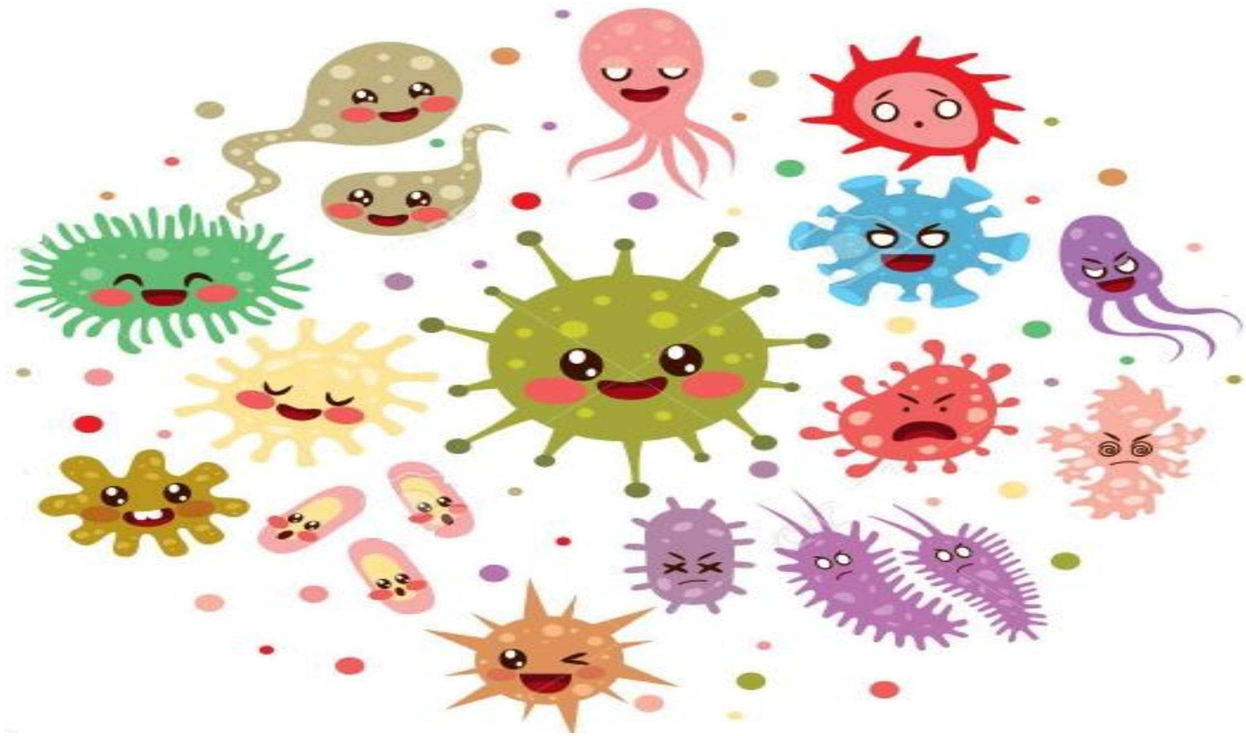
BIOLOGY AND DIVERSITY OF VIRUSES, BACTERIA AND FUNGI
(PAPER CODE: BOT 501)



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OBJECTIVES

The main objective of the present lecture is to cover the topic and make it easy to understand and interesting for our students/learners.

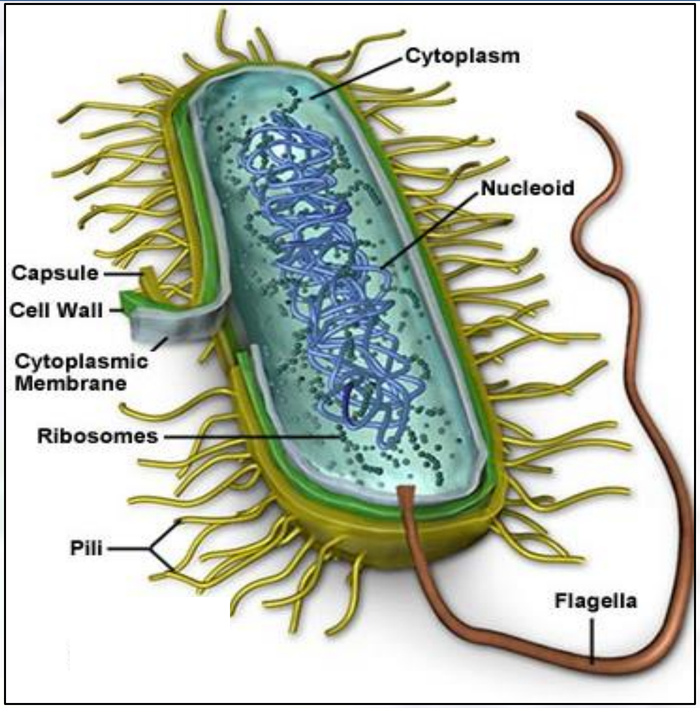
BLOCK – II : BACTERIA

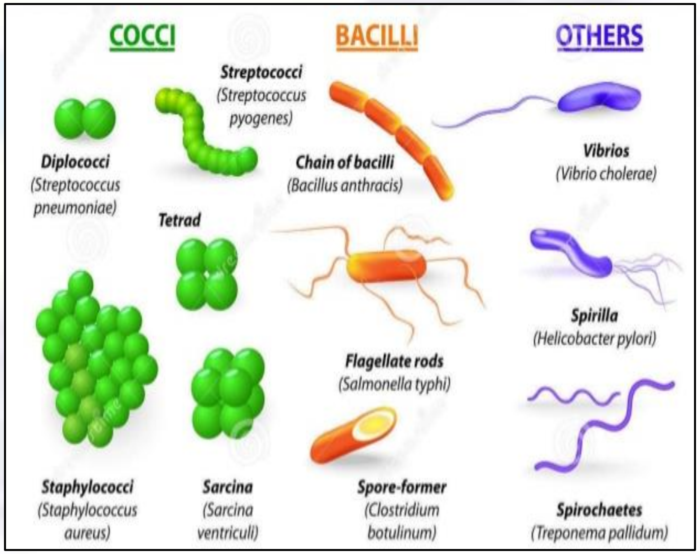
Unit –6 : General Account and Classification of Eubacteria, Archaebacteria and Cyanobacteria

CONTENT

WHAT ARE THE EUBACTERIA ????

- ❖ Eubacteria are called true bacteria.
- ❖ These are single-celled prokaryotic relatively more complex domain of kingdom monera.
- ❖ They are cosmopolitan in their distribution and found in most of the habitats on earth like soil, water and inside or outside of large organisms.
- ❖ Eubacteria do not consist of membrane-bound organelles, almost all the metabolic reactions take place in the cytoplasm.
- ❖ Some eubacteria are involved in the nitrogen cycle as well. They also exhibit both parasitic and pathogenic effects on their host organisms.
- ❖ Other than usual asexual reproduction methods, eubacteria exhibit sexual reproduction methods like conjugation.
- ❖ Individual eubacterium is 0.5-5 µm in diameter.
- ❖ Eubacteria exhibit a variety of shapes and arrangements. Cocci and bacilli are the major shapes. Vibrio, rods, filaments and spirochetes are the other shapes of eubacteria.





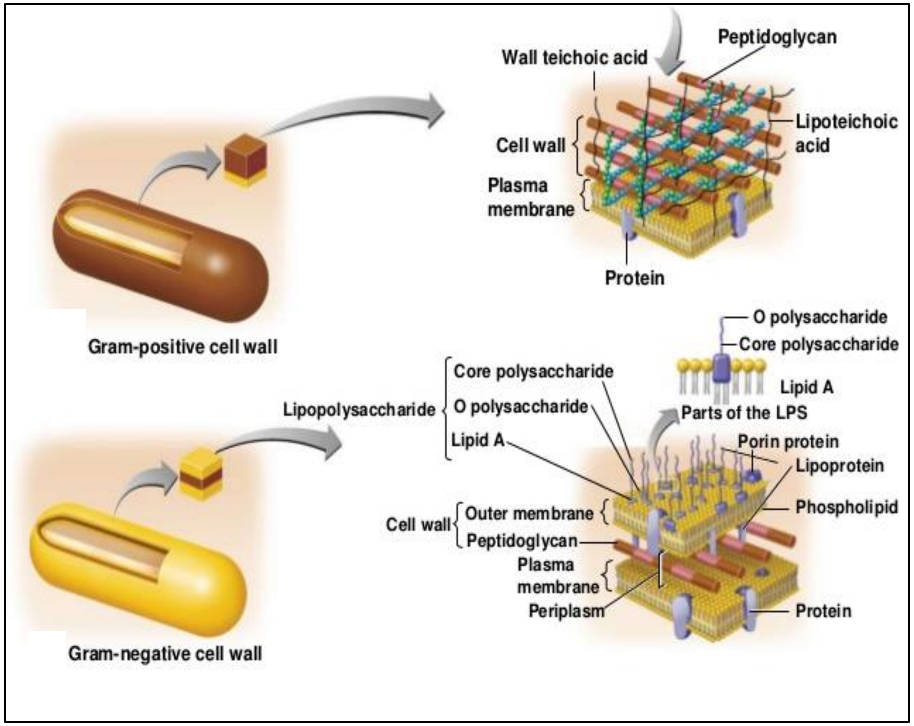
CHARACTERISTICS OF EUBACTERIA

❑ Cell Structure

❖Eubacteria lacking a well defined nucleus.

❖The cell wall is made up of peptidoglycans in a cross-linked chain pattern. This gives the wall of the bacteria the strength needed to maintain its shape and size during changing environments.

❖Depending on the cell wall thickness, eubacteria can be divided into two categories: gram positive and gram negative bacteria.



❖The peptidoglycan layer of gram positive bacteria binds with the gram stain, giving positive results.

❖The cell wall structure of gram negative bacteria is more complex than gram positive bacterial cell wall and incapable of binding with gram stain.

❖Unlike eukaryotes, bacteria have cholesterol present in the membrane to enhance permeability properties of the membrane and increase stiffness.

❖Similar to eukaryotes, bacteria also have a plasma membrane within the cell wall.

