The Microbial World and You

Microbes in Our Lives

Most microorganisms are not harmful and indeed play a vital role in maintaining our global environment. Only a minority are **pathogenic** (disease producing). Microbes are part of the food chain in oceans, lakes, and rivers; they break down wastes, incorporate nitrogen gas from the air into organic compounds, and participate in photosynthesis, which generates food and oxygen.

Naming and Classifying Microorganisms

The system of naming **(nomenclature)** we now use was established by **Carolus Linnaeus.** Scientific nomenclature assigns each organism two names. The **genus,** the first name, is always capitalized, and the **specific epithet (species),** which follows, is not capitalized. The scientific names of organisms are always either underlined or italicized. At first, organisms were grouped into either the animal kingdom or the plant kingdom.

Types of Microorganisms

Bacteria and Archaea

Bacteria and **Archaea** are simple, one-celled organisms whose genetic material is not enclosed in a special nuclear membrane. For this reason, bacteria are called **prokaryotes** (prenucleus). (Note: The word *Bacteria,* when capitalized, refers to the domain. When not capitalized, it usually describes any prokaryotic cell.) Bacterial cells generally have one of three shapes: **bacillus** (rodlike), **coccus** (spherical or ovoid), and **spiral** (curved or corkscrew). Individual bacteria may form pairs, chains, or other groupings, which are usually the same within a species. Bacteria are enclosed in cell walls largely made of a carbohydrate and protein complex called peptidoglycan (cellulose is the main substance of plant cell walls). Bacteria generally reproduce by **binary fission** into two equal daughter cells. Many move by appendages called flagella, and although most use organic material for nutrition, some use inorganic substances or carry out photosynthesis. The Archaea are often found in extreme environments. Their cell walls lack peptidoglycan. Groups included are *methanogens, extreme halophiles,* and *extreme thermophiles.* They are not known to cause disease in humans.

Fungi

Fungi are **eukaryotes;** they contain DNA within a distinct nucleus surrounded by a nuclear membrane. They may be unicellular or multicellular. Their cell walls are composed primarily of *chitin.* **Yeasts** are unicellular nonfilamentous fungi larger than bacteria. **Molds** form mycelia of long filaments (*hyphae*).

Protozoa

Protozoa are unicellular, eukaryotic microbes, members of the kingdom Protista. They are classified by their means of locomotion, such as *pseudopods, cilia,* or *flagella.*

Algae

Algae are photosynthetic eukaryotes, mostly of the kingdom Protista, and are usually unicellular. They need light and air for growth.

Viruses

Viruses are very small and are not cellular. They have a core of either DNA or RNA, surrounded by a protein coat. They may have a lipid envelope layer as well. They reproduce only inside the cells of a host organism.

Multicellular Animal Parasites

Flatworms and **roundworms,** collectively called **helminths,** are not strictly microorganisms. A part of their life cycles involves microscopic forms, however, and identifying them requires many of the techniques used in identifying traditional microorganisms.

A Brief History of Microbiology

The First Observations

Antoni van Leeuwenhoek was the first to report on the observation of microorganisms seen with magnifying lenses, beginning in 1674. He made detailed drawings of "animalcules" that have since been identified as representing bacteria and protozoa. About this time, **Robert Hooke** observed with a microscope the boxlike openings in slices of plants. He called them "cells." His discovery, reported in 1665, marked the beginning of the **cell theory**—that all living things are composed of cells.

The Debate over Spontaneous Generation

Until the second half of the nineteenth century, it was generally believed that life could arise spontaneously from nonliving matter, a process known as **spontaneous generation.** An early opponent of spontaneous generation, **Francesco Redi,** demonstrated in 1668 that maggots, the larvae of flies, do not arise spontaneously from decaying meat.

