include the following:

- Bacteria
- Protozoa
- **Viruses**[24]
- Algae
- **Fungi**[25]

[24] Virus – A submicroscopic organism that passes through filters capable of removing bacteria.

[25] Fungi – Non-chlorophyll-bearing plants that lack roots, stem, or leaves, that occur in water, sewage or sewage effluents, and that grow best in the absence of light.

What to Study

To understand how to minimize growth and control pathogens, you must study the structure and characteristics of the microorganisms. In the sections to follow, we will look at size, shape, types, nutritional needs, and control of each of the major groups of microorganisms. We will also discuss some of the specific waterborne pathogens.

Bacteria

Most Common Microorganism

Bacteria are among the most common microorganisms in water. Bacteria are primitive, single-celled organisms with a variety of shapes and nutritional needs.

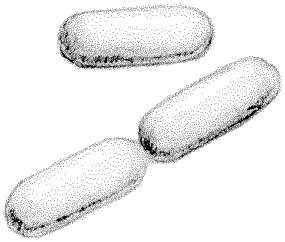
Size Range

Bacteria range in size from 0.5 to 2 microns in diameter and about 1 to 10 microns in length. A micron is a metric unit of measurement equal to one-millionth of a meter or one-thousandth of a millimeter. Another way to visualize the size of bacteria is to consider that it would take about 1000 bacteria, lying side-by-side, to reach across the head of a straight pin.

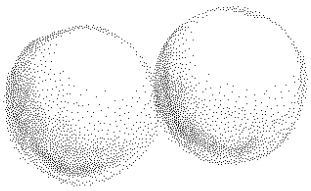
Three Shapes

There are three general groups of bacteria based on their physical shape:

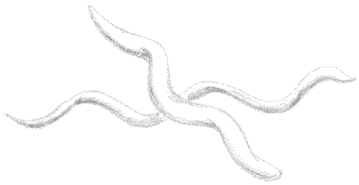
- **Rod-shaped bacteria** are called bacilli.
- **Spherical-shaped bacteria** are called cocci.
- **Spiral-shaped bacteria** make up the third group.



Bacilli



Cocci



Spiral-shaped bacteria

Within these three groups, there are many different arrangements. Some exist as single cells, others as pairs, as packets of four or eight, as chains, and as clumps.

Food Requirements

Most bacteria require organic food to survive and multiply. This food comes from plant and animal material that gets into the water where the bacteria exist. The bacteria convert the food to energy and use the energy to make new cells. Some bacteria can use inorganics (such as iron) as an energy source. These bacteria can exist and multiply even where organic pollution is not present.

Temperature Requirements

Temperature affects the rate at which bacteria grow. The warmer the environment, the faster the rate of growth. Typically, for each increase of 10° C, the growth rate doubles. This means that bacteria will multiply more quickly when it is warm, and more chlorine may be required to obtain proper disinfection.

pH Requirements

pH affects bacteria growth. Most bacteria grow best at a neutral pH. Extreme acidic or basic conditions will inhibit growth. Other materials, such as metal ions (copper, lead, silver), and some organics, such as pesticides and herbicides, are toxic and inhibit bacterial growth.

Oxygen Requirements

Many bacteria are **aerobic**[26]. They require free or dissolved oxygen in their aquatic environment. A few bacteria are **anaerobic**[27]. They can exist and multiply in an environment that lacks dissolved oxygen. Some bacteria that are normally aerobic can switch to anaerobic. These adaptable bacteria are said to be **facultative**[28]. One of the most troublesome bacteria in the water business is the iron bacteria, which is a facultative organism. The bacteria responsible for most of the biological treatment of wastewater are aerobic.

[26] Aerobic – A condition in which "free" or dissolved oxygen is present in the aquatic environment.

[27] Anaerobic – A condition in which "free" or dissolved oxygen is not present in the environment.

[28] Facultative – Microorganisms that can switch from aerobic to anaerobic growth or can grow in an anaerobic or aerobic environment.