- ❖The bacterial cytoplasm is composed of mainly water (approximately 80%), but has a gel-like consistency.
- ❖Bacteria do not have membrane-bound organelles (mitochondria, chloroplasts etc).
- ❖The ribosomes are present, which are composed of RNA and used for protein synthesis.
- ❖Nucleus is not membrane bound and well defined. Some time resemble with true nucleus therefore called nucleoids.

❑ Locomotion

- ❖Some bacteria may have a flagella, or a projection composed of protein filaments that is used for movement.
- ❖Other bacteria may have pili, which are small projections all over the outside of the cell, and are used for sticking to surfaces and transferring DNA.
- ❖When a large amount of bacteria are attached to a surface and are surrounded by a polysaccharide sac, this is referred to as a biofilm. This complex has high antimicrobial resistance.

❑ Genetic Material

- ❖Within the cytoplasm, free floating genome, or bacterial DNA, found in the nucleoid.
- ❖Bacterial chromosomes are often circular but can also be linear in shape.

❖Metabolism

❖Eubacteria display a higher diversity in their energetic sources and metabolic pathways.

❖In the absence of organic matter, many species (described as chemoautotrophic eubacteria) have been shown to obtain their energy through the oxidization of mineral compounds.

❖Eubacteria, diversity in the modes of metabolism is also due to the wide variety of chemical compounds that serve as substrates as well as the ability to produce energy in different environmental conditions.

❖Various photosynthetic forms require oxygen for photosynthesis, others can depend on fermentation processes for energy and only grow well in the absence of oxygen.

❖Some of the main nutritional modes of different species in the domain Eubacteria include:

- **Autotrophic** - Produce their own food through photosynthetic processes.
- **Heterotrophic** - Obtain nutrients from their environment (unable to synthesize their own food).
- **Strictly or facultatively aerobic** - Survive in the presence of oxygen (strict aerobes) or can switch to anaerobic respiration in the absence of oxygen (facultative anaerobes).
- **Strictly or facultatively anaerobic** - Survive in the absence of oxygen (strict anaerobes) or can survive with or without oxygen (facultative anaerobes)

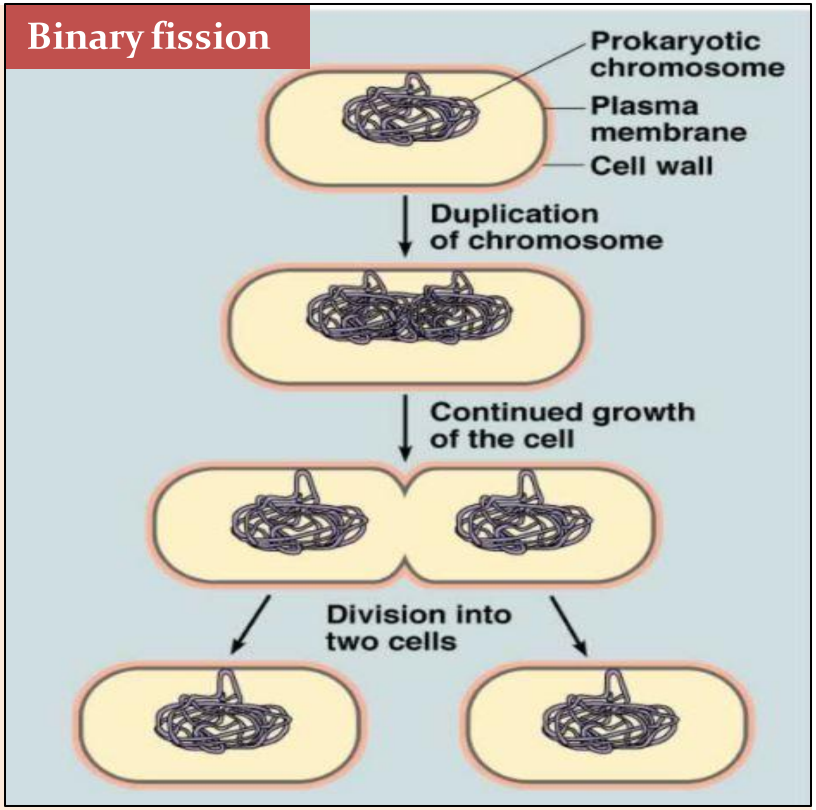
❖ In the food chain, they play an important in various environments not only as prey of various unicellular eukaryotes, but also as producers that support various metazoans and decomposers that break down dead material that is then re-used by plants.

❑ Reproduction

❖Bacteria can asexually reproduce through binary fission, fragmentation, budding and endospore etc.

❖Binary fission is when two equal progeny cells are produced. Bacteria that undergo binary fission must first elongate before separating. Budding is when there is growth off the parent cell.

❖Binary fission produces two equal daughter cells, while budding produces a new cell while the parent cell remains.



✓Plasmids

❖Plasmids are also found within bacteria separate from the bacteria's circular DNA. Also referred to as "replicons", plasmids are autonomous replicating DNA molecules.

❖Not all plasmids replicate in bacteria, though. These elements allow for horizontal gene transfer, which is a way for a bacterium to gain new genes and therefore traits.

❖They primarily aid in the rapid mutation in bacteria to several factors.

❖Similar to the other genetic material, the plasmids can be passed onto daughter cells during replication. They are the common DNA structure used in research because they are relatively easy to manipulate, implant and measure.

✓Endospore Formation

❖During the unfavorable condition, eubacteria have the ability to become endospores.

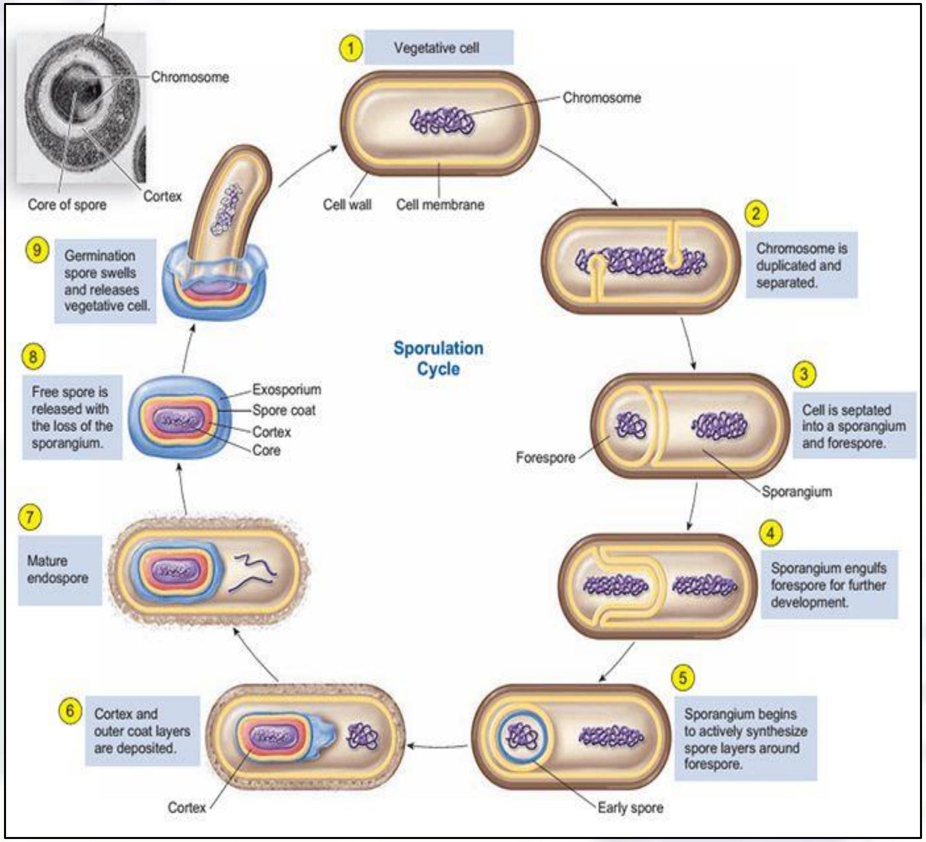
❖In this state, the bacteria can tolerate exceedingly high and low temperatures, acidic and basic conditions, and large amounts of radiation.

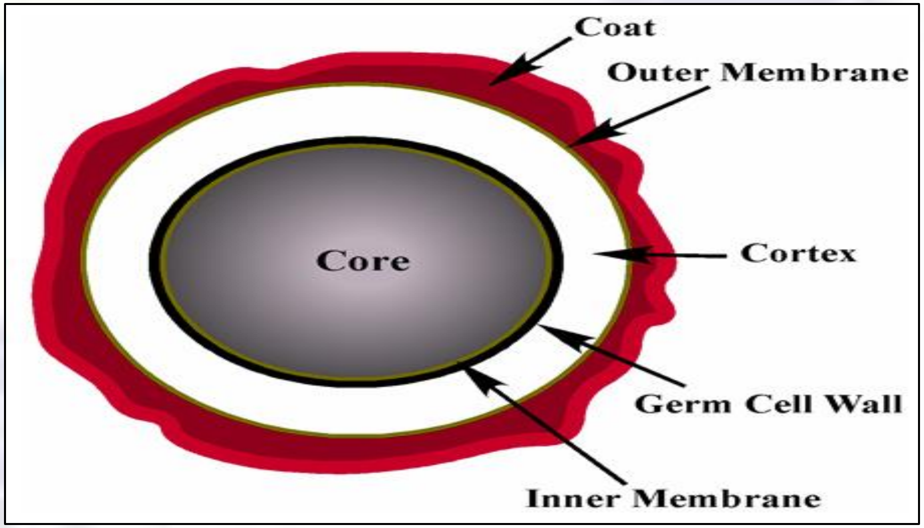
❖Endospores are extremely hard to kill. Surprisingly, they can be boiled for hours and still survive.

❖Endospores can only be made by Gram-positive bacteria.

❖Within the endospore remains the bacterial DNA, but the cytoplasm has a decreased water concentration.

❖This is thought to help in protecting against high heat. The bacteria will take on a tough coating composed of calcium and dipicolinic acid, creating a dense and impregnable barrier to stabilize the DNA within the cell. DNA repair enzymes are also still active, aiding in the resistance of the endospore.





