Chapter 1- The Main Themes of Microbiology*

*Lecture notes are to be used as a study guide only and *do not* represent the comprehensive information you will need to know for the exams.

1.1 The Scope of Microbiology

Microbiology is the study of microorganisms – organisms so small, that microscopes are required to see them and special laboratory techniques are needed to study them. **Microbe** - Gr. *mikros*, small, and *bios*, life. Microorganisms are generally less than 0.1 mm (100 µm) in diameter. The major biological groups of microorganisms, also called **microbes**, includes: **bacteria**, **viruses**, **fungi**, **protozoa**, **algae**, and **helminths** (Figure 1.3). Microorganisms have a profound influence on all aspects of life on this planet. They are ubiquitous, meaning they are everywhere. Microbes are useful for study. They have "simple" genetics, grow rapidly and are used to understand basic life processes.

Applications of Microbiology (Table 1.1): Within the field of Microbiology there are many sub-disciplines:

1. Immunology – study of how the body defends itself against infection.
2. Epidemiology – monitoring and controlling the spread of disease.
3. Medical microbiology & Pathology – focuses disease causing microbes.
4. Agricultural microbiology – studies the microbes involved in soil fertility, livestock health, and plant diseases.
5. Food & dairy microbiology and aquatic microbiology examine the roles of microbes in consumable food and drink.
6. Biotechnology – the application of biological processes: broad scope ranges from how bread is baked, fermentation processes, and the manufacture of recombinant human drugs such as insulin.
7. Genetic engineering involves the manipulation of the genetic makeup of microorganisms to produce new compounds and unique organisms used for medical or environmental applications.
8. Microbial ecology is the interaction between microorganisms and their environment and with other organisms.

1.2 General Characteristics of Microorganisms and Their Roles in the Earth's Environments

The Origins and Dominance of Microorganisms

All living things are made up of cells. Generally speaking, cells are essentially bags of water and nutrients with DNA inside them and are capable of reproducing themselves. Some organisms are made up of trillions of cells each with their own function (such as humans), while other organisms are only one cell (such as bacteria and Protists). Cell complexity ranges widely between different organisms. One way to classify cells is whether they are eukaryotic or prokaryotic (fig. 1.2):

eukaryotic – Gr. *eu*, true, and *karyon*, nucleus

Organisms that have a **nucleus** and intracellular organelles (like mitochondria)
E.g. *Homo sapiens* – humans.

prokaryotic – Gr. *pro*, before, and *karyon*, nucleus

Organisms that <u>*lack*</u> both a nucleus and intracellular organelles. These are the **bacteria.**

E.g. *Escherichia coli* – a bacterium

The Cellular Organization of Microorganisms

Most prokaryotes are smaller than eukaryotic cells, and the prokaryotes lack highly specialized internal compartments called **organelles**. Organelles are specialized structures in eukaryotic cells that carry out specific functions, like the mitochondria and Golgi bodies.

Prokaryotes are typically single celled organisms. Prokaryotes include bactera and archaeons.

<u>All prokaryotes are microorganisms</u>, but only some eukaryotes are microorganisms, such as algae, protozoa, molds, and yeasts.

Where Do the Viruses Fit?

Viruses are not considered cells! They are non-living organisms. But, they are microscopic and cause infectious disease.

Microbial Dimensions: How Small is Small?

Do you use a water filter on your sink at home? What size pores are in the membrane? What size are the bacteria? Can viruses be filtered out?

Microorganisms are measured using the metric system: (Figure 1.4)

1 meter = 1.09 yards (a little over 3 feet) **Meter** is abbreviated with a lowercase **m**.

1 millimeter (**mm**) = 1/1000th of a meter = 0.001m = 10^{-3}m

1 micrometer (**μm**) = 1/1,000,000th of a meter = .000001 millimeters = 10^{-6} meters (micrometers are usually referred to as **"microns"**)

1 nanometers (**nm**) = 10^{-9} m (1 billionth of a meter)

Average sizes for microscopic organisms:

- **protozoa = 100 μm**
- **eukaryotic cell = 10 – 100 μm**
- **bacteria = 1 to 5 μm in length, some reach 20 μm in length**
- **viruses = 0.01 μm or 10 nm**

  smallpox virus = 250 nm or 0.25 μm

  polio virus = 20 nm

Why so small? Surface to volume ratio. Bacteria have a large surface-to-volume ratio and are able to concentrate nutrients rapidly. The nutrients are then able to diffuse rapidly inside of the cell. Small size also enables them to multiply rapidly.

