Technical Assistance
HYDROLOGY PROJECT

World Bank & Government of The Netherlands funded

Training module # WQ - 20

Introduction to Microbiology

New Delhi, June 1999

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DHV Consultants BV & DELFT HYDRAULICS

with
HALCROW, TAHAL, CES, ORG & JPS

Table of contents

1 Module context

This module introduces the principles of microbiology, and provides some background for subsequent training modules on microbiological lab techniques, and measurement of coliforms. Other related modules in this category are listed below.

While designing a training course, the relationship between this module and the others, would be maintained by keeping them close together in the syllabus and place them in a logical sequence. The actual selection of the topics and the depth of training would, of course, depend on the training needs of the participants, i.e. their knowledge level and skills performance upon the start of the course.

No.	Module title	Code	Objectives
1	Basic water quality concepts[a]	**WQ – 01**	• Become familiar with common water quality parameters • Appreciate important water quality issues
2	Basic chemistry concepts[a]	**WQ – 02**	• Convert units from one to another • Understand the basic concepts of quantitative chemistry • Report analytical results with the correct number of significant digits
3	How to prepare standard solutions[a]	**WQ - 04**	• Recognise different types of glassware • Use an analytical balance and maintain it • Prepare standard solutions
4	Microbiological laboratory techniques	**WQ - 21**	• Explain methods of bacteria identification • Discuss methods of bacteria enumeration • Follow methods of good laboratory practice
5	Coliforms as indicators of faecal pollution	**WQ – 22**	• Identify the main water quality problems caused by micro-organisms • Explain why coliform bacteria are good indicators • Explain the principles of the coliform analysis method
6	How to measure coliforms	**WQ - 23**	• Measure total and faecal coliforms in water samples

a - prerequisite

2 Module profile

Title	:	Introduction to Microbiology
Target group	:	HIS function(s):Q2, Q3, Q5, Q6, Q7, Q8
Duration	:	1 session of 60 min
Objectives	:	After the training the participants will be able to*:* • classify different types of micro-organisms • identify certain water borne diseases
Key concepts	:	• classification • types of cells • important types of micro-organisms • pathogenic micro-organisms/health effects
Training methods	:	Lecture, discussion, exercises
Training tools required	:	Board, flipchart, OHS
Handouts	:	As provided in this module
Further reading and references	:	• The Microbial World, Stanier et al, Prentice-Hall, 1986 • Standard Methods: for the Examination of Water and Wastewater, APHA, AWWA, WEF/1995. APHA Publication

3 Session plan

No	Activities	Time	Tools
1	***Preparations***		
2	***Introduction***: • Introduce the subject of microbiology • Define what micro-organisms are	10 min	OHS
3	***Classification and nomenclature*** • Explain how all life forms are classified • Explain nomenclature for micro-organisms • Review different types of cells	20 min	OHS
4	***Major Types of micro-organisms*** • Explain the main categories of micro-organisms • Review some of the common diseases associated with each category	20 min	OHS
5	***Wrap up and evaluation***	10 min	

4 Overhead/flipchart master

OHS format guidelines

Type of text	Style	Setting
Headings:	OHS-Title	Arial 30-36, with bottom border line (not: underline)
Text:	OHS-lev1 OHS-lev2	Arial 24-26, maximum two levels
Case:		Sentence case. Avoid full text in UPPERCASE.
Italics:		Use occasionally and in a consistent way.
Listings:	OHS-lev1 OHS-lev1-Numbered	Big bullets Numbers for definite series of steps. Avoid roman numbers and letters.
Colours:		None, as these get lost in photocopying and some colours do not reproduce at all.
Formulas/Equations	OHS-Equation	Use of a table will ease horizontal alignment over more lines (columns) Use equation editor for advanced formatting only

Introduction to microbiology

- Significance
- Classification
- Nomenclature
- Nutritional requirements
- Micro-organisms in water & wastewater

Significance

- Microbiology is the study of micro-organisms, too small to be clearly seen by the unaided eye (< 1 mm)
- Micro-organisms facilitate many important chemical reactions in nature:
  - *making of cheese, yoghurt, bread*
  - *production of alcohol*
  - *retting of flax (coconut husks)*
  - *breaking down organic matter (e.g. BOD)*

Significance

- Micro-organisms exist everywhere in nature:
  - *soil, air, water, the table top, your stomach*
- Micro-organisms in water directly impact water quality:
  - *transmission of diseases (pathogens)*
  - *bad tastes, or odours (e.g. hydrogen sulphide)*
  - *corrosion or biofouling of surfaces*

Nomenclature

- Classification of (all) life on earth based on 7 categories:

Category	**Example: human beings**
Kingdom:	**Animal**
Phylum:	**Chordata**
Class:	**Mammalia**
Order:	**Primate**
Family:	**Hominidae**
Genus: *(*always capital*, italic)*	***Homo***
Species: (lower case, *italic*)	***Sapiens***

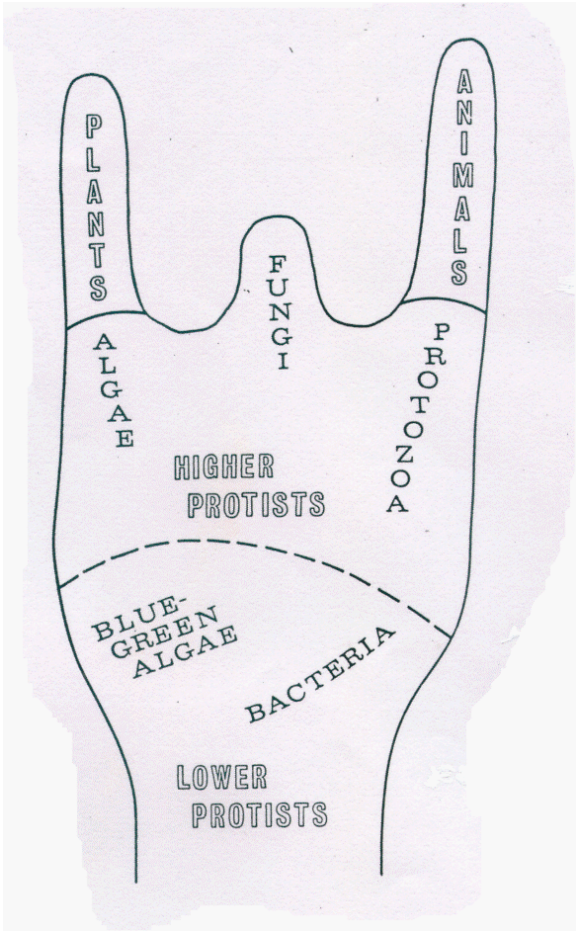
- Common bacteria: *E. coli*
  - *genus: Escherichia, species: coli*

Protists

- Most micro-organisms belong to Kingdom ‘Protista’ protists)
  - *Higher protists (eucaryotes – organized cell)*
  - *Lower protists (procaryotes – simple cell structure)*

- Protists are not animals or plants
- Many are uni-cellular, some multi-cellular