ORIGIN AND TAXONOMY OF EUBACTERIA

- ❖It is not known whether the ancestor of bacteria originated on Earth or elsewhere.
- ❖Some scientists believe that a life form existed extra terrestrially in the Martian meteorite ALH84001.
- ❖Whether primitive life originated on Earth or elsewhere, current consensus is that bacteria were present on Earth 3.8 billion years ago.
- ❖In recent years, highly conserved genes such as the gene coding for the small subunit ribosomal RNA have been used as principal taxonomic characters.
- ❖As bacteria evolve over time the sequence of this molecule changes, allowing taxonomic relationships between bacteria to be discerned.
- ❖Many diversion exist within the Bacteria. More recently, full genome sequencing has revealed that genes can move between cells and even between species.
- ❖Thus, bacterial genomes are in constant flux driven by gene acquisition from other species as well as evolutionary forces.
- ❖The known bacterial tree of life is remarkable, but as 99 percent of bacterial life remains uncultured, this tree will undoubtedly expand greatly over time.
- ❖The Eubacteria are the largest and most diverse taxonomic group of bacteria. Some scientists regard the Eubacteria group as an artificial assemblage, merely a group of convenience rather than a natural grouping.
- ❖Other scientists regard eubacteria as comprising their own kingdom.

- Another recent classification holds Eubacteria and Archaebacteria as domains or major groupings, classified above the kingdom level.
- The Eubacteria are all easily stained, rod-shaped or spherical bacteria. They are generally unicellular, but a small number of multicellular forms do occur.
- They can be motile (presence of numerous flagellae) or nonmotile.
- Thick cell walls are an evolutionary adaptation that allows survival in extreme situations where thinner walled bacteria would dry out.
- One commonality that can be found within the group is that they all reproduce by transverse binary fission, although not all bacteria that reproduce in this manner are members of this group.
- Eubacteria are often classified according to the manner in which they gain energy.
- Photoautotrophic Eubacteria manufacture their own energy through photosynthesis.
- Cyanobacteria, often called blue-green algae , are common photoautotrophic Eubacteria.
- Although not true algae, Cyanobacteria grow in chain-like colonies and contain chloroplasts as do aquatic algae.
- Heterotrophic Eubacteria are among the most abundant and diverse bacteria on Earth, and include bacteria that live as parasites, decomposers of organic material (saprophytes), as well as many pathogens (diseasecausing bacteria).
- Chemoautotrophic Eubacteria bacteria obtain their own energy by the oxidation of inorganic molecules. These are responsible for releasing the sulfur resulting in a sulfur taste of freshwater near many beaches (such as in Florida), and for supplying nitrogen in a form able to be used by plants.

CLASSIFICATION OF EUBACTERIA

❖While all groups within this domain are prokaryotes, they display high diversity in their general morphologies, metabolism, and habitats. This has made it possible to classify and describe different types of bacteria in nature.

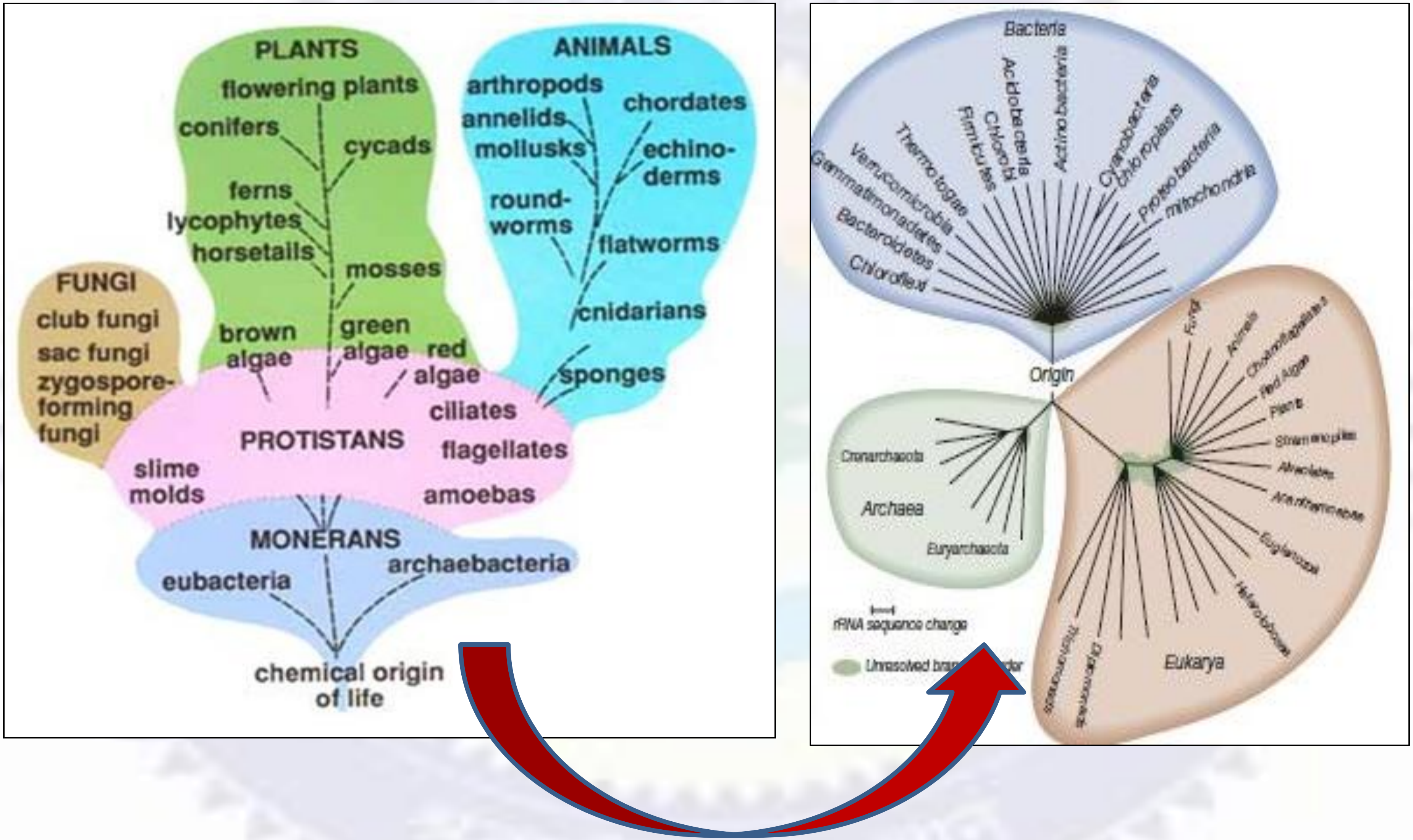
❖Various groups exist as parasites and are responsible for animal and plant diseases. However, some are free-living with some being beneficial to man.

❖**Eubacteria**, the taxonomic domain that contains the single kingdom Bacteria, comprising the true bacteria. There are 11 main groups:

- Purple (Photosynthetic)
- Gram Positive
- Cyanobacteria
- Green Non-sulphur
- Spirochaetes
- Flavobacteria
- Green Sulphur
- Planctomyces
- Chlamydiales
- Deinococci
- Thermatogales

❖The only feature common to all bacteria is their prokaryotic cellular organization. The majority of bacteria are single-celled, and most have a rigid cell wall. Bacteria are almost universal in distribution and may live as saprotrophs, parasites, symbionts, pathogens etc.

CLASSIFICATION OF EUBACTERIA



Monera divide into 2 kingdoms: Eubacteria and Archaebacteria
*** Modified version of Whittaker's five kingdom system of classification**

DIVERSITY OF EUBACTERIA

- ❖Bacteria show an incredible range of metabolic diversity.
- ❖Some bacteria can get their energy from light (these are referred to as phototrophic organisms), organic compounds (organotrophic), or inorganic compounds such as hydrogen (H_2), sulfur compounds (H_2S), inorganic nitrogen compounds or ferrous iron compounds (chemolithotrophic).
- ❖Some bacteria can make all of their organic compounds by fixing carbon (autotrophic), while others need to break down organic compounds to provide a carbon source (heterotrophic).
- ❖Many bacteria are capable of fixing atmospheric nitrogen as a nitrogen source, in addition to organic and inorganic sources of nitrogen. Because of this metabolic diversity, bacteria play an important role in biogeochemical cycles such as the carbon, nitrogen, and phosphorous cycles.
- ❖This metabolic diversity also permits them to occupy a wide range of habitats. Bacteria can thrive in extremes of temperature, pH, salt, pressure, or toxic substances.
- ❖Some bacteria can survive these conditions by spore formation, while other bacteria are able to multiply under extreme conditions.
- ❖The most primitive bacteria extant today are theromophiles, leading to the consensus view that life arose under extreme conditions.
- ❖Bacteria are found in marine, aquatic, terrestrial and subterranean environments.
- ❖There are bacteria that are obligate aerobes and some that are obligate anaerobes, and many that fall somewhere in between.