Microbial Involvement in Energy and Nutrient Flow

One way to classify microbes is according to their primary role in the environment: (Figure 1.5)

1. Microbes involved in energy and nutrient flow:

   a. **Producers** – Photosynthesis: photosynthetic microorganisms including algae and cyanobacteria account for more than 50% of the Earth's photosynthesis. Thus, they not only serve as the basis for the food chain, they contribute the majority of oxygen (O_2) to the atmosphere.

   b. **Decomposers** – Nutrient Recycling: decomposers play strategic and often specific roles in the cycling of elements such as nitrogen, sulfur, phosphorus, and carbon between living things and their non-living environment.

   c. **Symbionts** – microorganisms which live in partnership with other living things. Examples including: bacteria living in the digestive systems of ruminants, bacteria living in our own digestive systems, and nitrogen fixing bacteria living in plant root nodules.

1.3 Human Use of Microorganisms

Microbes, particularly bacteria, have been used to help solve human problems. (Figure 1.6). **Biotechnology** has advanced the fields of genetic engineering and bioremediation.

1. Genetic Engineering: manipulate genes, moves genes to other organisms to understand a life process, such as protein function. Use **recombinant DNA** technology to accomplish the process.
2. Bioremediation: use microbes (and sometimes other organisms like plants) to remove toxic compounds from the environment.

1.4 Microbial Roles in Infectious Diseases

Infectious diseases influence the human condition (human health):

Pathogens – Gr. *pathos*, diseases, and *gennan*, to produce. A pathogen is a microorganism or virus that causes disease.

Many pathogens are considers **parasites**, an organisms that lives at the expense of another organism called a **host**. The parasite will use the host for its nutrient source.

Some numbers:

- Nearly 2,000 different species of microbes can infect the human body and cause disease.
- The WHO estimates 10 billion new infections across the globe every year.(Figure 1.7)
- Infectious diseases are the most common cause of death in many communities and account for about 30% of deaths in the U.S.
- Worldwide fatalities from infectious disease = about 12 million per year. Table 1.2.

Infectious diseases are diseases that are caused by microbes. Two categories of infectious diseases are:

1. **Emerging diseases** – recent, unexpected diseases like the H1N1 influenza virus
2. **Re-emerging diseases** – diseases that existed at low levels in the population, but are now back on the rise, such as gonorrhea.

1.5 The Historical Foundations of Microbiology

The Development of the Microscope: “Seeing is Believing”

Antonie van Leewenhoek (Figure 1.8) developed the first microscope (Figure 1.9). He made it possible to visualize microbes for the first time.

Historical Highlights (Appendix A, pgs. A3-A4)

- 1676 – **Antoine van Leeuwenhoek** observes bacteria and protozoa using his home made microscope – the first of its kind.
- 1798 – **Edward Jenner** demonstrates that it is possible to vaccinate against smallpox using pus from cowpox lesions – the first vaccine.
- 1850 – **Ignaz Semmelweis’** insistence on hand washing reduces mortality rate of puerperal sepsis from 8.3% to 2.3%.
- 1861 – **Louis Pasteur** disproves spontaneous generation theory with his swan-neck flask experiment (1.2 Making Connections) and develops process of pasteurization in 1864. Contributes to proving germ theory of disease.
- 1876 – **Robert Koch** demonstrates conclusively that a bacteria (*B. anthracis*) causes a disease (anthrax). Develops procedures for identifying pathogenic microorganisms (Koch’s postulates). Germ theory confirmed.
- 1908 – **Paul Ehrlich** formulates the concept of drug specificity and develops the drug salvarsan to treat syphilis, thereby starting the use of chemotherapy to treat diseases.
- 1929 – **Alexander Fleming** discovers and describes the properties of the first true antibiotic, penicillin.

The Scientific Method and the Search for Knowledge

The **scientific method** is used to explain certain natural phenomenon. A very important aspect of the scientific method is to develop a **hypothesis**, a statement that can be supported or discredited by experimentation. The most common way to prove or disprove a hypothesis is to use the **deductive approach**. (Figure 1.10). Over time as the hypothesis survives scrutiny it becomes a **theory,** for example, the gravitational theory.

