Chapter 2

BACTERIA AND ARCHAEA

- *Bacteria and Archaea comprise a diverse group of single-celled, prokaryotic organisms which live in the soils of every ecosystem -from warm, moist, densely vegetated soils to the deserts and grasslands.*
- They are the smallest of all the cellular organisms that live in soil. Only the viruses which exist not as cells, are smaller.

- Despite their small size, the bacteria and archaea exhibit a greater variety of metabolic capabilities than any other groups of organisms and play crucial roles in:
  - ✓ soil formation,
  - ✓ organic matter decomposition, remediation of contaminated soils,
  - ✓ biological transformations of mineral nutrients and
  - ✓ interactions with plants and plant diseases.

Bacteria = only Bacterias.
bacteria = Bacteria + Archea.

CLASSIFICATION

Currently no universally accepted system for classifying these diverse microorganisms.

Each species does have one officially recognized name.

Most widely accepted system for classifying these single-celled, prokaryotic microorganisms is described in **Bergey's Manual of Determinative Bacteriology.**

Kingdom: *Prokaryotae*

Four divisions on the basis of walls the cells possess.

Division I: ***Gracilicutes***
Prokaryotes with Gram-negative cell wall.

Division II: ***Firmicutes***
Prokaryotes with Gram-positive cell wall

Division III: ***Tenericutes***
Prokaryotes that have no cell wall, commonly called mycoplasmas.

Division IV: ***Medosicutes***
Prokaryotes with walls that do not contain the bacterial polymer peptidoglycan.

Division I-III are placed in the domain Bacteria and division IV (*Medosicutes*) in Archaea.

The Gram negative and Gram positive bacteria are the most abundant cellular organisms found in soil.

Purple Pink

...n-positive cocci in chains

Gram-negative rods

Although the two domains (Bacteria & Archaea) differ radically in many fundamental properties yet the generic term bacteria (note lower case) is commonly applied to both groups of prokaryotes.

The Archaea include microorganisms that grow in harsh environments (extreme halophiles and thermophiles) and strictly anaerobic methanogens, which can reduce carbon dioxide to methane gas.

Archaea resemble Bacteria and have some genes that are similar to bacterial genes, but they also contain other genes that are more like what are found in eukaryotes. Furthermore, they have some genes that are not like any found in anything else.

Comparison of Bacteria, Archaea, and Eucarya

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
Cell Wall	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

The primary taxonomic unit in bacterial classification is the *species* which can be defined as "a collection of strains that share many features in common and differ considerably from other strains". In bacteriology, a *strain* is a culture of cells descended from a single pure isolate.

Characteristics commonly used to classify bacteria:

Cellular morphology:
Size, shape, and arrangement of cells; staining reactions; presence or absence of specific structures.

Chemical characteristics:
Chemical nature of cellular constituents.

Cultural characteristics:
Nutritional and environmental requirements for growth; appearance of cultures in liquid or solid media.

Metabolism:
Chemical reactions carried out by cells to satisfy nutritional and energy requirements.

Antigenic characteristics:
Distinctive chemical components of cells that react specifically with antibodies produced by animal.

Genetic characteristics:
Base composition and nucleotide sequence of chromosomal or plasmid DNA.

Pathogenicity:
Ability to produce disease in plant or animal hosts.

Ecological characteristics:
Normal habitat and distribution of the organism in nature, interactions with other organisms.

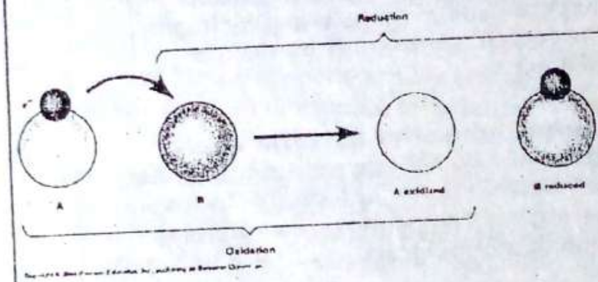
Some bacteria can synthesize all necessary cellular constituents and obtain energy for growth using a single carbon source and a few mineral nutrients.

Others have more complex nutritional requirements.

Many soil bacteria require **specific organic compounds** that they are unable to synthesize from simple straight materials. Organic nutrients of this type are called ***growth factors*** and are usually classified into one of the following categories:

- Amino acids (precursors of protein synthesis)
- Purines and pyrimidines (precursors for nucleic acid synthesis) and
- Vitamins (precursors for the synthesis of certain enzymes).