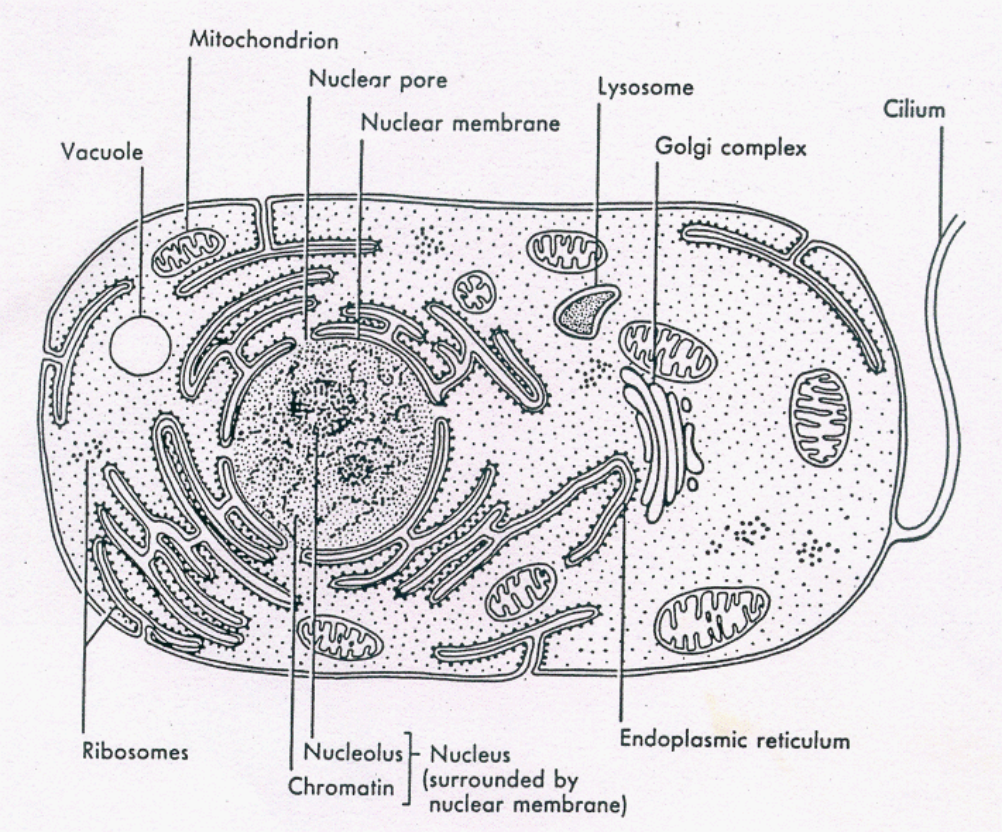
General taxonomy of life forms



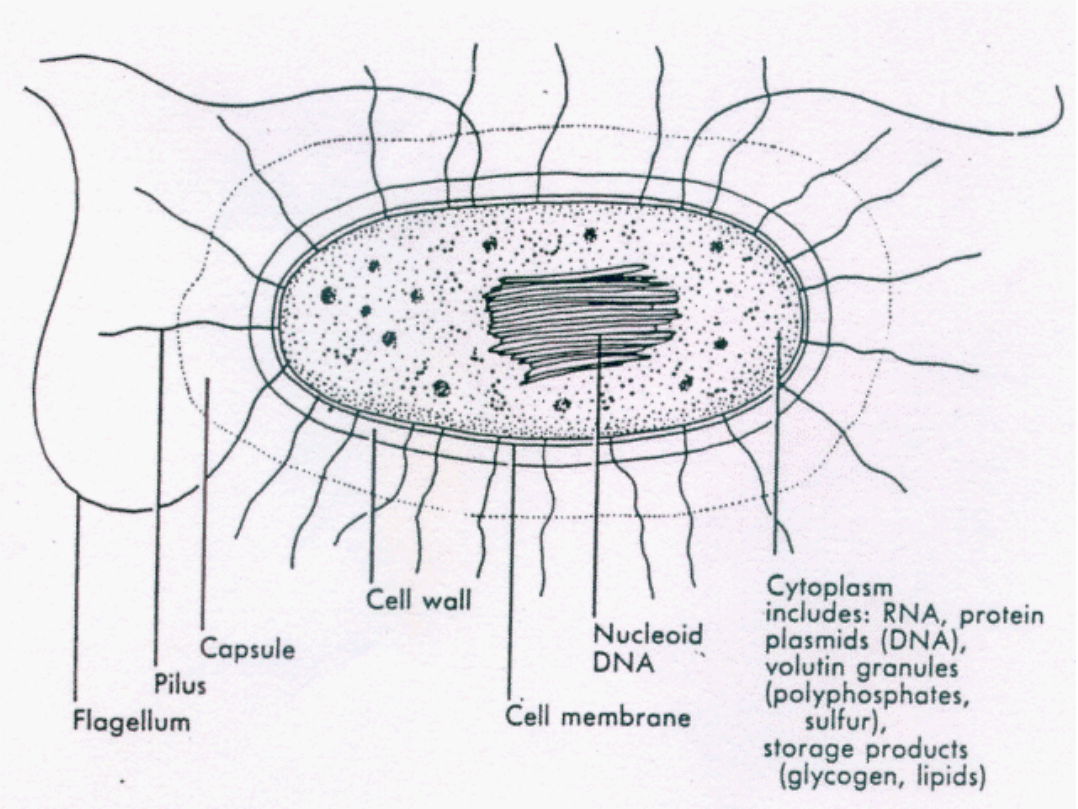
Protists

- Higher protists: Eucaryotic cell with nucleus in nuclear membrane:
  - *Protozoa, most algae, fungi (molds and yeasts)*
- Lower protists: Procaryotic cell with ‘nuclear area’, no clear nuclear membrane:
  - *Bacteria, blue-green algae*
- Viruses: even simpler than procaryotic cell;
  - *not really a cell*

Eucaryotic cell



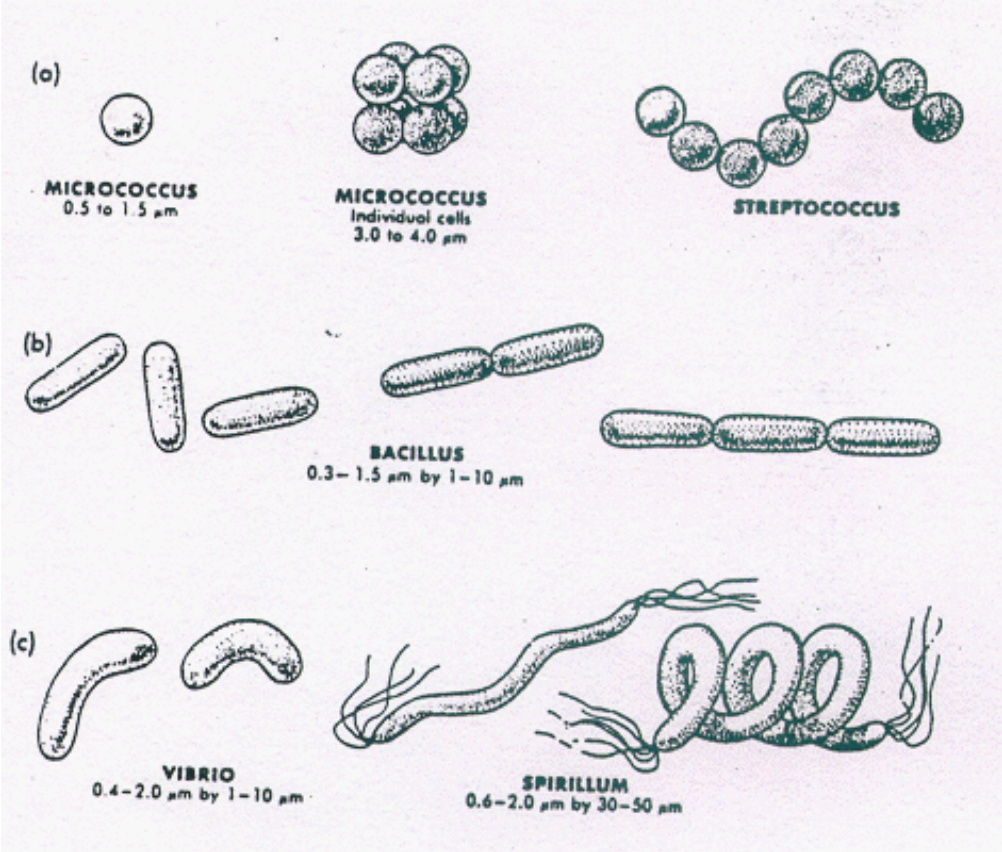
Procaryotic cell



Bacteria

- Bacteria: Lower protists, procaryotic (simple) cells
- Hundreds – thousands of bacteria
- mostly single-celled organisms, in 4 basic shapes:
  - *Spherical (cocci),*
  - *cylindrical rods (bacilli),*
  - *curved or helical rods (vibrio and spirilla), and*
  - *filaments (multi-cellular)*

Shapes of bacterial cells



Pathogenic micro-organisms

- Pathogenic bacteria cause many diseases of man
- 'Enteric' bacteria cause water borne diseases:
  - *Escherichia coli (E. coli):* *diarrhoea, urinary tract infection*
  - *Salmonella typhimurium :* *diarrhoea, fever, nausea*
  - *Salmonella typhi :* *typhoid fever*
  - *Shigella (several species):* *dysentery*
  - *Vibrio cholera :* *cholera*