How They Multiply

Under optimum conditions, bacteria grow very rapidly. They multiply by a simple dividing process referred to as binary fission. Each cell splits into two identical new cells. Bacteria growing under optimal conditions can double their number about every 20 to 30 minutes. This means that as long as nutrients hold out, even the smallest contamination can result in a sizable growth in a very short time.

Disinfection Process

The destruction of pathogenic microorganisms is called disinfection. Disinfection does not mean that all microbial forms are killed. Rather, that is **sterilization**[29]. However, disinfection does destroy most disease-causing organisms and reduces the total number to an acceptable level. Growing bacteria are fairly easy to control by disinfection. Some bacteria, however, form spores, which are much more difficult to destroy. **Spores**[30] are survival structures formed by some bacteria to resist harsh, threatening environments.

[29] Sterilization – The process of destroying all living organisms.

[30] Spores – A resistant, viable structure regarded as the resting stage of an organism.

Pathogenic Bacteria

Bacteria are responsible for a number of the most infamous epidemic diseases. The bacterial pathogens responsible for these diseases enter potential drinking water supplies through fecal contamination and are ingested by humans if the water is not properly treated and disinfected.

The table below lists a number of bacterial waterborne diseases.

Bacteria	Disease
Salmonella typhi	Typhoid Fever
Shigella spp.	Gastroenteritis
Vibrio cholerae	Cholera
Campylobacter spp.	Gastroenteritis
Enteropathogenic *E. coli*	Gastroenteritis
Leptospira spp.	Leptospirosis

Review

1. Microorganisms that cause disease by transmission through contaminated water are called:

2. Microbiology is the study of:

3. The five groups of microorganisms of interest to the water industry:

4. _____ range in size from 0.5 to 2 microns in diameter and about 1 to 10 microns long.

5. List the three common bacterial shapes:

Review Continued

6. Although some bacteria can use inorganic chemicals as an energy source, most bacteria require _____ chemicals as a food source.

7. Bacteria that require an environment *with* free or dissolved oxygen are said to be:

8. Bacteria that require an environment *without* free or dissolved oxygen are said to be:

9. Bacteria that can exist in an environment *with or without* free or dissolved oxygen are said to be:

10. Some bacteria produce _____, which are strong, resistant resting stages that make them more resistant to disinfection.

11. Three waterborne diseases caused by bacteria:

Protozoa

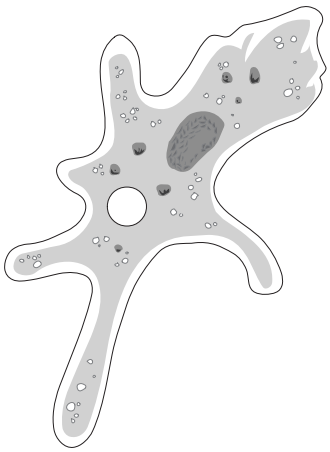
Definition and Size

Protozoa are one-celled animal-like organisms with a fairly complex cellular structure. The protozoa are the giants of the microbial world. They are many times larger than bacteria and range in size from 4 to 500 microns. The larger ones can almost be seen with the naked eye.

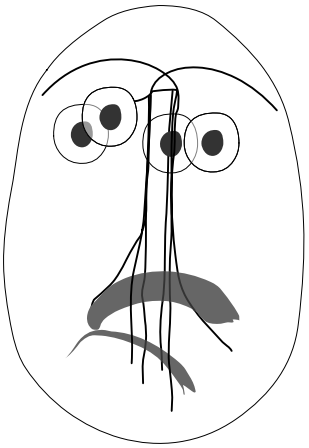
Groups of Protozoa

The major groups of protozoa are based on their method of locomotion or movement:

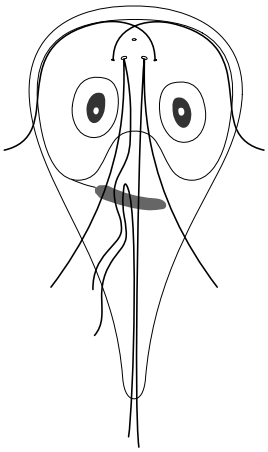
- **Amoebas** move about by a streaming or gliding action. The shape of an amoeba changes as they sort of ooze from place to place.
- **Ciliates** are covered with short hair-like projections, called cilia, which beat rapidly and propel the ciliate through the water. Most ciliates are free-swimming, although some are attached to floating material or basin walls.
- **Flagellates** have one or more long whip-like projections, called flagella, which propel the free-swimming organisms.
- **Suctoria** are attached organisms, similar to attached ciliates, but have tentacles rather than cilia.
- **Sporozoa** are non-mobile and are simply swept along with the current of the water.



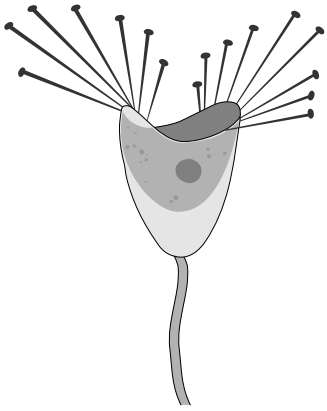
Amoeba



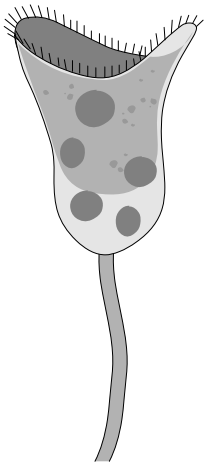
Giardia lamblia
Cyst, form



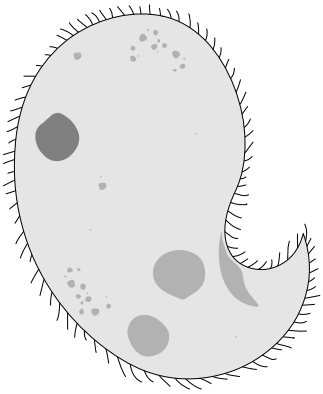
Giardia lamblia
Trophozoite, form



Suctoria



Stalked Ciliate



Free-swimming Ciliate

Food Requirements

Protozoa use organics for food. In fact, bacteria are among their favorite prey. Protozoa are mostly aerobic or facultative in regards to oxygen requirements. In the same manner as bacteria, pH, toxic materials, and temperature affect their rate of growth.

Life Cycle

Most protozoa have a complex life cycle in which they alternate between an active growth phase, when they are called trophozoites, and a resting stage, called cysts. Cysts are extremely resistant structures that protect the organism from destruction when it encounters harsh environmental conditions.

Resistance to Chlorine

Because of their relative complexity and ability to form the extremely resistant cysts, protozoa require higher disinfectant concentrations and longer contact time to control them. In fact, some types of protozoa may be almost completely resistant to disinfection by chlorination.

Waterborne Disease

Three protozoan waterborne diseases are listed in the table below.

Protozoa	Disease
Entamoeba histolytica	Amoebic dysentery
Giardia lamblia (5 to 21 μ in size)	Giardiasis
Cryptosporidia (4 to 6 μ in size)	Cryptosporidosis

Review

1. _____ are single-celled, animal-like microorganisms, many times larger that bacteria.
2. Protozoa that move using short, hair-like projections are called:
3. Protozoa that move using long, whip-like projections are called:
4. Protozoa that move using a flowing or gliding action are called:
5. Most protozoa have an active, growing life stage called a trophozoit and a resistant, resting stage called a:
6. Three waterborne diseases caused by protozoa:

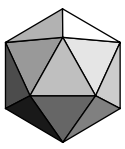
Viruses

Description and Size

Viruses are the midgets of the microbial world. They are many times smaller than bacteria. They range in size from 0.02 to 0.25 microns in diameter. Viruses are intracellular parasites that must have a host cell in which to multiply. They are extremely simple life forms. A central molecule of genetic material is surrounded by a protein shell, called a capsid, and sometimes by a second layer, called an envelope. They contain no mechanisms by which to obtain energy or reproduce on their own.