- Energy Source
  - Phototroph
    - Uses light as an energy source
  - Chemotroph
    - Uses energy from the oxidation of reduced chemical compounds
- Electron (Reduction potential) Source
  - Organotroph
    - Uses reduced organic compounds as a source for reduction potential
  - Lithotroph
    - Uses reduced inorganic compounds as a source for reduction potential



- Carbon source
  - Autotroph
    - Can use CO_2 as a sole carbon source (Carbon fixation)
  - Heterotroph
    - Requires an organic carbon source; cannot use CO_2 as a carbon source

imp

Chemoheterotrophs:

Most soil bacteria are chemoheterotrophs. They obtain energy by oxidizing the organic matter in soils and use the products of energy metabolism or other organic compounds as sources of carbon for growth.

Most of these bacteria are ***saprophytes*** which feed on nonliving plant and animal residues or on humic substances in soils.

A few species are ***symbionts*** **or** ***pathogens*** which invade the tissues of other living organisms.

Symbiotic bacteria feed on organic compounds in the tissues of a host organism and usually benefit the host.

Pathogenic bacteria harm the hosts whose tissues they invade, thereby causing disease.

Photoheterotrophs:

These are the bacteria which use light as source of energy and organic compounds as source of carbon. These include green sulfur bacteria and purple nonsulfur bacteria.

Photoautotrophs:

They capture light energy and use it to synthesize carbohydrates (photosynthesis) with carbon dioxide as their source of carbon

The *cyanobacteria* resemble eukaryotic algae (and plants) in the manner in which they use light energy and water to fix carbon dioxide (forming oxygen in the process).

The **green bacteria** produce green photosynthetic pigments and use reduced sulfur compounds (sulfide or thiosulfate) or hydrogen gas as electron donors.

The **purple bacteria** produce purple photosynthetic pigments and are divided into two groups:

- **purple sulfur bacteria** which use reduced sulfur compounds, hydrogen , or organic compounds as electron donors
- **purple nonsulfur bacteria** which generally do not use reduced sulfur as an electron donor and oxidize hydrogen or organic compounds when growing photoautotrophically.

Chemoautotrophs:

also known as *lithotrophs*.

They obtain energy by oxidizing reduced inorganic compounds in soil and use carbon dioxide as their source of carbon to synthesize carbohydrate.

Two groups of chemoautotrophic bacteria, collectively known as **nitrifying bacteria**, obtain energy by oxidizing inorganic nitrogen in soil:

The ***ammonia-oxidizing bacteria*** (*Nitrosomonas* and related genera) obtain energy by oxidizing ammonia (NH_3) to nitrite (NO_2^-).

$$2NH_3 + 3O_2 \rightarrow 2NO_2 + 2H^+ + 2H_2O$$

The ***nitrite-oxidizing bacteria*** (*Nitrobacter* and related genera) which obtain energy by oxidizing nitrite to nitrate (NO_3^-). They usually accompany ammonia-oxidizing bacteria in soils.

$$2NO_2 + O_2 \rightarrow 2NO_3^-$$

obligate - Strictly.

The ***sulfur-oxidizing bacteria*** obtain energy by oxidizing sulfides, elemental sulfur, or thiosulfate.

The oxidation of these substances results in the production of substantial amounts of sulfuric acid, significantly lowering the pH of the microenvironment in which sulfur oxidation occurs.

Several sulfur-oxidizing bacteria are ***obligate acidophlies*** that not only tolerate the acid they produce but are actually unable to grow at pH greater than 4.

H-oxidizing bacteria

Thiobacillus thiooxidans

$2S^0 + 3O_2 + 2H_2O \rightarrow 2SO_4^{2-} + 4H^+$

Thiobacillus ferrooxidans

$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+$

$4Fe^{2+} + 4H^+ + O_2 \rightarrow 4Fe^{3+} + 2H_2O$

Thiobacillus denitrifican

$5S^0 + 6KNO_3 + 2H_2O \rightarrow K_2SO_4 + 4KHSO_4 + 3N_2$

The ***hydrogen-oxidizing bacteria*** normally grow as chemoheterotrophs when organic substances are available in the soil.