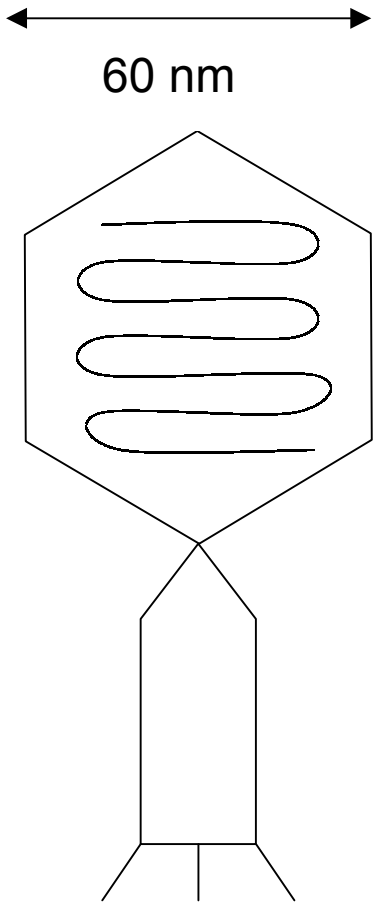
Viruses

- sub-microscopic particles, much smaller than bacteria
- must live & replicate in a living host animal

  → *therefore: ALL viruses are parasitic*
- viruses are very host specific

Viruses

- Example virus form:
  - *T-shaped viruses*
- Has single RNA or DNA strand embedded in a protein coat



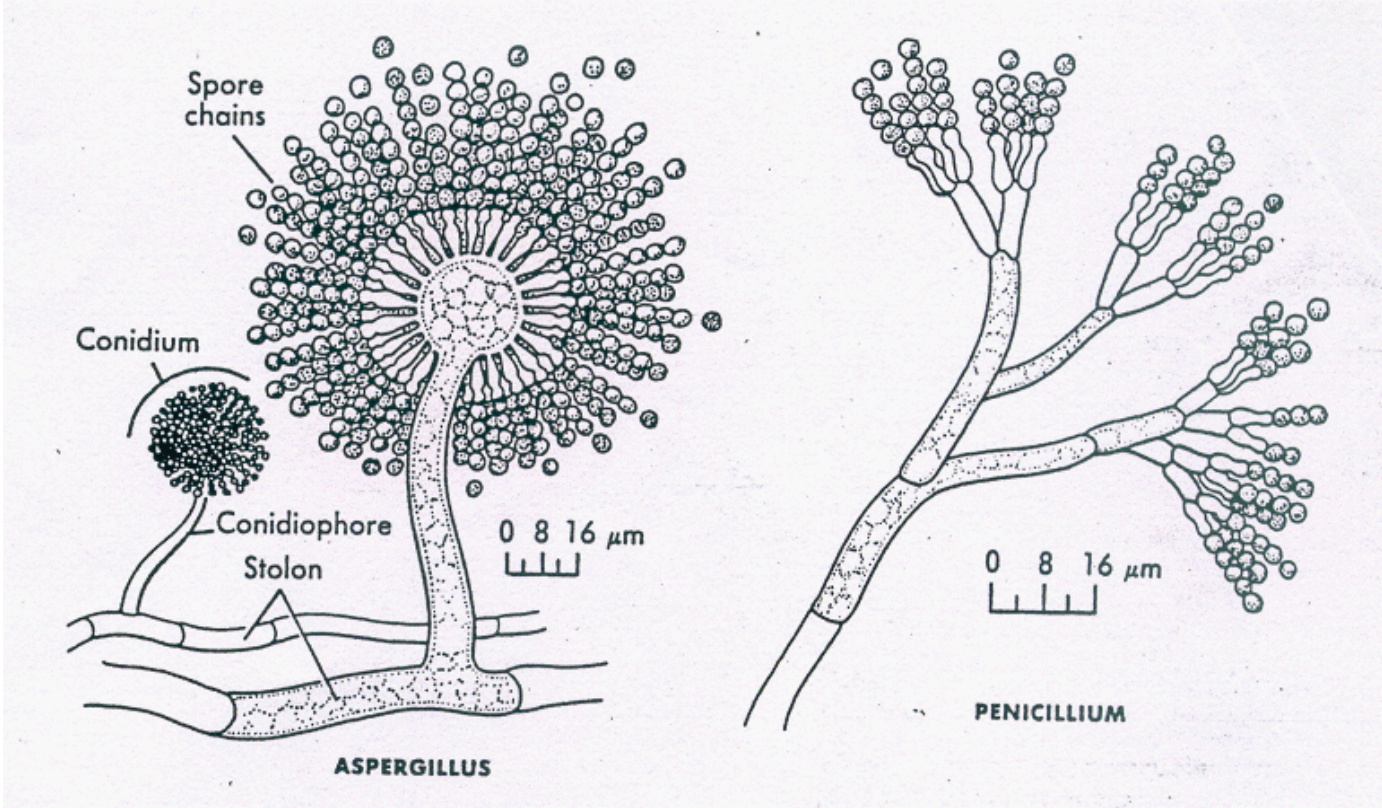
Pathogenic viruses

- Viruses cause many water-borne diseases:
  - *entero viruses:* *gastro-enteritis (mild-severe diarrhoea)*
  - *hepatitis A virus:* *infective hepatitis*
  - *polio virus:* *polio*
  - *coxsackie virus:* *disease of central nervous system*
  - *other virus:* *trachoma (eye infections, blindness)*

Fungi

- Fungi: higher protists, have eucaryotic cells
- Have vegetative structure ‘mycelium’:
  - *rigid branching system of tubes carrying cytoplasm*
  - *forms by germination and outgrowth of single spore cell*
- Yeasts are uni-cellular fungi with no mycelium
- Fungi important for decomposing organic matter
- Are mostly aerobic organisms

Examples of fungi



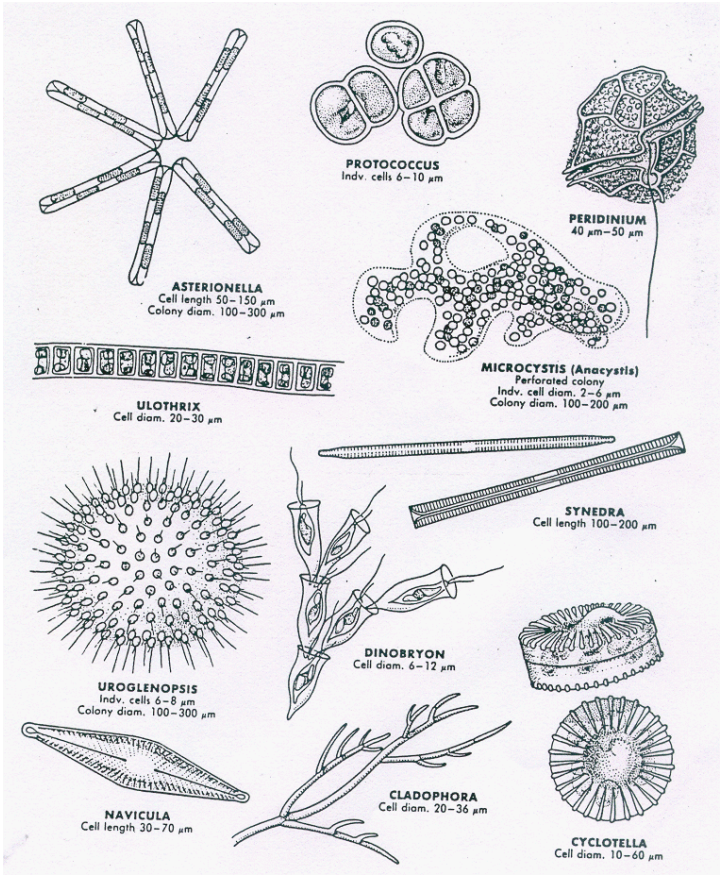
Algae

- Algae: uni-cellular or multicellular higher protists
- All algae have light absorbing pigments (e.g. chlorophyll)
- Conduct photosynthesis, producing oxygen:

$$\mathbf{6CO_2 + 6H_2O + nutrients \longrightarrow 6CH_2O + 6O_2}$$

- Range in size from single cells to large branched forms
- Freshwater and saltwater species