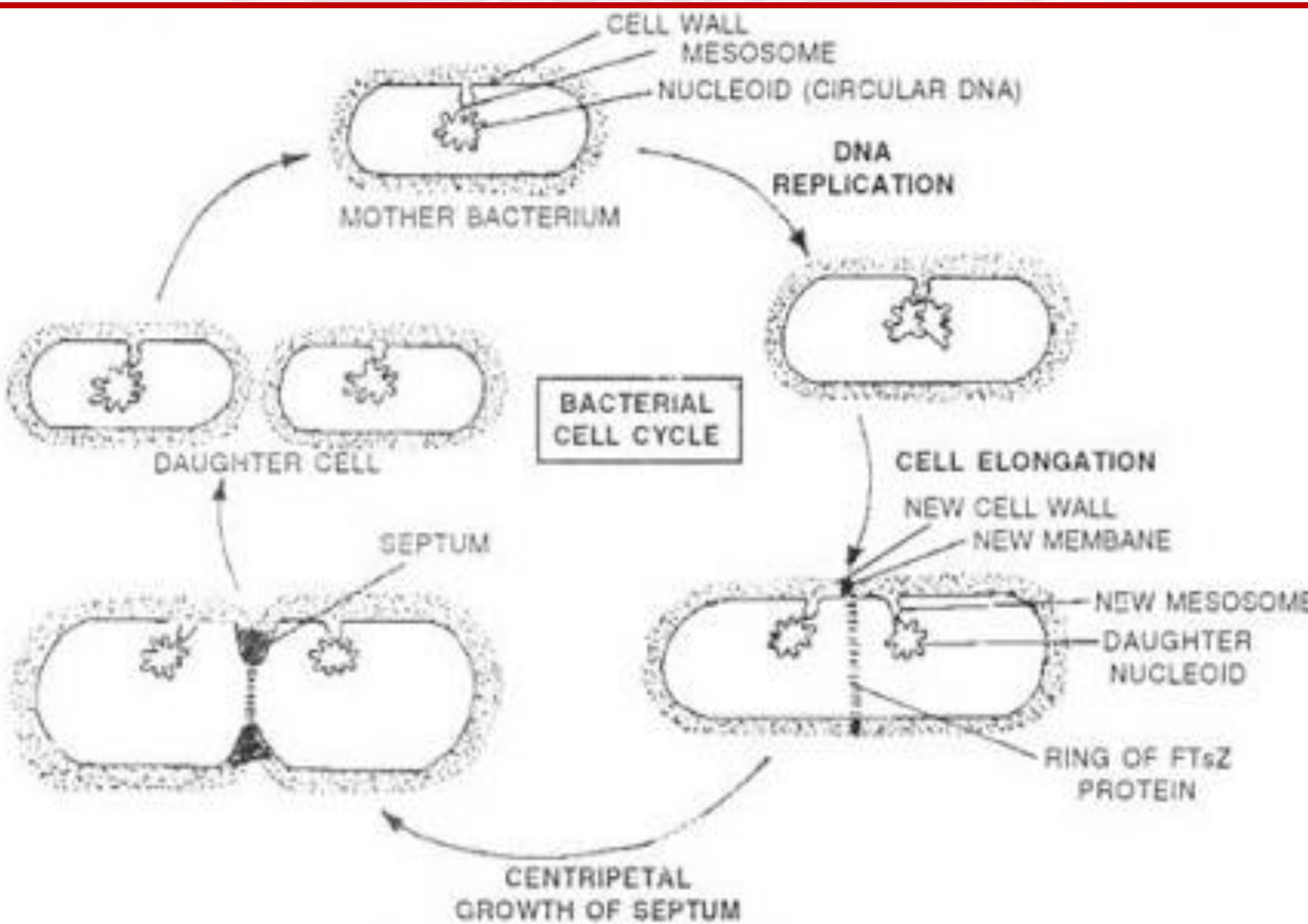
ASSOCIATION OF EUBACTERIA

- ❖The most bacteria are free living at some point of their life cycles, many bacteria are capable of living in close associations with other organisms, including eukaryotes.
- ❖Some of these symbiotic associations are so highly evolved as to be obligate, while other associations are facultative, meaning the symbiotic partners can live apart from each other.
- ❖In some symbioses, the eukaryotic host provides a highly specialized structure within which the bacteria reside, such as the nitrogen-fixing root nodules found on leguminous plants. In looser symbiotic associations, the host provides no specialized structure for the symbiotic bacteria.
- ❖Organisms that populate the root zone of plants can provide growth benefits; these bacteria are in turn making use of plant products exuded though the roots.
- ❖There are also bacteria that are very harmful or even fatal to eukaryotic hosts. An example of this is *Yersinia pestis,* causative agent of the bubonic plague.
- ❖Not all associations between bacteria and their eukaryotic hosts have such a drastic result. Many bacteria exist in relatively benign associations with their hosts, such as the *Escherichia coli* bacteria in the human large intestine.
- ❖Some resident bacteria can become pathogenic under certain circumstances. These opportunistic pathogens can cause serious infection in hosts whose defenses are compromised by age or previous illness.
- ❖Some association can be very intimate, occurring on the intracellular level. It is generally accepted that the eukaryotic chloroplasts and mitochondria arose from associations between bacteria and other cells. These organelles are similar in size to bacteria and contain remnants of bacterial genomes.

LIFE CYCLE OF EUBACTERIA

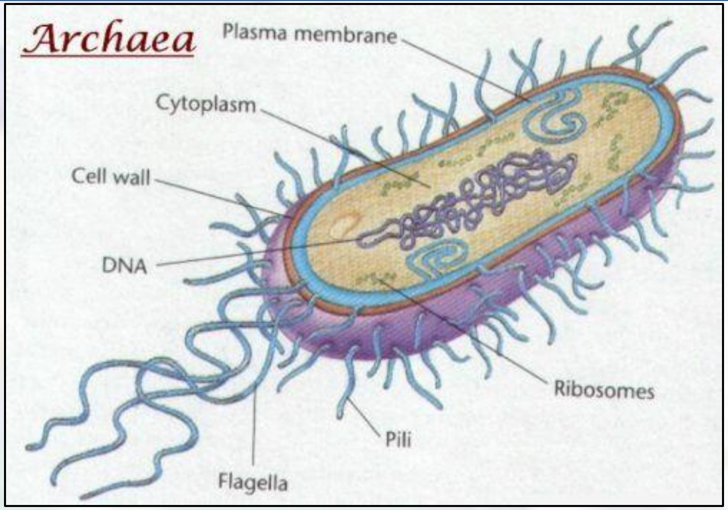
- ❖Eubacteria are reproduced asexually by the methods of binary fission, fragmentation, budding, conodia formation, endospore formation etc.
- ❖No meiosis is evolved in the reproduction of eubaceria.
- ❖When provided with adequate nutrients at a suitable temperature and pH, *E. coli* bacteria can double in number within 20 minutes.
- ❖This is faster than most species grow, and faster than *E. coli* grows under natural conditions.
- ❖Regardless of the rate, the growth of a bacterium involves synthesizing double the quantity of all its parts, including membrane, proteins, ribosomes, and DNA.
- ❖Separation of daughter cells, called binary fission, is accomplished by creating a wall between the two halves. The new cells may eventually separate, or may remain joined.
- ❖When environmental conditions are harsh, some species (including members of the genus *Clostridium*) can form a special resistive structure within themselves called an endospore.
- ❖The endospore contains DNA, ribosomes, and other structures needed for life, but is metabolically inactive.
- ❖It has a protective outer coat and very low water content, which help it survive heating, freezing, radiation, and chemical attack.
- ❖Endospores are known to have survived for several thousand years, and may be capable of surviving for much longer, possibly millions of years. When exposed to the right conditions (presence of warmth and nutrients), the endospore quickly undergoes conversion back into an active bacterial cell.

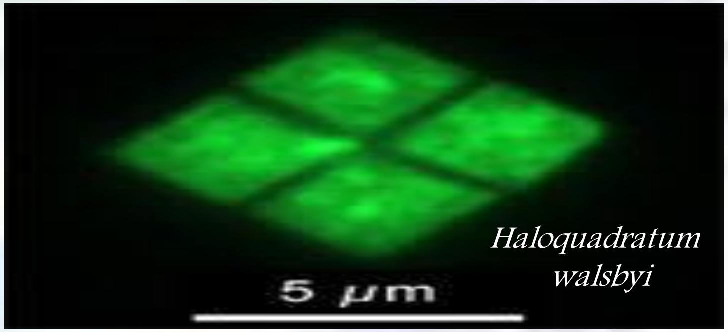
LIFE CYCLE OF EUBACTERIA



WHAT ARE THE ARCHAEBACTERIA ????

- ❖Archaea constitute a domain of prokaryotes, single-celled microorganisms, lacking of cell nuclei.
- ❖Archaea and bacteria are generally similar in size and shape, although a few archaea have very different shapes.
- ❖ Their cell membrane including archaeols.
- ❖Archaea use more energy sources than eukaryotes: these range from organic compounds, such as sugars, to ammonia, metal ions or even hydrogen gas.
- ❖They reproduce by binary fission and budding, endospores formation is not known in them yet.
- ❖The first observed archaea were extremophiles, living in extreme environments, such as hot springs and salt lakes with no other organisms.
- ❖Archaea are particularly numerous in the oceans, and the archaea in plankton may be one of the most abundant groups of organisms on the planet.
- ❖Their morphological, metabolic, and geographical diversity permits them to play multiple ecological roles: carbon fixation; nitrogen cycling; organic compound turnover; and maintaining microbial symbiotic and syntrophic communities.





Archaea Are Diverse but Share Some Common Features

❖For many years, archaea and bacteria had been lumped together and referred to as prokaryotes.

❖Today *Archaea* and *Bacteria* are recognized as distinct taxa. The separation of bacteria and archaea into distinct taxa correlates with the observation that they each have unique and distinguishing characteristics. Some of these are summarized here:

Properties	Bacteria	Archaea
Plasma membrane lipids	Ester-linked phospholipids and hopanoids from a lipid bilayer; some have sterols	Glycerol diethers from lipid bilayers; glycerol tetraethers from lipid monolayers
Cell wall constitution	Peptidoglycan is present in nearly all; some lack cell walls	Very diverse but peptidoglycan is always absent; some consist of S-layer only, other combine S-layer with polysaccharides or protein or both; some lack cell walls.
Inclusions present	Yes, including gas vacuoles	Yes, including gas vacuoles
Ribosome size	70S	70S
Chromosome structure	Most are circular, double standed (ds) DNA usually a single chromosome	All known are circular, ds DNA
Plasmids present	Yes, circular and linear ds DNA	Yes; circular ds DNA
External structure	Flagella, fimbrae (pili) common	Flagella, pili and piluslike structure common
Capsule or slime layer	Common	Rare

SHAPE ARRANGEMENT AND SIZE OF ARCHAEA

❖For many years, archaea and bacteria had been lumped together and referred to as prokaryotes.

❖Archaeal cells, like bacterial cells, exhibit a variety of shapes. Cocci and rods are common. Both usually exist singly, but some cocci form clusters and some rods form chains.

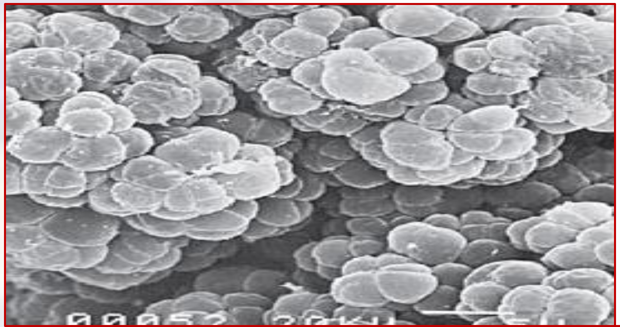
❖Curved rods, spiral shapes, and pleomorphic (many shaped) archaea have also been observed.