The Development of Medical Microbiology

Once it was understood that microbes are everywhere, ubiquitous, the connection was made to their existence and medicine. This connection led to the development of medical microbiology.

Jenner and the Introduction of Vaccination

Developed a method to control smallpox by inoculating his patients. He is considered the “Father of Immunology”.

The Discovery of Spores and Sterilization

The existence of **spores** was discovered by experiments conducted by **John Tyndall** and **Ferdinand Cohn**. The concept of objects being **sterile**, which means completely free of living organism, including spores and viruses, became essential to microbiology.

The Development of Aseptic Technique

Robert Koch – his studies linked a microbe with a specific disease.

Another very important contribution to microbiology was the practice of **aseptic technique** – working in a manner such that unwanted microbes do not contaminate the specific working environment. Observations conducted by **Dr. Oliver Wendell Holmes,** who observed that mothers who gave birth at home had fewer infections that mothers who gave birth in hospitals; **Dr. Ignaz Semmelweis**, who established the importance of hand washing; and **Dr. Joseph Lister**, who used phenol to disinfect surgical instruments.

The Discovery of Pathogens and the Germ Theory of Disease

The **germ theory of disease**, that infectious diseases are causes by microorganisms is a relatively new idea. The fact that microorganisms actually cause disease and food spoilage was not known until the 19th century. Until about 1880, it was not understood that microorganisms, “germs”, caused disease. The causes were explained by everything from witchcraft to punishment from God.

Louis Pasteur – invented pasteurization.

Robert Koch demonstrated that a particular organism, a bacterium, was responsible for a particular disease using a series of procedures now named after him. Some of the pathogens Koch linked to disease include:

- Anthrax (1876) - *Bacillus anthracis*
- Tuberculosis (1881) - *Mycobacterium tuberculosis*

- Cholera (1883) - *Vibrio cholerae*

Koch's Postulates for determining the etiologic agent of a disease:

1. **Collection**: The specific microorganism thought to be the causative agent (etiologic agent) of a disease must be consistently collected from individuals suffering from the disease, but not from healthy individuals.
2. **Isolation**: The suspected etiologic agent (potential pathogen) must be isolated and cultivated in pure culture outside the host *in vitro*[1]. (as opposed to *in vivo*[2]).
3. **Characterization**: Complete microscopic and biological characterization of isolated organism.
4. **Testing**: Pure cultures of the suspected pathogen, when introduced into a suitable and susceptible host (mice or rabbit) must produce the signs and symptoms characteristic of the disease.
5. **Re-isolation** from test subject: The same organisms must be consistently isolated in pure culture from the experimental host and be cultivated again *in vitro*.

It is not always possible to follow Koch's postulates exactly. For example: *Treponema pallidum* (syphilis) and *Mycobacterium leprae* (leprosy/Hansen's disease), as well as viruses, must be cultivated *in vivo*, so pure culture is technically impossible.

1.6 Taxonomy: Organizing, Classifying, and Naming Microorganisms

1. Taxonomy – the formal system of organizing, classifying and naming living organisms. An important aspect of this is **nomenclature**, assigning names to various species.

The Levels of Classification

From top to bottom: Domain, Kingdom, Phylum, Class, Order, Family, Genus, Species (Figure 1.13).

Assigning Specific Names

Aristotle (4th century BC) was probably the first taxonomist, the first to classify organisms. He classified living things into two kingdoms: Animals (Animalia) and Plants (Plantae).

[1] ***in vitro*** – Latin for "in glass", i.e. culturing microorganisms in the lab in test tubes or on plates.
[2] ***in vivo*** – Latin for "in life", i.e. microorganisms would be growing in a living host.

Carl von Linné (Linnaeus) (1735) devised a system of **binomial nomenclature** – two words, **genus** and **species**, to represent each organism as opposed to a long, Latin description.

Examples: *Homo sapiens*, *Staphylococcus aureus, Streptococcus pneumoniae, Vibrio cholerae*.

The proper scientific name of any organism is always written in *italics* with the genus name capitalized and the species name in lower case.

For example:

***S**taphylococcus **a**ureus*

(*Staphylococcus* = genus name and *aureus* = species name)

It is common to see only the **genus name abbreviated** with an upper-case letter such as:

***S**. aureus*

In older texts or when written by hand, the name of the organism is underlined: S. aureus.