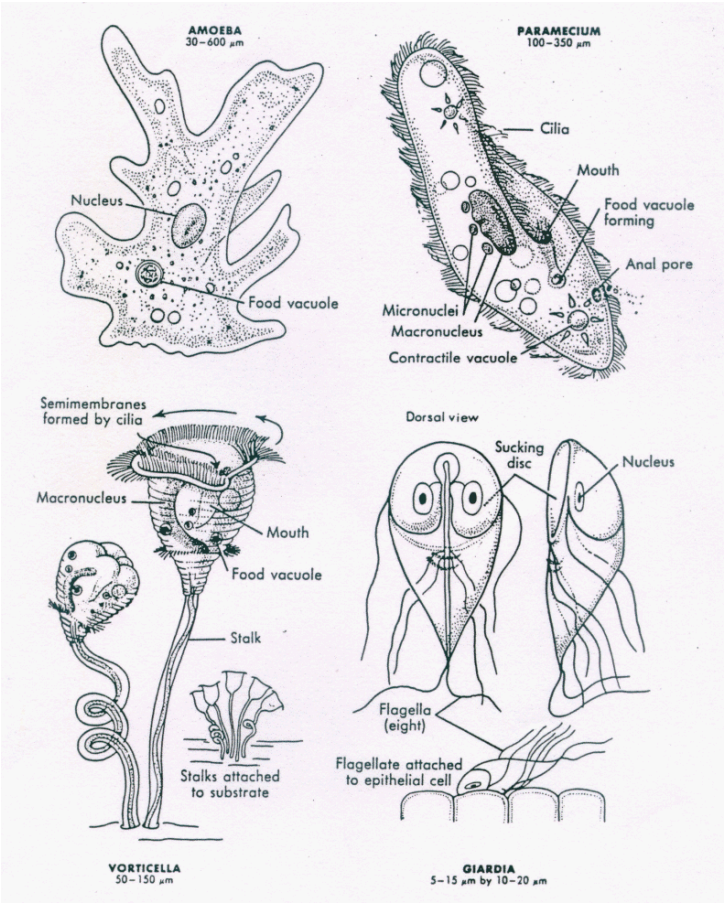
Fresh water algae



Protozoa

- Protozoa: higher protists (eucaroytic cells), aerobic
- Mobile organisms: amoeba motion, flagella, or cilia
- Several protozoa cause water-borne diseases:
  - *Entameoba histolytica* *amoebic dysentery*
  - *Giardia lamblia* *giardiasis (diarrhoea, nausea, fever)*

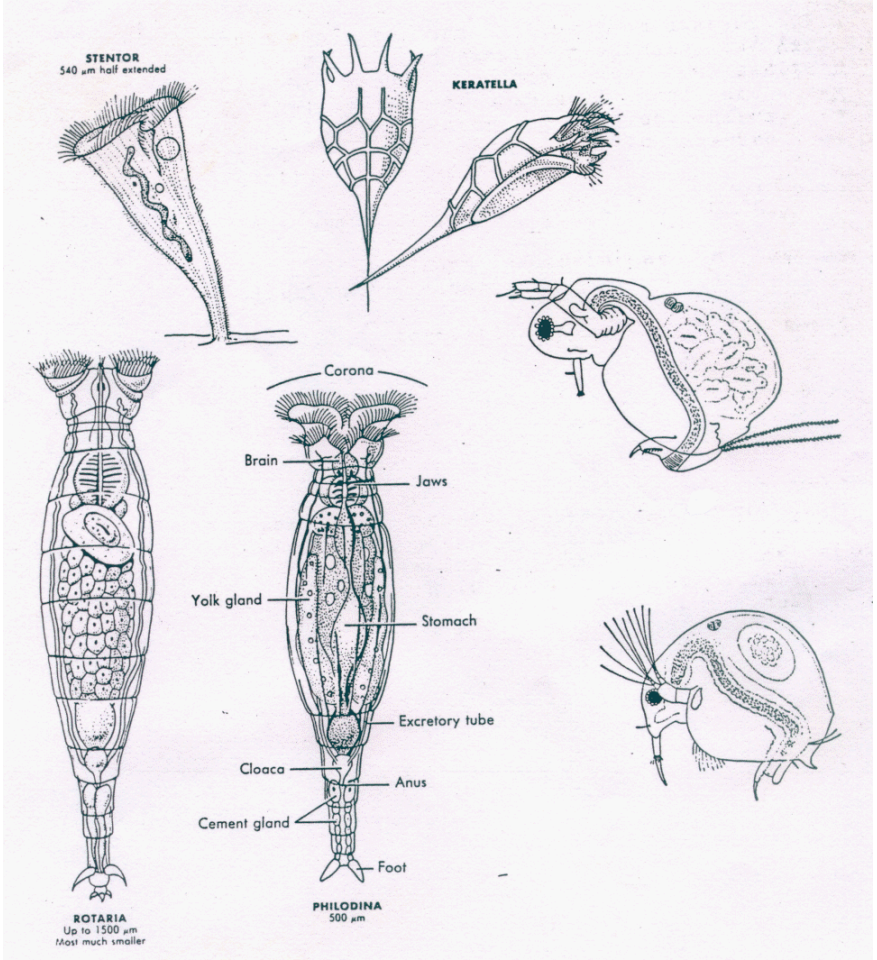
Protozoa


AMOEBA
30–600 μm
Nucleus
Food vacuole
PARAMECIUM
100–350 μm
Cilia
Mouth
Food vacuole forming
Anal pore
Micronuclei
Macronucleus
Contractile vacuole
Semimembranes formed by cilia
Macronucleus
Mouth
Food vacuole
Stalk
Stalks attached to substrate
VORTICELLA
50–150 μm
Dorsal view
Sucking disc
Nucleus
Flagella (eight)
Flagellate attached to epithelial cell
GIARDIA
5–15 μm by 10–20 μm

Multicellular organisms

- Rotifers:
  - *the simplest multi-cellular animals*
  - *named for rotating cilia on the head of organisms*
  - *mostly eat bacteria*
- Crustaceans:
  - *hard shelled, multi-cellular organisms*
  - *mostly eat bacteria and algae*
  - *are important food source for fish*