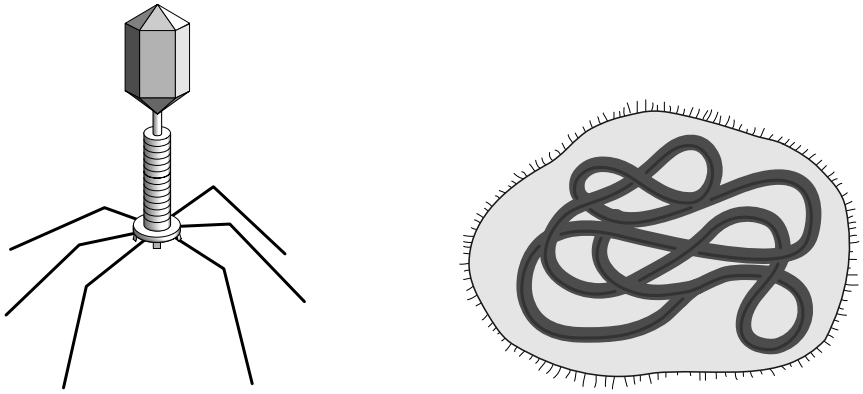
Shapes

Viruses occur in many shapes:



Geometric polyhedrals

Long slender rods



Elaborate irregular shapes

Need for a Host

There are almost as many kinds of viruses as there are types of other living organisms. Viruses exist that can invade virtually every kind of living cell: animals, plants, insects, fish, and even bacteria. After they invade their specific host, they take over the machinery of the host and force it to make more viruses. The host cell is then destroyed, and hundreds of new viruses are released into the environment.

Disinfection

Because they lack sensitive cellular machinery and because they have relatively tough capsids and envelopes, viruses are hard to destroy by normal disinfection practices. Increased disinfectant concentration and contact time must be used to effectively destroy viruses by chlorine disinfection.

Waterborne Diseases

Waterborne viruses can cause three diseases:

- Hepatitis
- Viral gastroenteritis
- Poliomyelitis

Review

1. _____ are many times smaller than bacteria and are considered to be intracellular parasites.

2. Viruses lack internal cell mechanisms, so they must have a(n) _____ cell in which to multiply.

3. Three waterborne diseases caused by viruses:

Algae

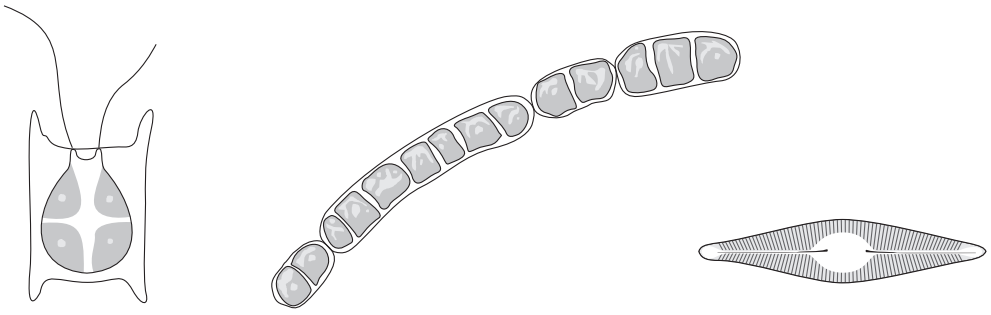
Description

Algae are a form of aquatic plants. Although in mass they are easily seen by the naked eye, many are microscopic as single cells. They exist as microscopic, single-celled forms and also as huge, multicellular forms, such as marine kelp. They oc-

cur in fresh and polluted water, as well as in salt water. Since they are plants, they are capable of using energy from the sun in the process called photosynthesis. They grow only where there is light, and they grow better where there is bright sunlight, as opposed to cloudy weather. They usually grow near the surface of the water because light cannot penetrate very far through the water.