❖To date, no spirochete-like and mycelial archaea have been discovered. However, some archaea exhibit unique shapes, such as the branched, flat, postagestamp shaped.

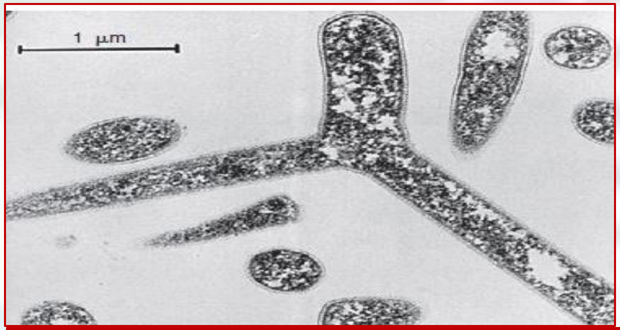
❖Archaeal cells also vary in size as much as in shape. Typical rods are 1 to 2 µm wide by 1 to 5 µm long; cocci are typically 1 to 3 µm in diameter.

❖However, extremely small and extremely large archaea have been identified. Several free-living, acid-loving (acidophilic), mine-dwelling microbes measure a mere 0.2 to 0.4 µm in diameter. The giant archaea that form long filaments up to 30 mm in length.

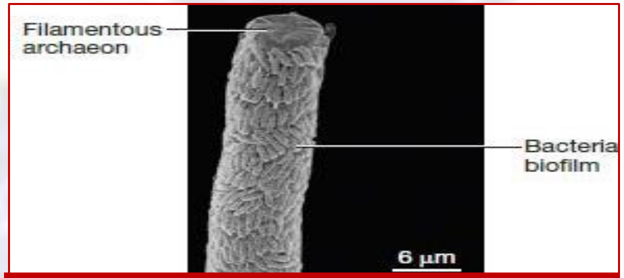
❖The filament of archaeon coated with a biofilm formed by a bacterium. The nature of this interaction is unknown, but it is thought that the archaeon is host and bacteria are symbionts.



Methanosarcina mazei- a coccus that forms cluster



Thermoproteus tenax- a branched archaeal cell

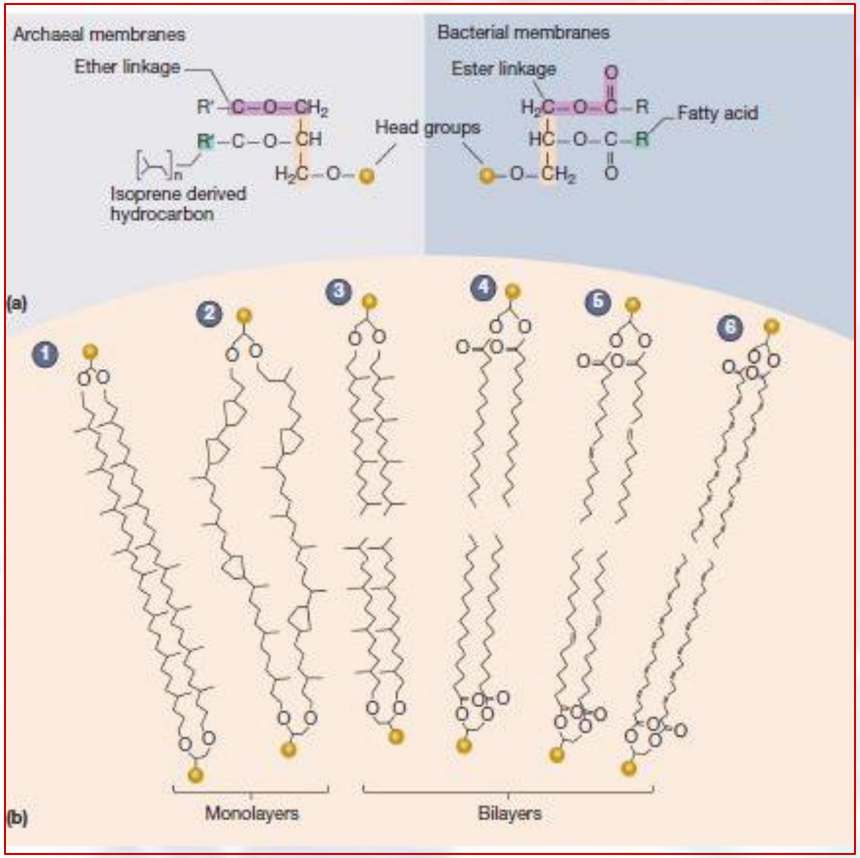


Candidatus- forms long filaments covered with bacterial biofilm

ARCHAEAL CELL ENVELOPES

- The cell envelope consists of the plasma membrane and all external coverings, including cell walls and other layers.
- Archaeal cell envelopes usually consist of only the plasma membrane and the cell wall.
- Archaeal membranes are composed of glycerol diether and diglycerol tetraether lipids.
- Archaeal membrane lipids are attached to glycerol by ether linkages instead of ester linkages, as found in bacteria and eukaryotes.
- The stereochemistry also differs. In archaeallipids, the stereoisomer of glycerol is sn-glycerol-1-phosphate; in bacterial lipids, the stereoisomer is sn-glycerol-3-phosphate. Thus in archaeal lipids, the side chains are attached to carbons 2 and 3 of glycerol, and in bacterial lipids, the side chains are attached to carbons 1 and 2.
- Examples of archaeal lipids are lipids 1, 2, and 3. Lipids 4, 5, and 6 are bacterial lipids. Note that some archaeal lipids form monolayers, whereas all bacterial lipids form bilayers.
- Membranes composed of glycerol diether are lipid bilayers. Membranes composed of diglycerol tetraethers are lipid monolayers.
- The overall structure of a monolayer membrane is similar to that of the bilayer membrane in that the membrane has a hydrophobic core and its surfaces are hydrophilic.
- Archaeal cell walls do not contain peptidoglycan, and they exhibit great diversity in their make
- The most common type of cell wall is one consisting of an S-layer composed of either glycoprotein or protein.

ARCHAEAL CELL ENVELOPES



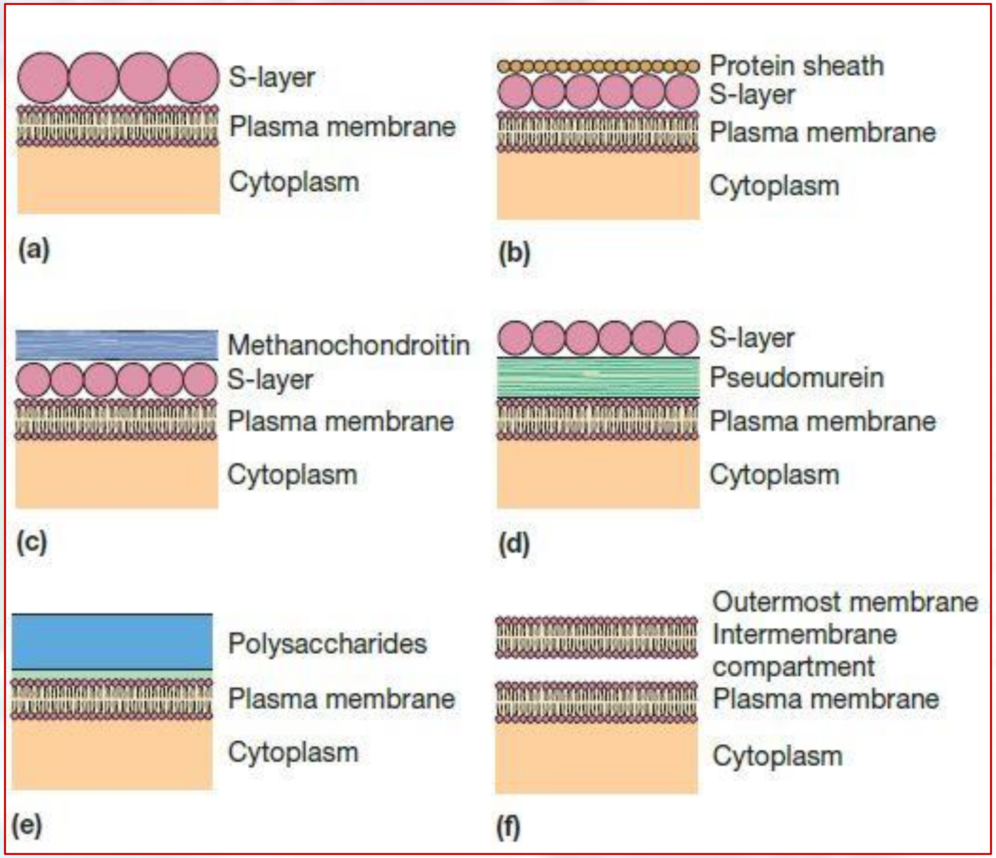


Figure: Comparison of Archaeal and Bacterial Membranes. (a) Archaeal membrane lipids are attached to glycerol by ether linkages instead of ester linkages, as found in bacteria and eukaryotes. The stereochemistry also differs. In archaeal lipids, the side chains are attached to carbons 2 and 3 of glycerol, and in bacterial lipids, the side chains are attached to carbons 1 and 2. (b) Lipids 1, 2, and 3 are Archaeal lipids. Lipids 4, 5, and 6 are bacterial lipids. Note that some archaeal lipids form monolayers (figure 4.5), whereas all bacterial lipids form bilayers.

Figure: Six major Archaeal Cell Envelopes. (a) ***Methanococcus, Halobacterium,*** *Pyrodictium, Sulfolobus, and Thermoproteus* species cell envelopes. (b) *Methanospirillum* spp. cell envelope. (c) *Methanosarcina* spp. cell envelope. (d) *Methanothermus* and *Methanopyrus* species cell envelopes. (e) *Methanobacterium, Methanosphaera, Methanobrevibacter, Halococcus*, and *Natronococcus* species cell envelopes. For *Methanosphaera* spp., the polysaccharide layer is composed of pseudomurein. (f) *Ignicoccus hospitalis* cell envelope. The outermost membrane contains protein complexes that form pores.

CYTOPLASM

❖The cytoplasm of archaeal cells is very similar to that of bacteria.

❖Within it can be found inclusions—polyhydroxyalkonates, polyphosphate granules, glycogen granules, and gas vacuoles, ribosomes, a nucleoid, and plasmids.