Examples of rotifers & crustaceans



5 Evaluation sheets

6 Handout

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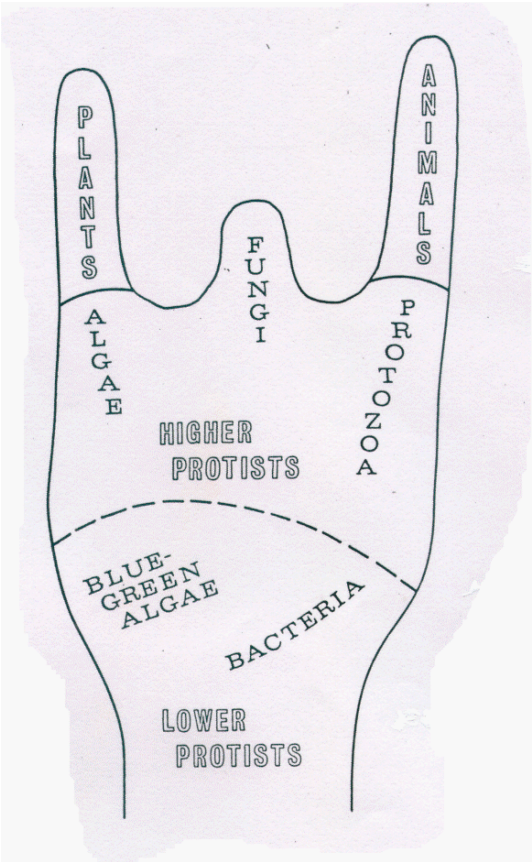
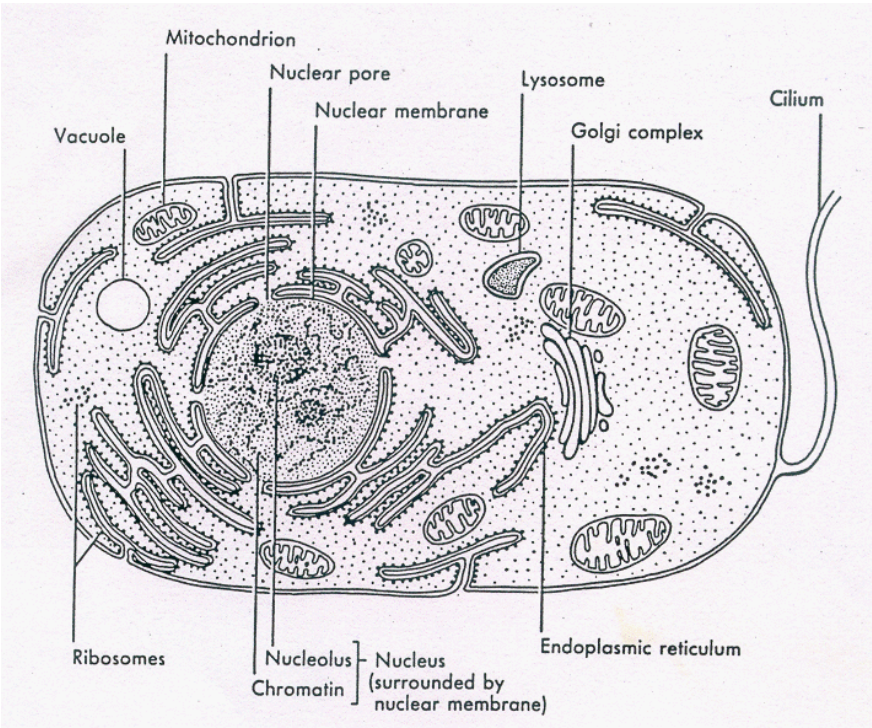
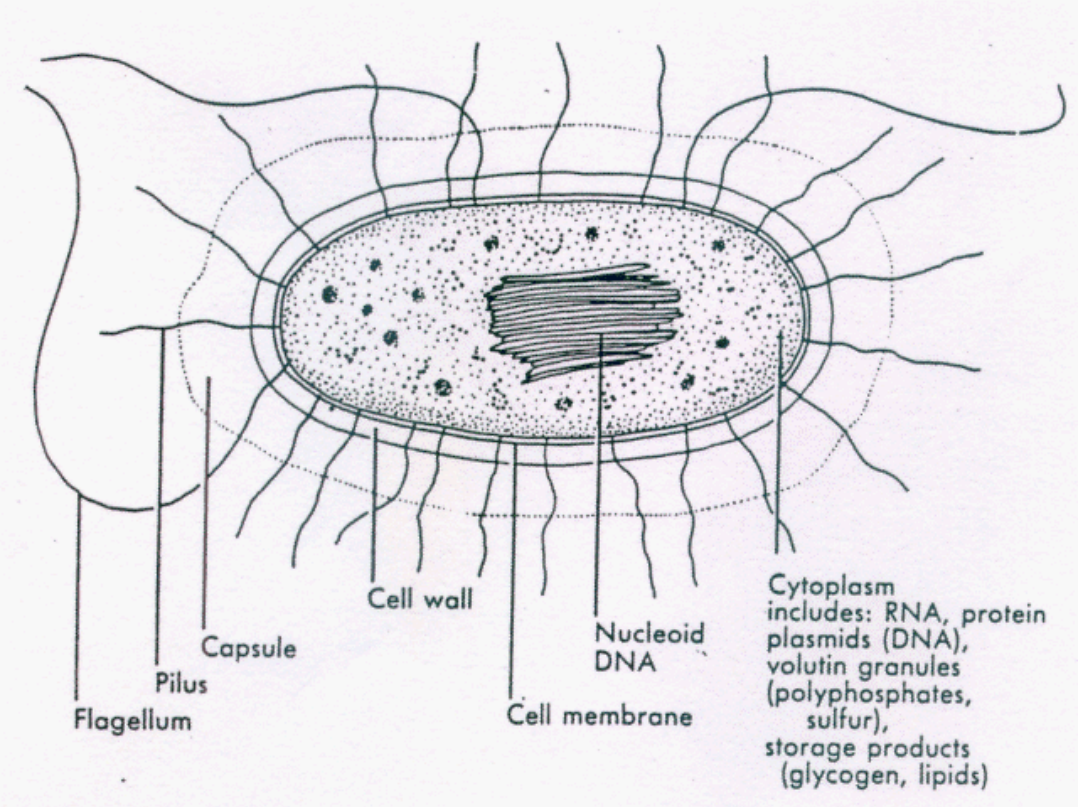