Algae are classified by their color:

- **Green algae** contain green chlorophyll and are found mostly in fresh water. This form is the green roadside ditch algae, and the type that grows on clarifier and basin walls.
- **Euglenoids** are single-celled, green-pigmented algae that resemble protozoa. They have flagella, but are considered algae because they carry out photosynthesis.
- **Diatoms** are golden-brown, single-celled forms that have a hard silica shell. The shells of millions of dead diatoms are mined commercially and known as diatomaceous earth.
- **Cyanobacterium** is bluish-green in color and undergoes photosynthesis. It was formerly called blue-green algae, but is now classified as a type of bacteria.



Euglenoids Blue-grean Diatoms

Problems Caused by Algae

Although algae are not considered to be waterborne pathogens, they do cause some problems with water operations. They grow easily on the walls of basins and troughs, and heavy growth can cause plugging of screens and intakes. Algae release chemicals that can cause taste and odor problems in drinking water.

Control of Algae

Algae in raw water supplies can be controlled with chlorine and potassium permanganate. In raw water reservoirs, algae blooms are often controlled with copper sulfate.

Fungi

Description

Fungi are of relatively minor importance to the water business. Fungi are non-photosynthetic organisms that grow as multicellular, filamentous, mold-like forms or as single-celled, yeast-like organisms. Fungi must have organic material as a food source.

Growth Environment

Fungi like to grow in damp organic material such as drying or composting sludge. As part of their reproductive cycle, they produce spores that are so small, they can easily be carried by dust and wind. When inhaled, some of these spores can cause respiratory infections. Fungi are not considered to be waterborne pathogens.

Review

1. _____ are a form of aquatic plants that can be either tiny, single-celled or large, multi-celled organisms.
2. Chemicals released by algae can cause _____ and _____ problems.
3. Algae blooms in raw water reservoirs can be controlled with:
4. _____ are non-photosynthetic, multicellular or single-celled filamentous or yeast-like organisms that require organic material for food.

Disease and Disease Transmission

The term "disease" refers in general to an abnormal condition that impairs the victim's function. Many different environmental factors can cause disease, such as chemical, biological, psychological, and even social factors. Waterborne pathogenic microorganisms are a major source of human disease.

Waterborne diseases are transmissible diseases because they can be passed from an infected individual to another person. The majority of the waterborne pathogens that transmit disease do so via the "feces – water – mouth" route. The pathogens exist in the intestines of an infected individual and are excreted into the environment with feces. From there they find their way into surface and groundwater supplies and to another individual through contact with or by ingesting contaminated water. Some waterborne pathogen can be acquired by breathing mist or sprays (such as in a shower). Waterborne disease can also be transmitted via a "feces – hand – mouth" route if good personal hygiene practices are not followed.

Drinking water treatment is designed to interrupt the "feces – water – mouth" cycle of transmission by removing and destroying the pathogenic microorganisms. If the treatment processes are carried out as intended, consumers should expect to have water available to them that is free of pathogens. But communities and individuals must also understand that the water can be contaminated after it is delivered to the home. Personal hygiene and sanitation practices are critical to avoiding potential waterborne disease.

Control of Microorganisms

Two terms are used in reference to the control of microorganisms:

- **Sterilization** means the complete destruction of all living forms, including single- and multi-celled microorganisms, bacterial spores, and protozoa cysts.

- **Disinfection** means the destruction of pathogenic microorganisms, but does not necessarily mean complete destruction of all life forms. Operators may sterilize glassware in the laboratory, but the addition of chlorine to treated water is a disinfection process, not sterilization.

Microorganisms can be controlled by manipulating their environment (such as applying heat or changing the pH), by limiting or removing their food supply, or by subjecting them to damaging chemical or physical processes.