❖Proteins that might form a cytoskeleton have also been identified, including FtsZ (tubulin homologue), MreB (actin homologue), and crenactin, an actin homologue unique to certain members.

❖Bacterial and archaeal ribosomes are 70S in size, but differ slightly in their morphology.

❖They also differ in terms of their protein content, with many archaeal ribosomal proteins being more similar to those in eukaryotic ribosomes than to those in bacterial ribosomes.

❖The nucleoid, irregularly shaped region in the cytoplasm contains the cell's chromosome and numerous proteins.

❖The genetic material of archaeal cells is located in the nucleoid, which is not enclosed by a membrane.

❖All known archaeal chromosomes consist of a double-stranded, covalently closed, circular DNA molecule.

❖In many archaea, the nucleoid contains a single chromosome. However, some archaea are polyploid, having more than one copy of their chromosome.

❖Like eukaryotes, some archaea use histone proteins to organize their chromosomes.

LOCOMOTION AND ATTACHMENT

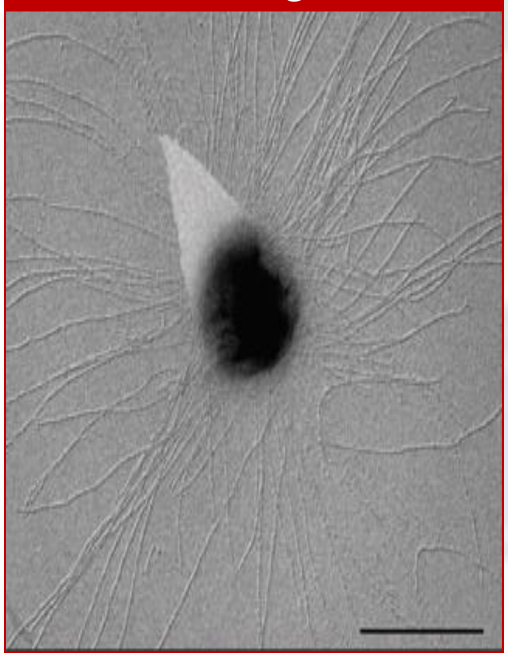
❖Many archaea have pili. Some archaeal pili are similar to bacterial type IV pili.

❖Cannulae and hami are external structures that are unique to archaea. Their function is not known, but it is likely that they help cells attach to surfaces, including other cells.

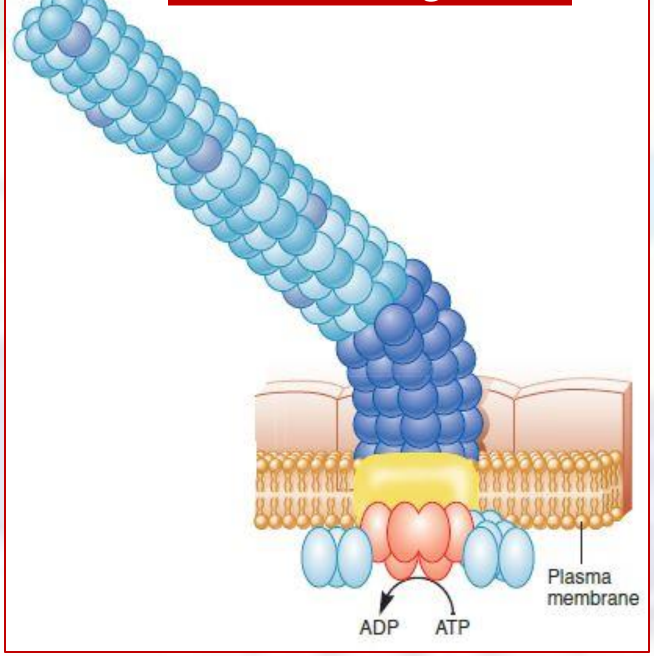
❖Many archaea are motile by means of flagella. Archaeal flagella are structurally related to bacterial type IV pili. They are rigid helices that rotate, and the direction of rotation determines if the cell moves forward or backward. Rotation is powered by ATP hydrolysis.

❖Motile archaea exhibit chemotaxis. Some are also phototactic. The archaeal taxis machinery is similar to that of bacteria.

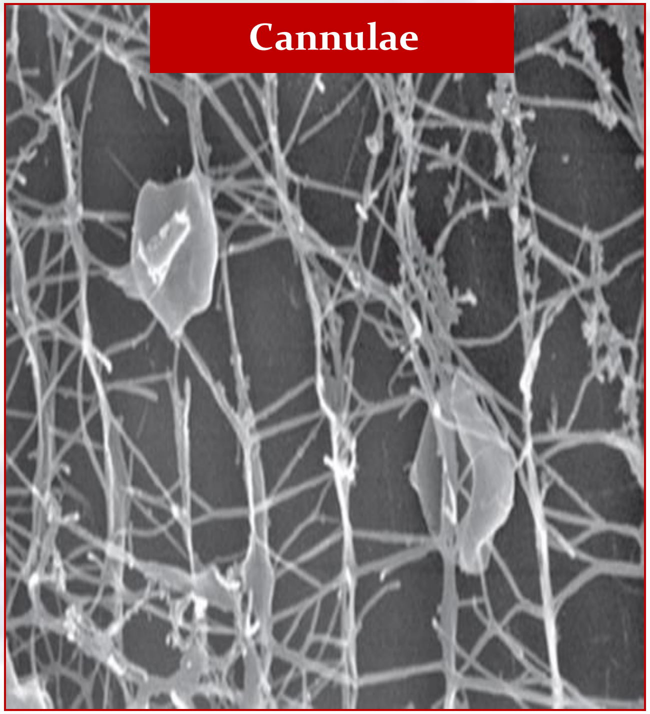
Hami radiating from cell



Archaeal Flagellum



Cannulae



TAXONOMY AND CLASSIFICATION OF ARCHAEA

❖Archaea can be divided into six major groups based on physiological and morphological differences.

Group	General Characteristics	Representative Genera
Methanogenic archaea	Strict anaerobes. Methane is the major metabolic end product. S^0 may be reduced to H_2S without yielding energy. Cells possess coenzyme M, factors 420 and 430, and methanopterin.	*Methanobacterium (E)*[1] *Methanococcus (E)* *Methanomicrobium (E)* *Methanosarcina (E)*
Archaeal sulfate reducers	Regular and irregular cocci. H_2S formed from thiosulfate and sulfate. Autotrophic growth with thiosulfate and H_2. Can grow heterotrophically. Traces of methane also formed. Extremely thermophilic and strictly anaerobic. Possess factor 420 and methanopterin but not coenzyme M or factor 430.	*Archaeoglobus (E)*
Extremely halophilic archaea	Rods, cocci, or irregular shaped cells that may include pyramids or cubes. Primarily chemoorganoheterotrophs. Most species require sodium chloride ≥1.5 M, but some survive in as little as 0.5 M. Most produce characteristic bright-red colonies; some are unpigmented. Neutrophilic to alkalophilic. Generally mesophilic; however, at least one species is known to grow at 55°C. Possess either archaerhodopsin or halorhodopsin and can use light energy to produce ATP.	*Halobacterium (E)* *Halococcus (E)* *Natronobacterium (E)*
Cell wall-less archaea	Pleomorphic cells. Thermoacidophilic and chemoorganotrophic. Facultatively anaerobic. Plasma membrane contains mannose-rich glycoproteins and lipoglycans.	*Thermoplasma (E)*
Extremely thermophilic S^0-metabolizers	Rods, filaments or cocci. Obligately thermophilic (optimum growth temperature between 70–100°C). Usually strict anaerobes but may be aerobic or facultative. Acidophilic or neutrophilic. Autotrophic or heterotrophic. Most are sulfur metabolizers. S^0 reduced to H_2S anaerobically; H_2S or S^0 oxidized to H_2SO_4 aerobically.	*Desulfurococcus (C)* *Pyrodictium (C)* *Pyrococcus (E)* *Sulfolobus (C)* *Thermococcus (E)* *Thermoproteus (C)*
Mesophilic aerobic ammonia-oxidizers	Globally distributed in marine and soil environments, chemolithoautotrophic, using ammonia as electron donor and oxygen as terminal electron acceptor. Use HP/HB[2] pathway for carbon fixation. Evidence that some deep-ocean thaumarchaea may use urea as carbon and nitrogen source.	*Cenarchaeum symbiosum (T)* *Nitrosopumilus maritimus (T)*

1 Indicates phylum; *E, Euryarchaeota, C, Crenarchaeota, T, Thaumarchaeota*   2 HP/HB, 3-Hydroxypropionate/4-Hydroxybutyrate Cycle

❖ Archaea contains a highly diverse group of microbes with respect to morphology, reproduction, physiology, and ecology. Although best known for their growth in anoxic, hypersaline, and high-temperature habitats, they also inhabit marine Arctic, temperate, and tropical waters.

❖ Bergey's Manual of Systematic Bacteriology (2001) divides Archaea into;

- **Phylum Euryarchaeota: Methanogens, Haloarchaea, and Others:**
  - The phylum Euryarchaeota *contains five major physiological* groups: methanogens, haloarchaea, thermoplasms, extremely thermophilic So-reducers, and sulfate-reducing archaea. Methanogenic archaea are strict anaerobes that obtain energy through the synthesis of methane. They have several unusual cofactors that are involved in methanogenesis.
- **Phylum Crenarchaeota: Metabolically Diverse Thermophiles:**
  - The extremely thermophilic So-metabolizers in the phylum *Crenarchaeota depend on sulfur for growth and are* frequently acidophiles.
  - The sulfur may be used as an electron acceptor in anaerobic respiration or as an electron donor by chemolithotrophs. Many are strict anaerobes and grow in geothermally heated soil and water that is rich in sulfur.
- **Phylum Thaumarchaeota: Mesophilic Ammonia Oxidizers:**
  - The discovery of an archaeal-specific lipid, now called thaumarchaeol, led to the discovery of globally distributed marine, mesophilic archaea.
  - These mesophiles are placed in the phylum *Thaumarchaeota* and are united by their capacity to oxidize ammonia. They are found in many marine and terrestrial habitats, where they can be important contributors to nitrification.

WHAT ARE THE CYNOBACTERIA ????