Many, however, still believed that the simpler organisms observed by Leeuwenhoek might undergo spontaneous generation. In 1745, **John Needham** found that heated nutrient fluids poured into covered flasks were soon teeming with microorganisms. He took this as evidence of spontaneous generation. Twenty years later, **Lazzaro Spallanzani** showed that Needham's microorganisms had entered the fluid after boiling. Heating such fluids in a sealed flask, he showed, prevented the growth Needham had observed. Objections still remained; Needham felt that the heating had destroyed some vital force necessary for spontaneous generation. The concept of **biogenesis,** that living cells can arise only from other living cells, was introduced in 1858 by **Rudolf Virchow.**

In 1861, **Louis Pasteur** designed the experiments that finally ended the debate about spontaneous generation. He showed that flasks left open to the air after boiling would soon be contaminated, but if they were sealed, they remained free of microorganisms. He also used flasks whose long necks he bent into S-shaped curves. Air, with its presumed vital force, could enter these flasks, but airborne microorganisms were trapped in the tubes. The flask contents remained sterile. Pasteur showed that microorganisms are present throughout the environment and that they can be destroyed. He also devised methods of blocking the access of airborne microorganisms to nutrient environments; these methods were the basis of **aseptic** (germ-free) **techniques,** which are among the first things that a beginning microbiologist learns.

The Golden Age of Microbiology

Fermentation and Pasteurization

At this time Pasteur was asked to investigate the problem of spoilage of beer and wine. Pasteur showed that, contrary to the belief that air acted on the sugars to convert them to alcohol, microorganisms called yeasts were responsible—and in the absence of air. This process is called **fermentation** and is used in making wine or beer. Spoilage occurs later when bacteria, in the presence of air, change the alcoholic beverage into acetic acid (vinegar). Pasteur prevented spoilage by heating the wine or beer just enough to kill such bacteria, a process that came to be known as **pasteurization.**

The Germ Theory of Disease

This association of yeasts with fermentation was the first concept to link a microorganism's activity to physical and chemical changes in organic materials. It suggested the possibility that microorganisms might be able to cause diseases as well—the **germ theory of disease.** In 1835, **Agostino Bassi** made the first association between a microorganism and a disease by proving that a silkworm disease was caused by a fungus. In 1865, Pasteur found that another silkworm disease was caused by a protozoan. Also in the 1860s, **Joseph Lister** applied the germ theory to medicine. He used carbolic acid (phenol) on surgical dressings and wounds, and greatly reduced the numbers of infections and deaths. In the 1840s, **Ignaz Semmelweis** demonstrated that chemically disinfecting the hands of physicians minimized infections of obstetrical patients. In 1876, **Robert Koch** demonstrated that certain bacteria in the blood of cattle that had died of anthrax were the cause of death. He showed that these bacteria could be isolated and grown in pure culture, be injected into healthy animals, and cause their death by anthrax. The same bacteria could then be isolated from the dead animals. This demonstration, which proved that a specific microbe is the cause of a specific disease, followed a set of criteria known today as **Koch's postulates.**

Vaccination

In 1798, **Edward Jenner** showed that the mild disease cowpox gave immunity to smallpox. He inoculated people with cowpox material by scratching their arm with a cowpox-infected needle. This process became known as **vaccination** (*vacca* is the Latin word for cow). The protection from disease provided by vaccination is called **immunity.** Years later, around 1880, Pasteur showed why vaccinations work. He found that the bacterium for fowl cholera lost its **virulence** (ability to cause disease) after it was grown for long periods in the laboratory. However, he showed that the weakened bacteria still retained their ability to induce immunity. Apparently the cowpox virus is related closely enough to smallpox to induce effective immunity.

The Birth of Modern Chemotherapy: Dreams of a "Magic Bullet"

The treatment of disease by chemical substances is called **chemotherapy.** When prepared from chemicals in the laboratory, these substances are called **synthetic drugs,** and when produced naturally by bacteria and fungi they are called **antibiotics. Paul Ehrlich** speculated about a "magic bullet" that would destroy a pathogen without harming the infected host. In 1910, he found *salvarsan*, an arsenic derivative, that was effective against syphilis. *Quinine*, an extract of South American tree bark, had until then been the only other such chemical available. Spanish conquistadors used it to treat malaria. In the late 1930s, a survey of dye derivatives uncovered the important group of antibacterial *sulfa drugs.* The first antibiotic was discovered by **Alexander Fleming,** who observed the inhibition of bacterial growth by the mold *Penicillium notatum.* The inhibitor, which he called penicillin, was mass-produced and clinically tested in the 1940s. Since then, many antibiotics have been discovered.