Microbial growth is slowed considerably by refrigeration, by lowering the temperature. Microbial growth can also be optimized by adjusting the temperature to one that favors a particular microorganism. Higher temperatures may be sufficient to sterilize an environment. Raising the pH with lime creates conditions in which most bacteria do not grow. Limiting sunlight prevents photosynthetic algae from growing. Knowing the environmental factors that affect the growth of microorganisms help implement strategies for control.

Limiting the food supply can control the growth of microorganisms. Since many bacteria and most protozoa require organic matter for food, removing organics from the water and keeping surfaces and basins clean and free from organic matter limit growth. The removal of minerals, such as iron, from water can also discourage the growth of bacteria that use minerals as a food source. Keeping pipes and tanks clean and free or organic sediment can help control growth in the distribution system.

A variety of chemicals and physical processes can be used to control microorganism growth. Chlorine, bromine, and iodine are well-known for their use as water disinfectants. Ozone is also an effective water disinfectant. Other chemicals, such as alcohol, formaldehyde, hydrogen peroxide, hexachlorophene, and certain heavy metals (silver and mercury) can be used to control growth. Some of these are strong and can only be used on inanimate objects. Others can be used to control microbial growth on skin and in eyes. Physical processes such as filtration, ultraviolet light, and gamma radiation are also effective.

Practicing good personal hygiene is an easy and effective way to control microorganism growth and to prevent the transmission of waterborne pathogens. Hand-washing is the most important practice. Washing hands after using the bathroom and before handling food and drinking water significantly reduces waterborne disease transmission. Coughing into the crook of an elbow, instead into hands, can also help prevent transmission. Proper handling and disposal of human waste, and carefully cleaning up afterwards, is also important. Water system operators must practice personal hygiene conscientiously to avoid contaminating equipment and water supplies.

Indicator Microorganism

To be sure that the water supplied to consumers is free of pathogens, operators must routinely sample and test the water for indications of the presence or absence of pathogens. It is beyond the capacity of treatment plant labs to directly test for any of the pathogenic microorganisms. But operators and technicians can test for bacteria called indicators, organisms whose presence indicates the possible presence of pathogens and whose absence means that the water is free of pathogens. The indicators used are a bacterial group known as total coliforms. As a group, coliforms live in the intestines of warm-blooded animals, as well as in the soil, in natural water, and on vegetation.

Although some total coliforms are pathogenic, most are not, and harmless coliforms are normal inhabitants of all human intestinal systems. So if coliforms are found in a water sample, there is a possibility that it has been contaminated by human feces. On the other hand, since coliforms are always found in human feces, if no coliforms are found in a water sample, it is safe to conclude that it has not been contaminated with human feces. If total coliforms are found in a water sample, the sample is further tested for a more restrictive group of coliforms called fecal coliforms or for *E. coli*, a specific coliform bacterium. The tests for fecal coliforms and *E. coli* are more sensitive, but more difficult to run, so they are used to confirm the results of the total coliform test. Their presence is a stronger indication of fecal contamination that could contain waterborne pathogens.

The Safe Drinking Water Act's Total Coliform Rule specifies the frequency and procedures for sampling and testing for coliforms. Analytical laboratories running coliform tests on drinking water samples for compliance purposes must be certified by the Alaska Department of Environmental Conservation (ADEC).

Review

1. A disease that can be passed from one person to another is said to be:

2. The majority of _____ – borne diseases are transmitted through the "feces – water – mouth" route.

3. _____ means the complete destruction of all organisms or cells.

4. _____ means the control of pathogenic microorganisms.

5. Manipulating a microorganism's _____ is one way of controlling it.

6. Limiting a microorganism's _____ supply is another way of controlling it.

7. Three chemicals, other than chlorine, that can be used to control microorganisms:

8. Practicing good personal _____ is an easy and effect way to control microorganism growth and to prevent the transmission of waterborne pathogens.