Many species of bacteria are subdivided into **strains.** A strain is a subtype of a particular bacteria species usually with unique characteristics. For example, ***E.coli* O157:H7** is a strain of *Escherichia coli* which has acquired the shiga toxin gene. One way to think of this is that all domesticated dogs are the same genus and species (*Canis familiaris*), but there are hundreds of breeds (Dobermans, Great Danes, Spaniels, etc.).

1.7 The Origin and Evolution of Microorganisms

All Life Is Related and Connected Through Evolution

Phylogeny is the study of how organisms are related on an evolutionary scale. Relatedness can be traced to **morphology**, the structure and shape of an organism, **physiology**, the function, and **genetics**, the inheritance.

Through **evolution** these changes are tracked over millions of years. Over time species adapt to their natural environment.

Systems for Presenting a Universal Tree of Life

The diagram showing how organisms are related are shown in a **phylogenetic tree** (Figures 1.14 and Figure 1.15).

The Kingdom System

Robert Whittaker proposed a **five kingdom system** based on types of cells. The **5 kingdom system** is:

Fig. 1.14:

Eukaryotes

- **Animal** Kingdom
- **Plant** Kingdom
- **Fungi** Kingdom
- **Protists** Kingdom

Prokaryotes

- **Monera** Kingdom (i.e. *only bacteria*)

Note: **Viruses** are not included in the classification of living things since, technically speaking, they are not alive.

The Domain System

This system is based on cell type (prokaryotic or eukaryotic) and genetic composition. The Domain system was devised by **Dr. Carl Woese** and **Dr. George Fox**. They showed the relatedness of species through comparing their rRNA. As a result three distinct Domain were organized (Figure 1.15):

Domain Bacteria – contains the true bacteria. These cells lack a nucleus and organelles.

Domain Archaea - contains organisms that have a prokaryotic cellular structure, but in some ways (genetic regulation mechanisms) are similar to eukaryotes. These organisms live in extreme environments.

Domain Eukarya – contains eukaryotic organisms such as trees, fish, birds, and yeast.

FYI = Microorganism Survey

Monera (Bacteria)[3] - *Single-cell **prokaryotes***. The study of bacteria is called bacteriology. Within the Monera kingdom there are four domains:

- **eubacteria** – typical, "true" bacteria. Most of the pathogens are in this domain.
- **archaea** – Domain Archaea contains primitive bacteria that live in extreme environments. Examples: methanogens, thermophiles, and halophiles. These do not cause disease.
- **cyanobacteria** – formerly blue-green algae; photosynthetic producers.
- **mycoplasmas** – atypical in that they lack a cell wall; one species causes the human disease known as "walking pneumonia".

Protozoa are in the K. Protista. They are *single-celled* eukaryotes with no tissue formation. Cells have organelles and a nucleus.

Fungi have their own kingdom: K. Fungi. Exist as either *single-celled or multicellular eukaryotes*. They lack chlorophyll and do not carry out photosynthesis. They take in food by absorption. The study of fungi is *mycology*. Yeasts and molds belong to this group.

Helminths – only microorganisms in K. Animalia. *Multicellular eukaryotes*. The organisms in this category of interest to us are the parasitic worms (for ex. hookworms).

3 *Bergey's Manual of Systematic Bacteriology* is a reference book in which one can find the names, morphological and physiological characteristics of all known bacteria. (On reserve in the library.)

Viruses have *no kingdom*. They are *not* living things. Non-cellular, they have no observable metabolic activity other than replication, which they cannot do outside another cell. They are intracellular obligate parasites.

Some interesting web sites to use as references

Medical Microbiology Text http://gsbs.utmb.edu/microbook/toc.htm

Very technical, but in depth coverage of major classes of microorganisms.

Center for Disease Control http://www.cdc.gov/

This is an ***EXCELLENT***, up to date reference for almost all known pathogens.

World Health Organization www.who.int/home-page

The *"Bad Bug Book"* http://vm.cfsan.fda.gov/~mow/intro.html

"Cool Microbiology" (links) http://www.cmdr.ubc.ca/cool.html

Texas Department of Health – Infectious Disease Control Unit

Information on infectious disease in Texas.

http://www.dshs.state.tx.us/idcu/default.asp