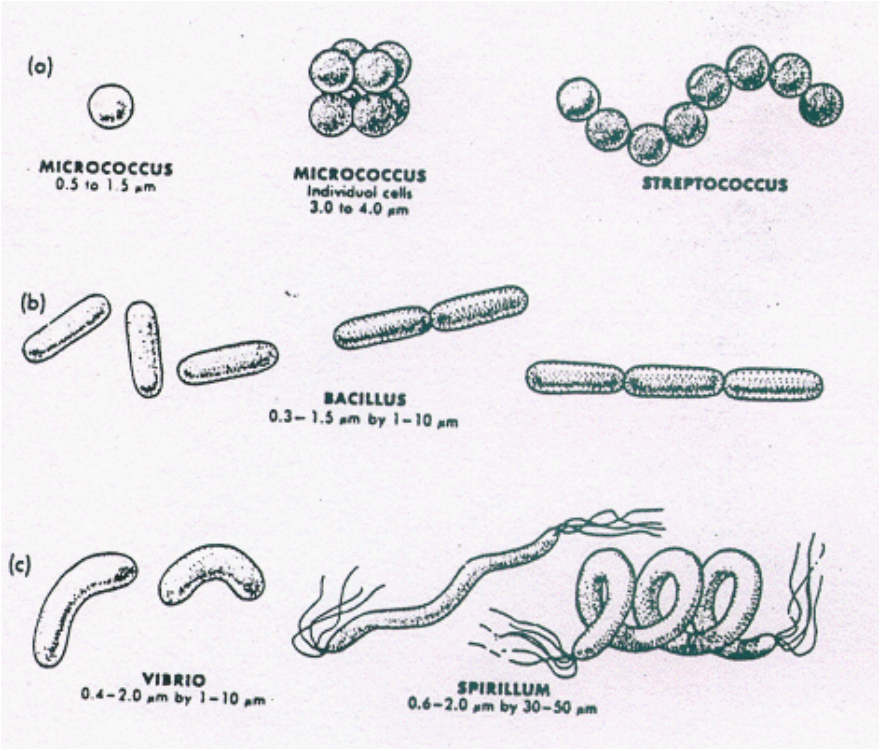
Eucaryotic cell



Procaryotic cell



Shapes of bacterial cells



Viruses

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  - *T-shaped viruses*
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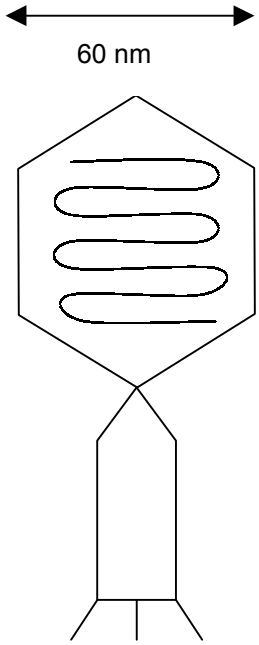
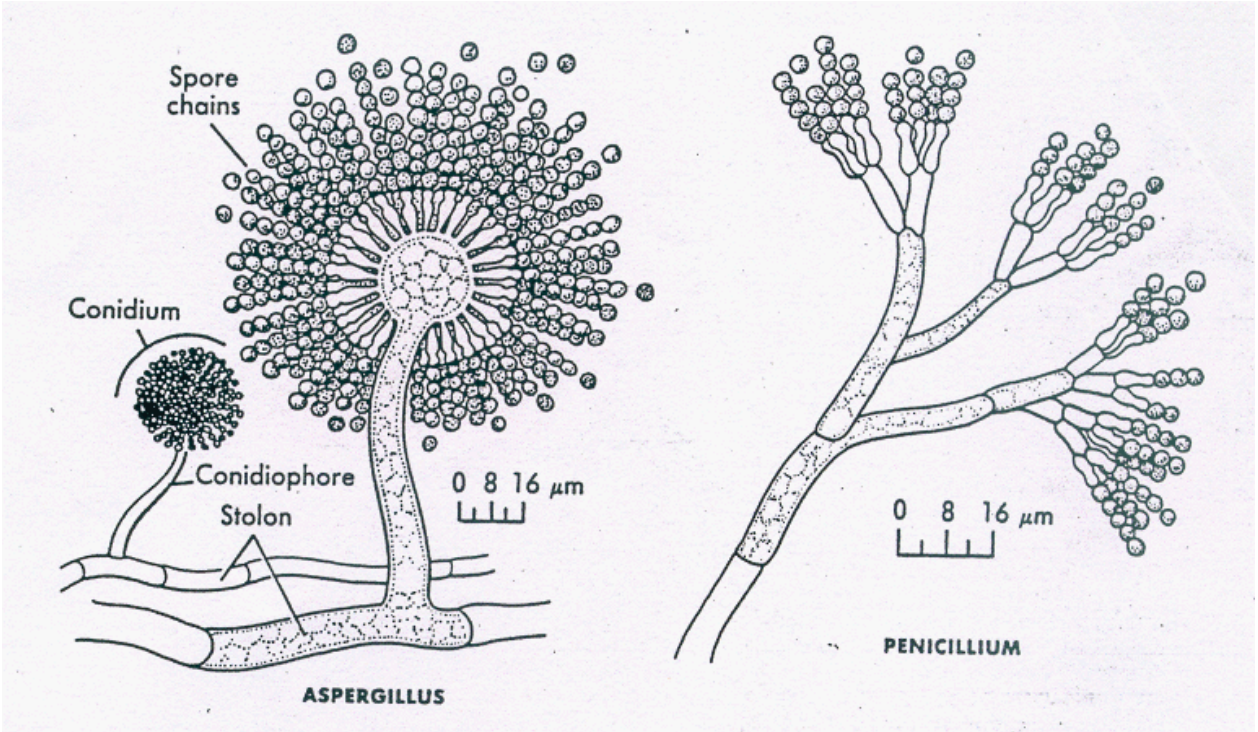
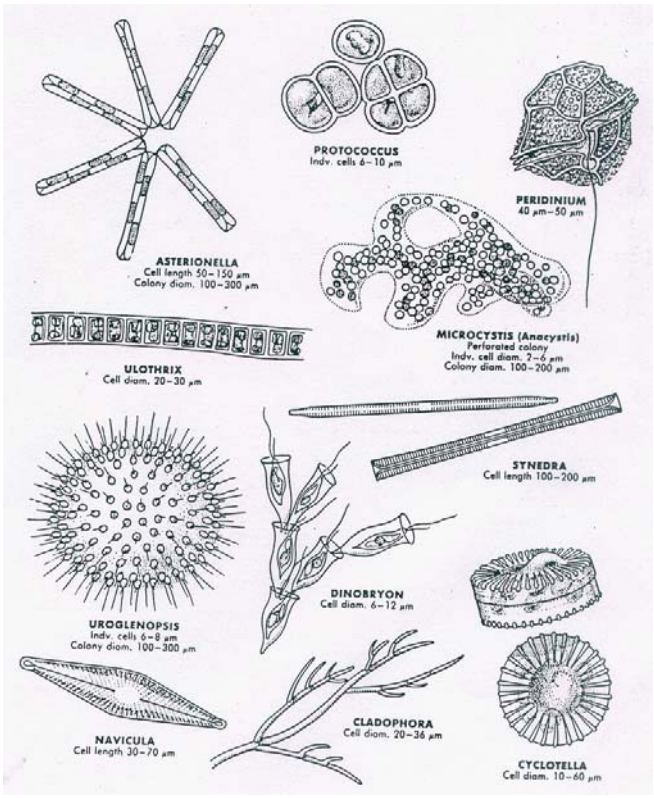


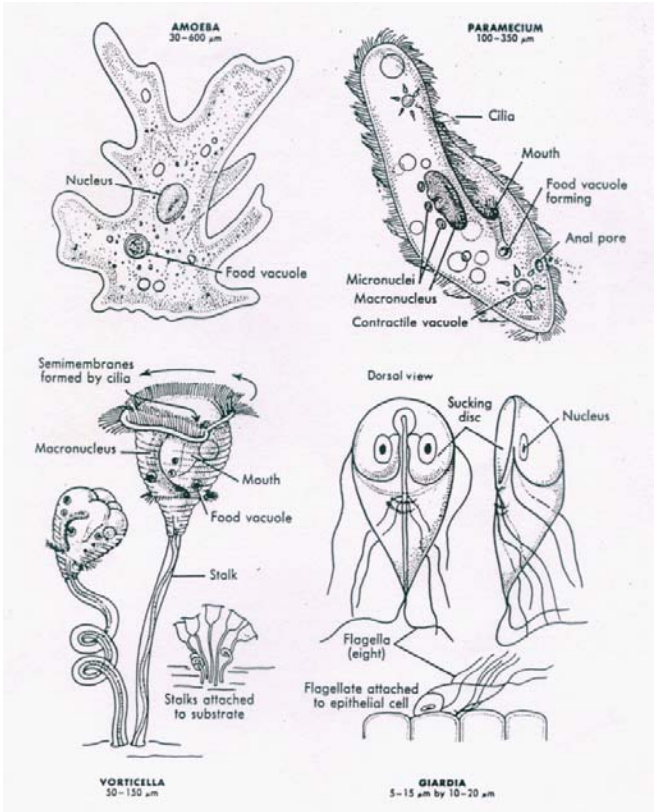
Examples of fungi



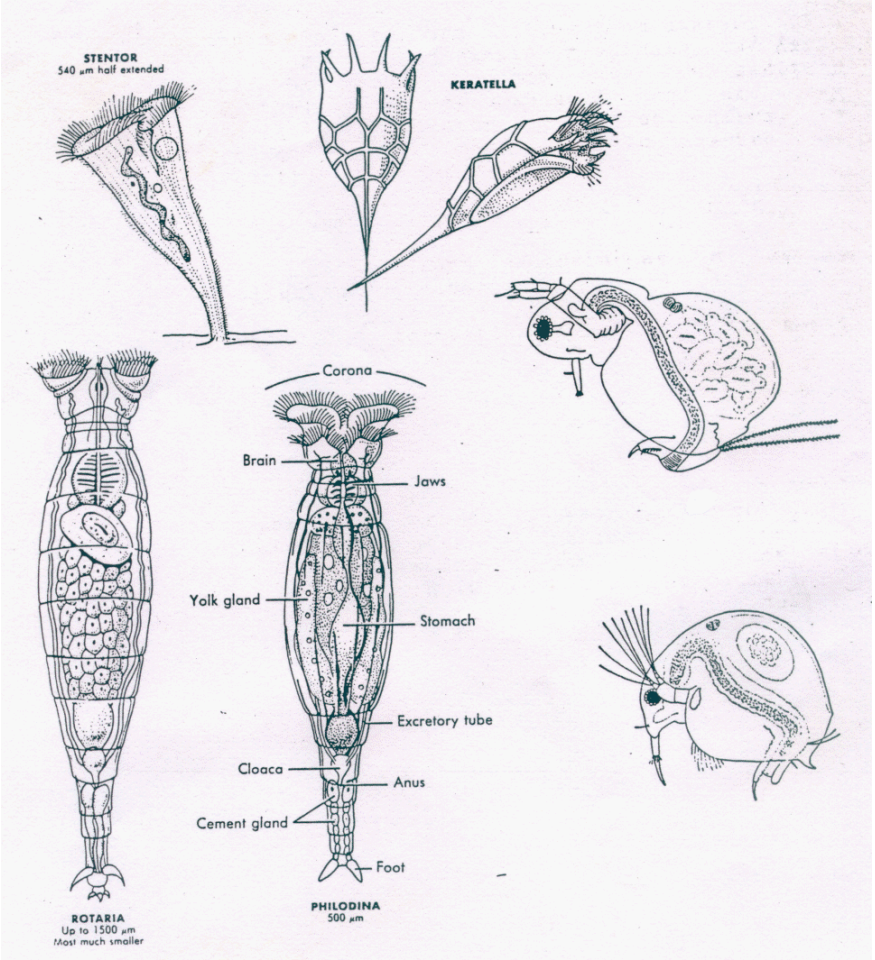
Fresh water algae



Protozoa



Examples of rotifers & crustaceans



Add copy of Main text in chapter 8, for all participants.

7 Additional handout

These handouts are distributed during delivery and contain test questions, answers to questions, special worksheets, optional information, and other matters you would not like to be seen in the regular handouts.

It is a good practice to pre-punch these additional handouts, so the participants can easily insert them in the main handout folder.

8 Main text

Contents

Introduction to Microbiology

1. Introduction

Microbiology is the study of organisms, called *micro-organisms,* that are too small to be perceived clearly by the unaided eye. If an object has a diameter of less than 0.1 mm, the eye cannot perceive it at all, and very little detail can be perceived in an object with a diameter of 1 mm. In general, organisms with a diameter of 1 mm or less are micro-organisms, and fall in to the broad category of microbiology.

Micro-organisms bring about a number of important chemical transformations in nature. Production of alcohol, making of cheese and yoghurt, and retting of flax are some of the processes mankind has harnessed since prehistoric times. Micro-organisms are also responsible for breaking down organic matter in nature.