9. A(n) _____ is an organism whose presence indicates the possible presence of pathogens.

10. The Total Coliform Rule specifies how often water systems must sample and test for _____ bacteria.

11. The absence of total coliform in a drinking water sample means the water is _____ to drink.

Biological Characteristics of Water Quiz

1. Microorganisms that cause disease by transmission through contaminated water are called waterborne:
   A. Poisons
   B. Toxins
   C. Pathogens
   D. Biogens

2. Which of the following is not a microorganism of interest to the water industry?
   A. Bacteria
   B. Virus
   C. Insects
   D. Protozoa

3. Which of these is the smallest microorganism?
   A. Virus
   B. Bacteria
   C. Protozoa
   D. Algae

4. A microorganism that requires an environment with free or dissolved oxygen present is said to be an _____ organism.
   A. Parasitic
   B. Aerobic
   C. Anaerobic
   D. Sensitive

5. Which of the following is a bacterial waterborne disease?
   A. Polio
   B. Giardiasis
   C. Hepatitis
   D. Typhoid fever

6. The tough, resistant resting stage formed by some bacteria is called a:
   A. Capsid
   B. Cyst
   C. Spore
   D. Seed

7. The complete killing of all living cells is called:
   A. Sterilization
   B. Disinfection
   C. Sanitization
   D. Chlorination

8. The destruction of pathogenic microorganisms is called:
   A. Sterilization
   B. Disinfection
   C. Sanitization
   D. Autoclaving

9. Protozoa that move with the aid of long, whip-like tails are classified as:
   A. Amoeba
   B. Ciliates
   C. Flagellates
   D. Sporozoa

10. Protozoa that move with the aid of short, hair-like bristles are classified as:
   A. Amoeba
   B. Ciliates
   C. Flagellates
   D. Sporozoa

11. The tough, resistant resting stage of the life cycle of protozoa is called a:
   A. Capsid
   B. Cyst
   C. Spore
   D. Seed

12. Which of the following is a protozoal waterborne disease?
   A. Polio
   B. Giardiasis
   C. Hepatitis
   D. Typhoid fever

13. Which of these microorganisms are considered obligate, intracellular parasites because they lack system to reproduce on their own?
   A. Bacteria
   B. Protozoa
   C. Viruses
   D. Fungi

14. Which of the following is a viral waterborne disease?
   A. Polio
   B. Giardiasis
   C. Cholera
   D. Typhoid fever

15. Which of the following is considered a form of aquatic plant because it is photosynthetic?
    A. Algae
    B. Protozoa
    C. Viruses
    D. Fungi

16. Diatoms belong to which group of microorganisms?
    A. Algae
    B. Protozoa
    C. Viruses
    D. Fungi

17. *Cyanobacterium*, now classified as a bacteria, used to be classified with which group of microorganisms?
    A. Algae
    B. Protozoa
    C. Viruses
    D. Fungi

18. Algae, in raw water reservoirs, can be controlled with which chemical?
    A. Sodium hypochlorite
    B. Calcium oxide
    C. Copper sulfate
    D. Soda ash

19. Diseases that can be passed from one person to another are said to be:
    A. Deadly
    B. Vectors
    C. Transmissible
    D. Toxic

20. Which of the following activity would not be considered a means of controlling microorganisms by manipulating their environment?
    A. Adding lime to raise pH
    B. Refrigeration
    C. Filtration
    D. Limiting exposure to sunlight

21. Which of the following is not used as a chemical means for controlling microorganisms?
    A. Bromine
    B. Alcohol
    C. Alum
    D. Hydrogen peroxide

22. An organism whose presence is evidence of the presence or absence of pathogens is called a(n):
    A. Pathogen
    B. Substitute
    C. Partner
    D. Indicator

23. What group of bacteria is used as an indicator for the presence of absence of waterborne pathogen in drinking water?
    A. Total coliforms
    B. Respiratory streptococcus
    C. Heterotrophs
    D. Human pathogens