In the absence of an oxidizable organic substrate, they can oxidize hydrogen for energy and synthesize carbohydrates with carbon dioxide as their source of carbon.

$$2H_2 + O_2 \rightarrow 2H_2O$$

$$2H_2 + NAD^+ \rightarrow NADH + H^+$$

Classification of organisms based on sources of C and energy used

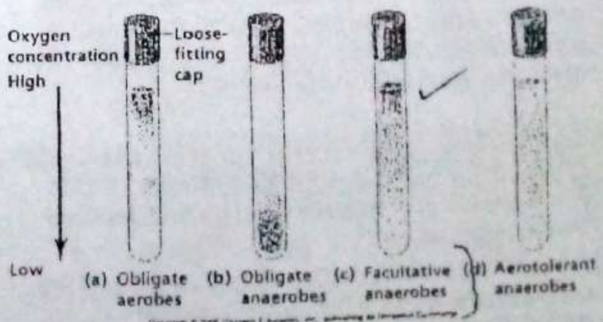
Carbon Source	Energy Source: Light (photo-)	Energy Source: Chemical compounds (chemo-)
[illegible]	Photoautotrophs • Plants, algae, and cyanobacteria use H_2O to reduce CO_2, producing O_2 as a byproduct • Photosynthetic green sulfur and purple sulfur bacteria do not use H_2O nor produce O_2	Chemoautotrophs • Hydrogen, sulfur, and nitrifying bacteria
Organic compounds [illegible]	Photoheterotrophs • Green nonsulfur and purple nonsulfur bacteria	Chemoheterotrophs • Aerobic respiration: most animals, fungi, and protozoa, and many bacteria • Anaerobic respiration: some animals, protozoa, and bacteria • Fermentation: some bacteria and yeasts

Classification of organisms based on O_2 utilization

- Oxygen concentrations in soils can vary widely from one microsite to another.
- Bacteria in a macropore filled with air may find plenty of oxygen to respire aerobically, while just a few millimeters away bacteria in a micropore filled with water may encounter strict anaerobic conditions.

- Oxygen concentrations can also vary widely with time, as soils undergo periods of saturation with water which may lead to temporary hypoxic or anoxic conditions and periods of dryness. no oxygen
- It is not surprising, then, that soil bacteria exhibit a **full range of adaptations to different oxygen concentrations.**

* less oxygen present.



obligate: with -
Facultative = wi

Obligate aerobes:

Many soil bacteria are obligate aerobes. Obligate aerobes obtain energy exclusively by aerobic respiration and can only grow in microsites where oxygen is available to use as a terminal electron acceptor.

Obligate anaerobes:

These cannot survive in the microsites where oxygen is available because they lack the enzymes that are needed to rid themselves of the toxic products (hydrogen peroxide and superoxide) that are initially formed when oxygen serves as an electron acceptor.

Obligate anaerobes grow exclusively in anaerobic microsites, obtaining energy either by fermentation or by anaerobic respiration.

Soil microbiologists recognize several groups of obligate anaerobes that generate energy by anaerobic respiration:

sulfate-reducing bacteria:

use sulfate as a terminal electron acceptor and produce hydrogen sulfide as a gaseous waste product. Along with the sulfur oxidizers, these bacteria play an important role in sulfur cycle.

$$SO_4^{2-} + 8e^- + 10H^+ \rightarrow H_2S + 4H_2O$$

Energy Aerobic > Anaerobic > fermen

Methanogenic bacteria:

use carbonate as a terminal electron acceptor and produce methane as a gaseous waste product.

$$CO_3^{2-} + 8e^- + 10H^+ \rightarrow CH_4 + 3H_2O$$

Acetogenic bacteria:

Also use carbonate as a terminal electron acceptor, but produce acetic acid as a waste product rather than methane.

$$2CO_3^{2-} + 8e^- + 12H^+ \rightarrow CH_3COOH + 4H_2O$$

Facultative anaerobes:

Many soil bacteria can grow either in the presence or absence of oxygen called as Facultative anaerobes.

These bacteria respire aerobically when oxygen is available, but can alter their metabolism to grow anaerobically in the absence of oxygen.

Some facultative anaerobes shift to **fermentative metabolism** under anaerobic conditions, whereas others shift to **anaerobic respiration** using nitrate or other inorganic compounds as the terminal electron acceptor. In either case aerobic respiration is the preferred mode of metabolism because it provides the bacteria with more energy than either fermentation or anaerobic respiration.

Diff b/w fermentation, anaerobic, aerobic

terminal electron acceptor in other then O_2, in anaerobic inorganic & in fermentation organic

Aerotolerant anaerobes:

The *aerotolerant* bacteria grow both under aerobic and anaerobic conditions, but do not shift from one mode of metabolism to another as conditions change.