Antony van Leeuwenhoelk (1632 - 1723) first discovered the microbial world. Some early scientists proposed a theory of spontaneous generation of microbial life. Pasteur in 1862 using sterilized equipment showed that growth of micro-organisms was possible only if an opportunity for outside contamination was provided. Rise of microbiology has refined the traditional microbiological processes and has added entirely new processes such as production of organic acids, solvents, vitamins, antibiotics, etc. An entirely different dimension to traditional microbiology has been added through genetic engineering.

Micro-organisms exist everywhere in nature: soil, air, water, the table top, your stomach. Each different environment has a specific set of micro-organisms which is ideally suited to living in that environment.

The (micro) biological characteristics of water, specifically the resident aquatic population of micro-organisms, impact directly on water quality. The most important impact is the transmission of disease by pathogenic organisms in water. Other important water quality impacts include the development of tastes and odors in surface waters and groundwaters and the corrosion and biofouling of heat transfer surfaces in cooling systems and water supply and wastewater management facilities.

To help understand the impact of the micro-organisms present in water on humans and on water quality, the following topics will briefly be covered.

- the classification used to group micro-organisms
- the scientific nomenclature used to describe micro-organisms
- nutritional requirements
- micro-organisms in water and wastewater

2. Classification of Micro-organisms

Before the advent of microscopy and discovery of micro-organisms, living beings were classified as either plants or animals. As knowledge of microbes grew it became apparent that many did not fit into either traditional class. Table 1 shows the taxonomic groupings used to accommodate the micro-organisms.

The principal groups of organisms found in water may be classified as protists (higher and lower), plants and animals. Commonly, the organisms listed in the table are characterised as *procaryotic* or *eucaryotic* depending on whether the nucleus within the cell is enclosed in a well-defined nuclear membrane.

The microscopic forms of life are collectively classified as protists. Many protists are unicellular, but even the multi-cellular ones lack the internal differentiation into separate cell types and tissue regions characteristics of plants and animals. The micro-organisms generally recognized as protists include algae, bacteria, fungi and protozoa. There is an additional group of pseudo- organisms that are not visible through a light microscope: the viruses.

Table 1 Taxonomic grouping of Micro-organisms

Kingdom	Representative Member	Cell Classification
Animal	Crustaceans Worms Rotifers	Eucaryotic cells: Cells contain a nucleus enclosed within a well-defined nuclear membrane
Plant	Rooted aquatic plants Seed plants Ferns Mosses	
Protista (Higher)	Protozoa Algae Fungi (molds and yeasts)	
Protista (Lower)	Blue-green algae Bacteria	Procaryotic cells: Nucleus not enclosed in a true nuclear membrane.

Electron microscopy has shown that the protists can be classified in two categories, higher protists, which have an organized cell, or eucaryotic cell, and lower protists which have a simple cellular structure or procaryotic cell. The eucaryotic cell is the unit of structure in protozoa, fungi and most groups of algae whereas the procaryotic cell is the unit of structure in bacteria and blue-green algae. The viral particles have a still simpler structure, which can not be classified, as a cell.

Eucaryotic cell

An eucaryotic cell is about 20 μm in diameter or larger. The main units of cell organization are:

- Nucleus consisting of sub-units called chromosomes which are composed of deoxyribonucleic acid (DNA), contains the genetic information. The nucleus is contained in a membrane.
- Mitochondria and chloroplasts are sites of energy generation.
- Vacuoles and lysosomes are involved in ingestion and digestion of food.
- Cytoplasm contains a colloidal suspension of proteins, carbohydrates and important organelles such as endoplasmic reticulum, Golgi apparatus and ribosomes, which are involved in protein synthesis. Cytoplasm is also a means of locomotion in cells without cell walls by amoeboid motion.
- Flagella provide a means of locomotion for cells, which have a rigid cell wall.

Procaryotic cell

These are usually smaller than 5 μm in diameter and have much simpler structure:

- Nucleus contains a single long molecule of DNA and is not separated from cytoplasm by a membrane.
- Cytoplasm occupies most of the space and is relatively uniform in structure.
- Enzymes for respiration and photosynthesis are housed in the cell membrane, which also regulates the flow of materials into and out of the cell.
- Most cells are surrounded by a rigid cell wall.
- Procaryotes move by the action of flagella.

Viruses

Viruses have a simpler chemical structure. They consist only of a protein coat surrounding a single kind of nucleic acid, either DNA or ribonucleic acid (RNA). With the exception of enzymes, which aid in penetration of the host cell they are devoid of enzyme activity and consequently can not be considered true cells. When a virus injects its nucleic acid into the host cell, it takes over the regulation of the cell and directs it towards the production of more viruses. The cell fills up with the newly formed viruses and then bursts spilling the viruses into the medium where each particle can infect other host cells.

3. Nomenclature for Micro-organisms

The nomenclature for micro-organisms, as for all organisms, is based on a classification system of 7 steps:

Kindom
Phylum
Class
Order
Family
Genus
Species

In this classification system, the scientific name for any organisms includes both the genus and the species name. The genus name is always given first, and is capitalized. The species name is not captalized. Both names are always written in *italics.*

As an example, the scientific name for human beings is *Homo sapiens*. That is, humans belong to the genus *Homo*, and the species *sapiens*. The full classification of human beings is:

Kingdom:	Animal
Phylum:	Chordata
Class:	Mammalia
Order:	Primate
Family:	Hominidae
Genus:	*Homo*
Species:	*sapiens*

An example of the scientific name for a common bacteria is *Escherichia coli* (also known as *E. coli*). This bacterium belongs to the genus *Escherichia* and the species *coli*.

4. Nutritional Requirements

To continue to reproduce and function properly, organisms must have sources of energy and carbon for synthesis of new cellular material. Inorganic elements, N and P and other elements such as S, K, Ca, and Mg are also vital. Organisms may be classified according to their sources of energy and carbon as given below (Table 2):
Micro-organisms may be further classified as aerobic, anaerobic or facultative depending upon their need for oxygen.

Table 2 Organism classification based on energy and carbon source

Classification	Energy source	Carbon*	Representative organisms
Photoautotroph	Light	Carbon dioxide	Higher plants, Algae, Photosynthetic bacteria
Photoheterotroph	Light	Organic	Photosynthetic bacteria
Chemoautotroph	Inorganic matter	Carbon dioxide	Bacteria
Chemoheterotroph	Organic matter	Organic matter	Bacteria, fungi, protozoa, animals
* organisms that use carbon dioxide as their only source of carbon are called self-feeding (autotroph). Autotrophy does not refer to energy source.			

5. Important types of micro-organisms

Bacteria

Bacteria are single cell protists. They are of the Kingdom of the lower protists, meaning they are procaryotic cells, with no clear nucleus, only a nuclear area. They use soluble food and reproduce by binary fission.

There are thousands of bacteria, but their general form falls in one of the four categories (Table 3):

- Spherical (cocci),
- cylinderical rods (bacilli),
- curved or helical rods (vibrio and spirilla), and
- filaments.

Most bacteria are about 0.5 to 1.0 micron in diameter. The spiral forms may be as long as 50 microns. The multicellular filamentous bacteria may be 100 microns or longer.

Table 3: Classification of bacteria according to shape

Shape	general name	size range
sphere	cocci (coccus, singular)	1-3 μm
rod	bacilli (bacillus, singuar)	0.3-1.5 μm (diameter) 1-10 μm (length)
curved rod or spiral	vibrio (curved) spirilla (spiral; spirillus, singular)	0.6-1 μm (diam), 2-6 μm (length) up to 50 μm
filament, (chains of indiv. cells)	variety of names	100 μm and longer

Metabolically, most bacteria are heterotrophic. The autotrophic forms obtain energy by oxidation of inorganic substrates such as ammonia, iron and sulphur. There are a few autotrophic photosynthetic bacteria also. Depending on their metabolic reaction, the bacteria may be classified as aerobic, anaerobic or facultative. Various pathogenic bacteria cause many diseases of man.

The group known as 'enteric bacteria' are a major cause of infection through food or water in all countries. The most common enteric bacteria are *Salmonella typhimurium, Escherichia coli,* and *Shigella* species. In all these infections, live bacteria must be ingested to produce disease. Following ingestion, symptoms begin after variable periods of time, usually 7 – 48 hours for *Salmonella typhimurium,* and 1-4 days for *Escherichia coli.* Abdominal pain and diarrhoea are the most prominent symptoms, but vomiting and fever are also common, persisting from several days to several weeks. Most adults recover, but loss of fluids can lead to death, especially for children and elderly people. Enteric bacteria act by colonizing the intestines and secreting toxins, namely enterotoxins. The resulting sickness is often known as gastro-enteritis.