Modern Developments in Microbiology

Bacteriology is the study of bacteria. **Mycology** is the study of fungi. **Parasitology** is the study of protozoa and parasitic worms.

Immunology, the study of immunity, expanded rapidly in the twentieth century. Smallpox was eliminated, and many new vaccines became available. A major challenge now will be to defeat the AIDS virus, which attacks the immune system. In 1933, **Rebecca Lancefield** proposed an immunologically based classification system for streptococci bacteria, classifying them as serotypes (variants within a species).

Virology, the study of viruses, really began in 1892 when **Dmitri Iwanowski** demonstrated that tobacco plant pathogens would pass through filters too fine for known bacteria. Much later, **Wendell Stanley** showed that the organism, called the tobacco mosaic virus, was so simple and homogeneous it could be crystallized.

Recombinant DNA Technology

Recombinant DNA technology, or **genetic engineering,** had its origin in **microbial genetics** (how microbes inherit traits) and **molecular biology** (how genetic information is carried in DNA, which is then used to direct synthesis of proteins). Because of their simplicity and rapid reproduction rate, bacteria are the preferred organisms in this field. Beginning in the early 1940s, **George W. Beadle** and **Edward L. Tatum** demonstrated the relationship between genes and enzymes. DNA was established as the hereditary material by **Oswald Avery, Colin MacLeod,** and **Maclyn McCarty. Joshua Lederberg** and **Edward L. Tatum** discovered bacterial genetic transfer by conjugation. In 1958, **James Watson** and **Francis Crick** proposed the structure of DNA. In the 1960s, **François Jacob** and **Jacques Monod** discovered messenger RNA, important in protein synthesis, and later made major discoveries about the regulation of gene function in bacteria. **Paul Berg** showed that fragments of animal DNA—genes—could be attached to bacterial DNA, the first examples of **recombinant DNA.** These genetically altered bacteria can be used to make large quantities of a desired protein.

Microbes and Human Welfare

Recycling Vital Elements

Microbes recycle vital elements such as nitrogen, carbon, oxygen, sulfur, and phosphorus. *Cyanobacteria* and certain soil bacteria may use atmospheric nitrogen directly (*nitrogen fixation*). The nitrogen fixed from the air is incorporated into living organisms and eventually returned as gaseous nitrogen, making up the **nitrogen cycle. Microbial ecology,** the study of the relationship between microbes and their environment, originated with the work of **Martinus Beijerinck** and **Sergei Winogradsky**. They first showed how bacteria helped recycle vital elements. In the **carbon cycle,** carbon dioxide is removed from the air by plants and algae, which convert it to food. In the **oxygen cycle,** oxygen is recycled to the air during photosynthesis. Microbes are used in treatment of sewage. Microbes are useful in treating oil spills, toxic waste sites, and so on, a process called **bioremediation.** Bacteria such as *Bacillus thuringiensis* are used in control of insect pests.

Modern Biotechnology and Genetic Engineering

Practical applications of microbiology are called **biotechnology.** The use of recombinant DNA technology has led to the advent of genetic engineering, which now produces insulin, interferon, clotting substances, vaccines, and other substances. Eventually it may become common to replace missing or defective genes in human cells, a process called **gene therapy.** Agricultural applications, including drought resistance and resistance to insects and microbial diseases, may also result from genetic engineering.

Microbes and Human Disease

The relationship between microbes and disease will remain of great interest to us all. Indeed, we are seeing many **emerging infectious diseases** such as bovine spongiform encephalopathy (mad cow disease, caused by an infectious protein called a **prion**), outbreaks of *E. coli* O157: H7 infections, Ebola hemorrhagic fever, *Hantavirus*, and, of course, AIDS. The study of the body's resistance to microbial infection and disease is a continuing part of microbiological research.