They lack the electron transport protein that function in aerobic and anaerobic respiration and obtain energy exclusively by fermentation.

Because they do not form toxic products by using oxygen as an electron acceptor, aerotolerant anaerobes are not poisoned by oxygen in the same manner as obligate anaerobes.

prefer O_2 b/c more energy produced.

system

Classification of organisms based on habitats

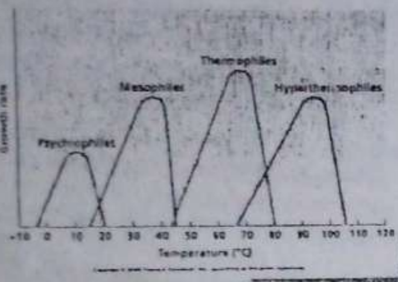
Bacteria exhibit an exceptional variety of adaptations that enable them to survive and grow in habitats that no other organisms can tolerate.

It has already been discussed that bacteria, through their various modes of energy metabolism, can grow in aerobic or anaerobic environments.

* Sulfate reducing bac.

Temperature

Bacteria can tolerate temperature extremes far beyond those tolerated by other organisms. These can be classified into following different groups on the basis of optimal temperature for growth.



Psychrophiles:

Some species of bacteria, known as psychrophiles, have adapted to grow optimally at temperatures below 15°C.

These psychrophilic bacteria often synthesize large quantities of unsaturated fatty acids that maintain the fluidity of the cytoplasmic membrane at low temperatures.

Mesophiles:

Most soil bacteria are mesophiles that grow optimally at temeratures in the range of 15 to 35 °C.

Thermophiles:

Some species of bacteria, known as thermophiles, survive and often thrive at temperatures in excess of 40 to 50°C (and as high as 100°C).

Most eukaryotes cannot survive temperatures above 45°C. Thermophilic bacteria typically produce heat-stable enzymes and structural proteins that do not denature at elevated temperatures.

pH

Several species of bacteria thrive best at particular pH, and are classified into following groups on this basis.

Acidophiles:

Some species of bacteria thrive best in acidic soils that predominate in regions with high precipitation. Some, such as the sulfur-oxidizing bacteria, tolerate extremely low pH that severely inhibit normal enzymatic activity.

These acidophiles maintain a neutral cytoplasmic pH by actively transporting H^+ ions out of the cell.

Alkalophilic:

These grow at pH as high as 10.5 in arid and semi arid regions and use a similar strategy (ion pumps as by acidphiles) for this purpose. Actinomycetes frequently predominate in alkaline soils because of their tolerance to high pH.

Pumps OH^- ,

Poor drainage and rapid surface evaporation in arid regions often lead to the formation of saline soils with stressful osmotic potential that inhibits the growth of many microbes.

Many species of bacteria have adapted to saline or arid environments by developing enzymes that function in solutions of high ionic strength or by accumulating solutes in the cytoplasm to compensate for the low water potential of the soil solution.

Plasmolysis – water drawn from body, membrane shrink

Halophiles:

Bacteria that can tolerate high salt concentrations are called halophiles.

Xerophiles:

Bacteria that tolerate dry habitats are called xerophiles.

Barophiles: Hydrostatic pressure is due to weight of H_2O. Organisms that live at great depths under the sea are called barophiles.

INTERACTIONS WITH OTHER ORGANISMS

Bacteria exhibit a broad spectrum of interactions with one another and with other soil microorganisms, ranging from neutral relationships at the center of the spectrum to symbiotic interactions at one extreme or antagonistic interactions at the other.

Symbiotic_______Neutral_________Antagonistic

Probably the most common type of interaction among soil microbes is ***Competetion.*** Bacteria, fungi, protozoa, and microscopic animals compete for water, food, shelter, and other vital resources that are present in short supply.

Beneficial interactions involving soil bacteria are also common. e.g. in complex material can't use to it, but other use & make it simple.

Decomposition of the complex constituents of soil organic matter, for instance, typically requires the **cooperative activity** of diverse community of microorganisms. One population may break down a complex substrate to an intermediate product that a second population can use as its source of carbon or energy for growth.

Bacteria may have a **negative impact** on one another and on other soil microbes by producing antibiotics or other substances that harm the organisms living nearby.

Bacteria also have important interactions with plants.

They **colonize plant roots** in greater numbers than any other group of soil microbes and profoundly influence plant growth and productivity in natural and agricultural ecosystems.