Typhoid fever, which is caused by *Salmonella typhi*, is endemic to many areas. The disease is acquired by ingesting food or water contaminated with human faeces. Within 6 to 14 days after exposure, headache and fever develop. The fever can continue for several days and rise above 40 ^{o}C. In most cases *S. typhi* is shed in the feces for several weeks. Approximately 3 percent of the patients who recover become carriers of the disease and continue to shed the organism for extended periods.

Cholera is another major disease caused bacteria. Throughout history, it has been a major disease in India and other parts of Southeast Asia, but is also known in many other areas, where it occurs in epidemics. The disease is caused by the bacteria *Vibrio cholerae*, a motile, Gram-negative rod bacteria. The disease is acquired by ingesting food or water contaminated by faecal material. After an incubation period of 2-5 days, diarrhoea and abdominal pain begin suddenly, and vomiting can occur. The bacteria acts by colonizing the intestines and secreting cholera toxin.

Viruses

Viruses are sub-microscopic particles that are unable to replicate or adapt to environmental conditions outside a living host. Thus all viruses are parasites, and require a host organism to survive and reproduce. A virus consists of a strand of genetic material, DNA or RNA, within a protein coat. The particles doe not have the ability to synthesize new compounds. Instead, they invade living cells, where the viral genetic material redirects cell activities towards production of new viral particles, at the expense of the host cell growth. When the infected host cell dies, large numbers of viruses are released to infect other cells.

All viruses are extremely host specific. Thus a particular virus can attack only one species of organism. A number of viral diseases are commonly transferred via water. The viruses of most significance in water quality are the enteric viruses, i.e. those that inhabit the intestinal tract. Viruses ingested from water can result in a variety of diseases including hepatitis, and diseases of the central nervous system caused by the poliovirus, coxsackieviruses, and echoviruses.

Fungi

Fungi are of the Kingdom of the higher protists. They are aerobic, multicellular, non-photosynthetic organisms having eucaryotic cells (i.e. clear cell nucleus with nuclear membrane). Most fungi are *saprophytes,* obtaining their food from dead organic matter. Fungi are mostly multinucleate organisms which have a vegetative structure known as mycelium. The mycelium consists of a rigid, branching system of tubes, through which flows a multinucleate mass of cytoplasm. A mycelium arises by the germination and outgrowth of a single reproductive cell, or spore. Yeasts are fungi that can not form a mycelium and are therefore unicellular.

Together with bacteria, fungi are the principal organisms responsible for the decomposition of carbon in the biosphere. In contrast to bacteria, fungi can grow in low-moisture areas, and they can grow in low-pH environments. Because of these characteristics, fungi play an important role in the breakdown of organic matter in both aquatic and terrestrial environments. As organic matter is decomposed, fungi release carbon dioxide to the atmosphere and nitrogen to the terrestrial environment.

Fungi vary in size from microscopic organisms to mushrooms, and are often divided into the following five classes:
1. Myxomycetes, or slime fungi
2. Phycomycetes, or aquatic fungi
3. Ascomycetes, or sac fungi
4. Basidiomycetes, including mushrooms
5. Fungi imperfecti, or miscellaneous fungi

With respect to water quality, the first two classes are the most important.

Algae

The name algae, is applied to a diverse group of eucaryotic micro-organisms that share some similar characteristics. Algae are unicellular or multi-cellular, autotrophic, photosynthetic protists. They are classified according to their photosynthetic pigment and taxonomic and biochemical cellular properties. They range in size from tiny single cells to branched forms of visible length.

Typically, algae are organisms which contain chlorophyll and are capable of photosynthesis. The presence of chlorophyll in the algae. is the principal feature used to distinguish them from fungi. In addition to chlorophyll, other pigments encountered in algae include carotenes (orange) and other colored pigments (red, brown, blue, yellow). Combinations of these pigments result in the various colors of algae observed in nature.

Algae, like all higher plants, utilize CO_2 and light for the synthesis of cell carbon, in a process known as photosynthesis. The light is absorbed by the cell pigments (e.g. chlorophyll or carotenoids), giving the energy for the photosynthetic reaction to occur. Oxygen is produced during the process. At night, algae utilize oxygen in the process of respiration. Respiration also occurs during the daytime, but the amount of oxygen consumed is less than the amount of oxygen produced by photosynthesis. Simplified reactions for photosynthesis and respiration are given below:

Photosynthesis: $6CO_2 + 6H_2O + \text{nutrients} \longrightarrow 6CH_2O + 6O_2$

Respiration: $CH_2O + O_2 \longrightarrow CO_2 + H_2O$

The major groupings used to classify algae are given in Table 4.

Table 4 Classification of major algae groups

Group	Descriptive name	aquatic habitat	description
Chlorophyta	Green algae	fresh and salt water	can be unicellular or multi-cellular
Chrysophyta	Diatoms, golden-brown algae	fresh and salt water	Mostly unicellular. Diatoms have shells composed mainly of silica.
Chryptophyta	Cryptomonads	salt water	
Euglenophyta	Euglena	fresh water	motile, colonial, unicellular and flagellated.
Cyanophyta	Blue-green	fresh and salt water	unicellular, usually enclosed in a sheath, no flagella. Can use N_2 from atmosphere as nutrient in cell synthesis.
Phaeophyta	Brown algae	salt water	
Pyrrhophyta	Dinoflagellates	fresh and salt water	
Rhodophyta	Red algae	fresh and salt water	
Xanthophyta	Yellow-green algae	fresh and salt water	

Protozoa

Protozoa are single-cell micro-organisms of the Kingdom Protista. Protozoa are motile, unicellular, aerobic heterotrophs. They are an order of magnitude larger than bacteria and often consume bacteria as a food source. They are eucaryotic cells, but have no cell walls.

Most protozoa are free-living in nature, although several species are parasitic, and must live on or in a host organism. The host organism can vary from primitive organisms such as algae to highly complex organisms, including human beings. The 4 major groups of protozoa are given in Table 5.

Table 5 Major groups of protozoa

			Typical members	
Class	**Mode of motility**	**Parasitic**	**Name**	**Remarks**
Ciliata	cilia (usually multiple)	No	*Paramecium*	free-swimming
Mastigophora	flagella (one or more)	usually parasitic	*Giardia lamblia* *Trypanosoma gambiense*	causes giardiasis causes African sleeping sickness
Sarcodinia	pseudopodia (amoeboid motion); some have flagella	some parasitic	*Entamoeba histolytica*	causes amoebic dysentery
Sporozoa	creeping, spore forming; often non-motile flagella at some stages	parasitic.	*Plasmodium vivax*	causes malaria

Giardiasis is the most widespread of the protozoan diseases occurring throughout the world. This intestinal disease is caused by ingestion of food or water contaminated with faeces from humans or other mammals containing the flagellate (Mastigophora), *Giardia lambia*. *Giardia lambia* colonizes the small intestine and causes diarrhoea and abdominal pain.

Worms

A number of worms are of importance with respect to water quality, primarily from the standpoint of human disease. Two important worm categories (Phylum) are the Platyhelminthes and the Aschelminthes. The common name for the phylum Platyhelminthes is flatworm. Free-living flatworms of the class Turbellaria are present in ponds and quiet streams all over the world. The most common form is planarians. Two classes of flatworms are composed entirely of parasitic forms. They are the class Trematoda, commonly known as flukes, and the class Cestoda, commonly known as tapeworms.

The most important members of the phylum Aschelminthes are the nematodes. About 10,000 species of nematodes have been identified, and the list is growing. Most nematodes are free-living, but it is the parasitic forms which cause several human diseases:

- *Trichinella*, causes trichinosis
- *Necator*, causes hookworm
- *Ascaris*, causes common roundworm infestation
- *Filiria*, causes filariasis: blocking of the nymph nodes, causing permanent tissue damage (e.g. elephantitis).

Rotifers

Rotifers are the simplest of multi-cellular animals. The name is derived from the apparent rotating motion of the cilia located on the head of the organisms, Figure 6. Metabolically, rotifers can be classified as aerobic chemoheterotrophs. Bacteria are the principal food source for rotifers.

Crustaceans

Like rotifers, crustaceans are aerobic chemoheterotrophs that feed on bacteria and algae. These hard-shelled, multi-cellular animals are an important source of food for fish. Some crustaceans are shown in Figure 6.