Advanced Microbiology
Microbial World and You

Name________________________________
Date/Hour____________________________

Self-Tests

In the matching section, there is only one answer to each question; however, the lettered options (a, b, c, etc.) may be used more than once or not at all.

I. Matching

___ 1. In 1668, demonstrated that maggots appeared only in decaying meat that had been exposed to flies.

___ 2. Introduced the concept that living cells arise from other living cells.

___ 3. Introduced the technique of vaccination for smallpox.

___ 4. First to use the microscope to observe "cells."

___ 5. Made an association between silkworm disease and a fungus.

___ 6. A surgeon who used carbolic acid to control wound infections.

___ 7. First to speculate about the possibility of a "magic bullet" that would destroy a pathogen without harming the host.

___ 8. Discovered penicillin.

___ 9. Using anthrax as a model, demonstrated that a specific microorganism is the cause of a specific disease.

___ 10. Originated our system of scientific nomenclature.

a. Antoni van Leeuwe
b. John Needham
c. Lazzaro Spallanzani
d. Louis Pasteur
e. Francesco Redi
f. Agostino Bassi
g. Joseph Lister
h. Robert Koch
i. Paul Ehrlich
j. Alexander Fleming
k. Edward Jenner
l. Carolus Linnaeus
m. Robert Hooke
n. Rudolph Virchow

II. Matching

____	1. Assigned a microbial cause to fermentation.	a. Louis Pasteur
____	2. First to crystallize a virus.	b. Wendell Stanley
____	3. Showed that mild heating of spirits kills spoilage bacteria without damage to the beverage.	c. Francis Crick
		d. Paul Berg
____	4. Devised a classification system for the streptococci based on an immunological system of serotypes.	e. Ignaz Semmelweis
____	5. Demonstrated that infections in obstetrical wards could be minimized by disinfecting the hands of physicians.	f. Rebecca Lancefield
		g. George Beadle
____	6. Participated in determining the structure of DNA.	h. Joshua Lederberg
____	7. First demonstrated that genetic information could be exchanged between bacteria by conjugation.	

III. Matching

____	1. Prokaryotes.	a. Protozoa
____	2. Noncellular; reproduce only inside cells of host organism.	b. Elephants
____	3. Helminths.	c. Fungi
____	4. Yeasts.	d. Bacteria
____	5. An infectious protein.	e. Viruses
____	6. Unicellular, eukaryotic microorganisms; members of kingdom Protista.	f. Multicellular animal parasites
		g. Prion

IV. Matching

____	1. Protection from a disease that is provided by vaccination.	a. Bioremediation
____	2. The treatment of a disease with chemical substances.	b. Chemotherapy
____	3. The use of microbes to clean up, for example, an oil spill.	c. Fermentation
____	4. The process by which yeasts change sugars into alcohol.	d. Aseptic
____	5. Techniques that keep areas free of unwanted microorganisms.	e. Immunity

V. Matching

____ 1. Photosynthetic bacteria; may fix nitrogen from air.

____ 2. Photosynthetic eukaryotes.

____ 3. Eukaryotes classified primarily by their means of locomotion.

____ 4. General name for a rod-shaped bacterium.

____ 5. General name for a spherical bacterium.

____ 6. Prokaryotes whose cell walls lack peptidoglycan and are often found in extreme environments.

a. Cyanobacteria

b. Coccus

c. Bacillus

d. Protozoa

e. Archaea

f. Algae

Fill in the Blanks

1. Bacteria generally reproduce by a process called ______________________ into two equal daughter cells.

2. The set of criteria that prove that a specific microorganism is the cause of a specific disease is known today as ______________________.

3. The concept that living cells can arise only from other living cells is called ______________________.

4. One objection that proponents of spontaneous generation made to experiments in which nutrient fluids were heated in sealed containers was that heating destroyed some ______________________ in the air.

5. According to the rules applied to the scientific naming of a biological organism, the ______________________ name is always capitalized.

6. Paul Ehrlich discovered an arsenic derivative, ______________________, that was effective against syphilis.

7. Antimicrobial chemicals produced naturally by bacteria and fungi are called ______________________.