Bacteria may increase the **availability of inorganic nutrients** in soils by **mineralizing soil organic matter** and **solubilizing soil minerals**, and that they may **compete** with plants for those same nutrients through the process of **immobilization**.

If more C, more bac grow. immobilization.
C:N narrow, N is more, need bac, add excess N can obtained by plant.

Many bacterial species influence plant growth directly by **producing hormones** or **toxins** that stimulate or impede root function and morphology.

A few species, e.g. Rhizobium, Bradyrhizobium, and Frankia, form intricate **mutualistic symbiosis** with selected plant species, while other bacteria produce disease in plants that they infect.

produce siderophores, compound with Fe, cant uptaked by pathogens so it kills

Most of the bacteria that colonize plant roots are harmless saprophytes that feed on the organic nutrients in root exudates and protect the plant from infection by competing with pathogens for nutrients, water, and places to attach to the root, or by excreting substances that directly inhibit the pathogen.

Several species of bacteria are currently being investigated as potential biological control agents because of their ability to inhibit the growth of plant pathogens.

THE ACTINOMYCETES

The actinomycetes constitute specialized group of bacteria that occurs in soils throughout the world.

The term actinomycete (*actinis*, meaning "ray" and *myces*, meaning "fungus") is a **misnomer**.

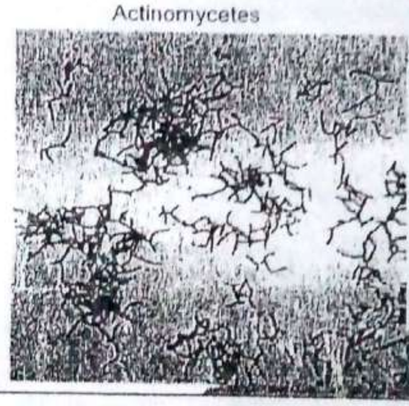
Relation of actinomycetes to fungi: (imp)

- formation of an aerial mycelium, although much smaller than that of fungi
- production of abundant asexual spores called *conidia* which give the colony a powdery or chalky appearance.

However, their resemblance to fungi is strictly morphological

Actinomycetes: Branches and Filaments

Actinomycetes



(imp)

The actinomycetes are classified with bacteria because they:

- are prokaryotic,
- contain peptidoglycan in their cell walls,
- are sensitive to lysozyme which degrades the polysaccharide backbone of the peptidoglycan,
- are sensitive to antibacterial but not antifungal antibiotics, and
- possess flagella typical of bacterial flagella in the few species that show motility.

- sensitive to bac. antibiotics

The actinomycetes include the microorganisms that produce colonies ranging from those typical of bacteria, such as species of *Mycobacterium* and *Corynebacterium*, to those that produce the tough, leathery mycelium characteristic of *Streptomyces* species.

The actinomyctes play important roles in soils and other environments such as compost piles.

colonization: to stay on roots.

- They are important agents in the degradation of organic materials in soil and contribute to the formation of stable humus.
- Recent research indicates that they, along with certain fungi, may play an important role in the degradation of lignin.
- They are also responsible for certain animal, plant, and human diseases.

The actinomycetes are often described as slow-growing organisms. For this reason, culture plates are often incubated for one or two weeks to allow differentiation of the actinomycete colonies.

Although the Actinomycetes do not compete well with the faster-growing bacteria and fungi for readily available carbon substrates, they are thought to be important in mineralizing carbon and nitrogen formed during the early stages of decomposition, such as fungal cell walls.

Many actinomycetes are good chitin degraders and simply because actinomycetes are "late colonizers" should not detract from the vital roles they play in the degradation processes and in the formation of humus.

Perhaps one of the most outstanding characteristics of the actinomycetes is their ability to produce antibiotics. Streptomycin, neomycin, erythromycin, and tetracycline are a few of the medically important antibiotics derived from species of ***Streptomyces***.

Actinomycetes tend to respond to environmental influences like bacteria. However, there are some exceptions.

- Actinomycetes tend to become more abundant in soils subjected to prolonged drying. This is generally attributed to the ability of actinomycete to produce conidia which withstand desiccation well.
- The conidia also confer a slight tolerance to increased soil temperature.

- Though most of the actinomyctes are mesophiles, thermophilic actinomycetes are important in the high-temperature transformations of organic substrates during composting.
- As a group, the actinomycetes tend to be sensitive to low pH. In general, as the soil pH decreases to 6.0 their number declines and below pH 5.0 they are almost absent.