❖Cyanobacteria consisting of free-living photosynthetic bacteria.

❖They obtain their energy through oxygenic photosynthesis. The oxygen gas in the atmosphere of earth is produced by cyanobacteria, either as free-living bacteria or as the endosymbiotic plastids.

❖Cyanobacteria are prokaryotes and also called "blue-green algae.

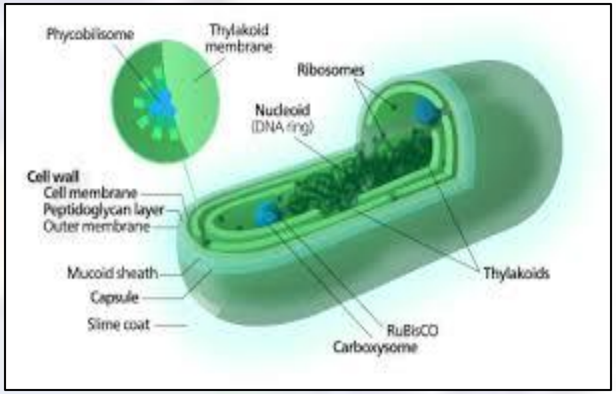
❖Cyanobacteria appear to have originated in freshwater or a terrestrial environment.

❖They have flattened sacs like internal membranes called thylakoids help in the photosynthesis.

❖Phototrophic eukaryotes such as green plants perform photosynthesis in plastids that are thought to have their ancestry in cyanobacteria, acquired long ago via a process called endosymbiosis.

❖Cyanobacteria produce a range of toxins known as cyanotoxins that can pose a danger to humans and animals.

❖The cyanobacteria show potential applications in biotechnology for bioethanol production, food colorings, as a source of human and animal food, dietary supplements and raw materials.



HABIT AND HABITAT

- ❖Cyanobacteria are arguably the most successful group of microorganisms on earth. They are the most genetically diverse; they occupy a broad range of habitats across all latitudes, widespread in freshwater, marine, and terrestrial ecosystems, and they are found in the most extreme niches such as hot springs, salt works, and hypersaline bays.
- ❖They can occur as planktonic cells or form phototrophic biofilms.
- ❖They are found in endolithic ecosystem. A few are endosymbionts in lichens, plants, various protists, or sponges and provide energy for the host.
- ❖Some live in the fur of sloths, providing a form of camouflage.
- ❖Aquatic cyanobacteria are known for their extensive and highly visible blooms that can form in both freshwater and marine environments.
- ❖The blooms can have the appearance of blue-green paint or scum. These blooms can be toxic, and frequently lead to the closure of recreational waters when spotted.
- ❖Marine bacteriophages are significant parasites of unicellular marine cyanobacteria.
- ❖Cyanobacteria soil crusts help to stabilize soil to prevent erosion and retain water. Example: *Microcoleus vaginatus, M. vaginatus.*
- ❖Some of these organisms contribute significantly to global ecology and the oxygen cycle.
- ❖Photoautotrophic, oxygen-producing cyanobacteria created the conditions in the planet's early atmosphere that directed the evolution of aerobic metabolism and eukaryotic photosynthesis.

MORPHOLOGY

❖They range from unicellular to filamentous and include colonial species.

❖Free living cyanobacteria are present in the water of rice paddies,

❖They can be found growing as epiphytes on the surfaces of the green alga.

❖Colonies may form filaments, sheets, or even hollow spheres.

❖Some filamentous species can differentiate into several different cell types:

- **Vegetative cells:** normal, photosynthetic cells that are formed under favorable conditions.
- **Akinetes:** climate-resistant spores that may form when conditions become harsh
- **Heterocysts:** contain the enzyme nitrogenase, vital for nitrogen fixation in an anaerobic environment due to its sensitivity to oxygen.

❖Many cyanobacteria form motile filaments of cells, called hormogonia, that travel away from the main biomass to bud and form new colonies elsewhere. The cells in a hormogonium are often thinner than in the vegetative state.

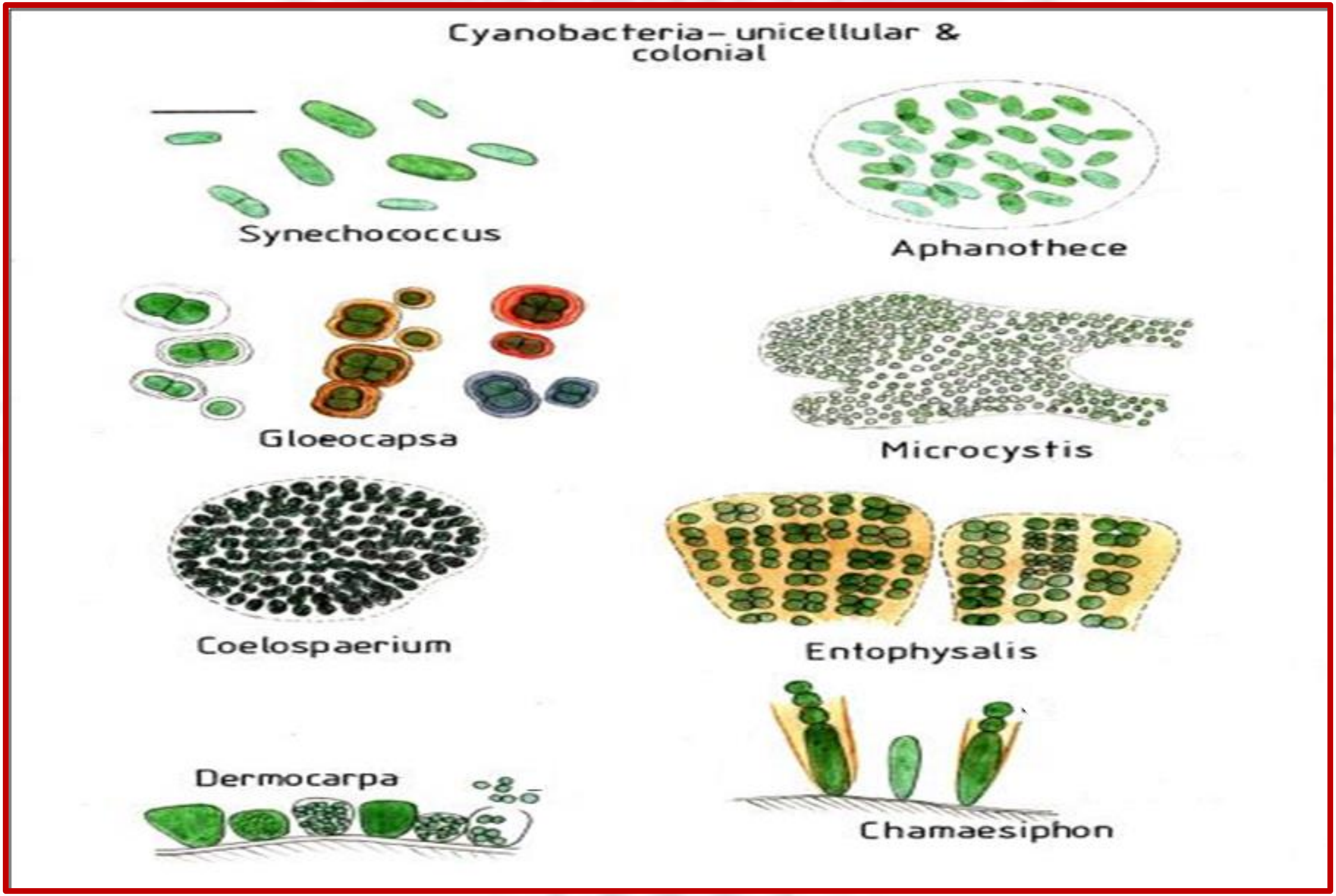
❖To break away from the parent colony, a hormogonium often must tear apart a weaker cell in a filament, called a necridium.

❖Each individual cell (each single cyanobacterium) typically has a thick, gelatinous cell wall.

❖They lack flagella, but hormogonia of some species can move about by gliding along surfaces.

❖Many of the multicellular filamentous forms of *Oscillatoria* are capable of a waving motion.

MORPHOLOGY



Cyanobacteria– unicellular & colonial
Synechococcus
Aphanothece
Gloeocapsa
Microcystis
Coelospaerium
Entophysalis
Dermocarpa
Chamaesiphon

CELL STRUCTURE

❖They are typically prokaryotic cell. Therefore, lack of membrane bound cell organelles and distinct nucleus.

❖**Cell envelope:** in this group consist of two parts:

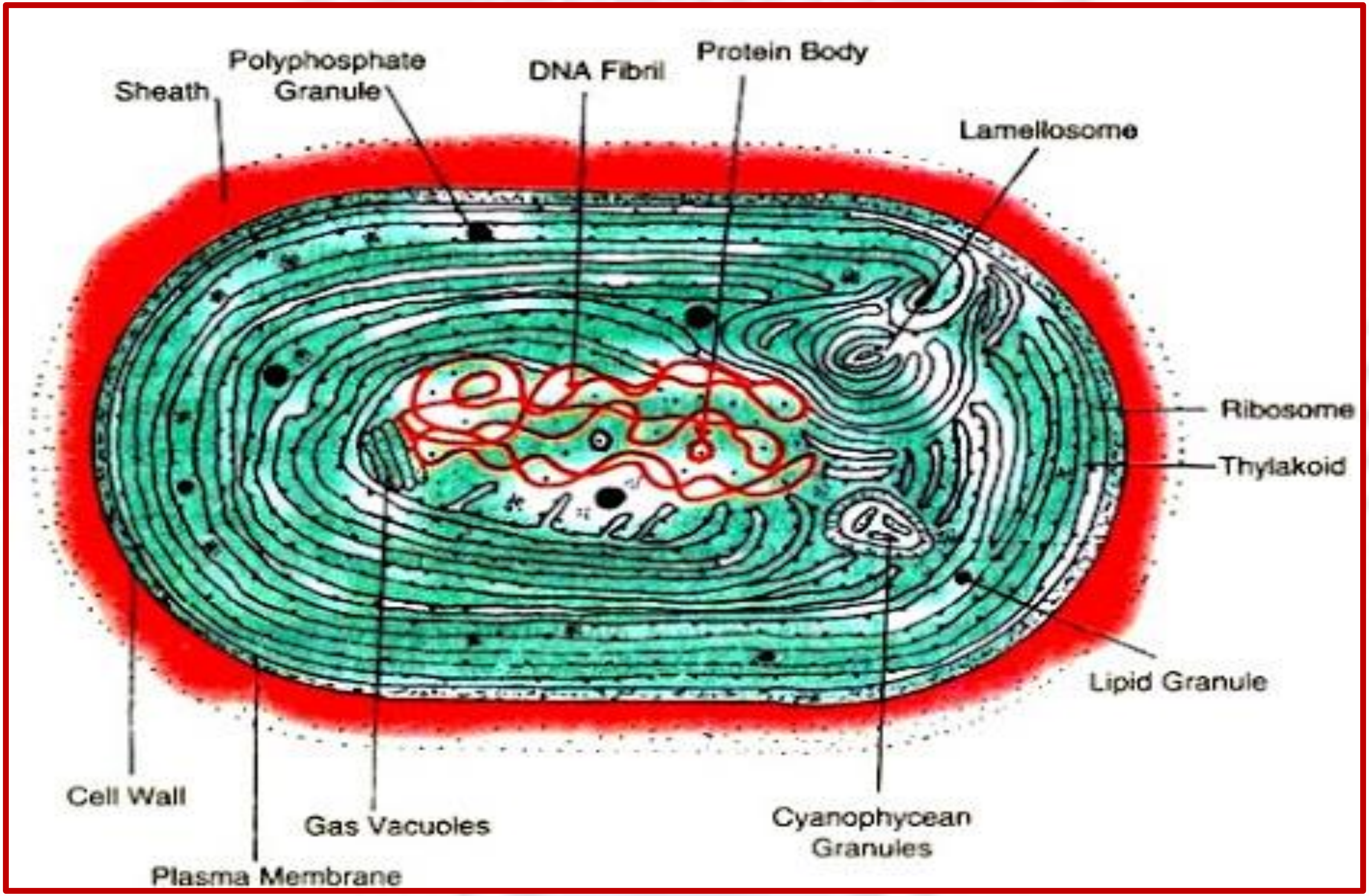
- Sheath: Layer of extracellular mucilaginous external to the cell wall. It is protective in nature.
- Cell wall: Just beneath the sheath a one of less electron density is present known as cell wall. It is further divided into four layers (L_1 to L_4). Overall, the cell wall is lack of microfibrils. Its principal components are glucosamine, diaminopimelic acid, amino acids and muramic acid with some amino sugar. Cellulose is absent in the cell wall.

❖**Protoplasm:** the protoplasm shows elementary internal differentiation. It divided into two regions. (i) central located clear area forming the core and (ii). The peripheral dense region surrounding it. All the cell organelles are descended in the protoplasm of the cell.

❖**Plasma membrane:** internal to the cell wall the protoplasm its periphery is differentiated into distinct typical unit membrane called plasma membrane. This membrane is to selective permeable and regulate the movement of molecules within the cell.

❖**Photosynthetic apparatus:** within the plasma membrane embedded in the peripheral region of the cytoplasm are elongated, flattened closed sac or disk shaped structure called thylakoids or lamellae are present. These are the photosynthetic apparatus of the organisms. Usually the thylakoids appear to be numerous and discrete within a cell. However, the thylakoids are not organized into the grana.

CELL STRUCTURE



- **Pigments:** The chlorophyll-α (but not chlorophyll-β) and a number of other pigments such as B-carotene, xanthophyll and phycobilins are present in this group. The bet known phycobilins are blue c-phycocynin, and red c-phycoerythrin. These two pigments are unique to cynobacteria and not found any other group. Prescott (1969) added phycocynin-r and allophycocynin to the list. The phycobilins are water soluble while chlorophyll and other carotenoids are fat soluble. Phycocynin-c is the charaterstic pigment of the blue green bacteria.

- **Gas vacuoles (psedovacuoles):** The pseudovacuoles were discover in certain members of the group. (*Anabaena*, *Polycyctis*). Each vacuole consist of a packed array of minute membranous cylindrical gas containing structures with closed ends. It is permeable to water but freely permeable to gases (oxygen, nitrogen and argon).

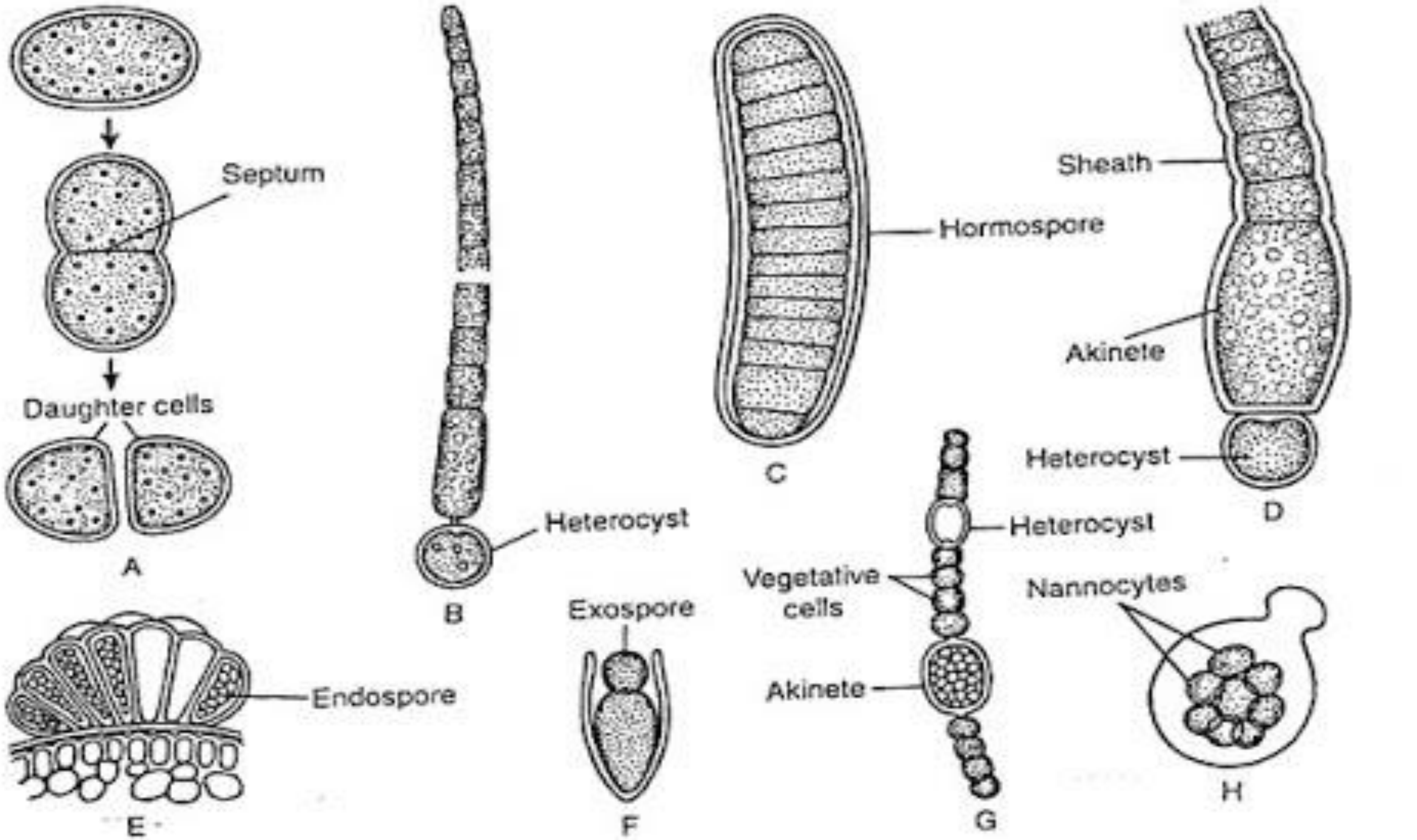
- **Granules:** The ribosomes which are the tiny and granulated structure found scattered in the protoplasm. The structured granules are large dense granules which usually occur near the cross wall. Frequently they are surrounded by the alpha-granules. Drew and Niklowitz considered them to b mitochondrial equivalent. The beta- granules are spherical and less in number than the alpha and ribosomes. They are occur between the lamellae near the cross wall. Shatkin (1960) suggested that they are storage products probably lipoidal in nature. Polyhydral bodies are crystalline granules and constantly present in the central region of the cell.

- **Nucleus:** The distinct cell nucleus are absent. The nucleoplasm is largely central but partially peripheral. It is not separated from the cytoplasm by the nucleus membrane. Nucleoli are absent. Instead it is a region of low electron density than the surrounding cytoplasm and contain numerous fine randomel oriented fibrils of DNA. Histones are absent. RNA is diffusedly distributed in the nucleoplasm. Genome is the word suggested for this type of primitive nucleus.

REPRODUCTION

- ❖Sexual reproduction including gametes formation, fertilization and zygote formation is absent.
- ❖Like bacteria, the cyanobacteria also reproduce asexually and the commonest mode of reproduction in them is transverse binary fission.
- ❖ In addition, there are certain specialized structures such as akinetes, hormogonia, hormocysts and spores, which are partly involved in the process of reproduction.
- ❖**Akinetes:** Most filamentous cyanobacteria develop dormant structures in adverse condition. These structures are larger than the vegetative cells, are equipped with thick walls, and are called akinetes. When favourable conditions return, they germinate and produce new filaments.
- ❖**Hormogonia:** All filamentous cyanobacteria reproduce by fragmentation of their filaments (trichomes) at more or less regular intervals to form short pieces each consisting of 5-15 cells. These short pieces of filaments are called hormogonia. The latter show gliding motility and develop into new full- fledged filaments.
- ❖**Hormocysts:** Some cyanobacteria produce hormocysts, which are multicellular structures having a thick and massive sheath. They may be intercalary or terminal in position and may germinate from either end or both the ends to give rise to the new filaments.
- ❖**Spores:** It includes endospores, exospores and nanocysts which contribute by germinating and giving rise to new vegetative cells when the unfavourable condition is over. Endospores are produced endogenously like those in bacteria; exospores are the result to exogenous budding of cells, and the nanocysts are produced endogenously like endospores. The difference between an endospore and a nanocyst is that in endospore formation the parent cell concomittantly enlarges in size, whereas in nanocyst formation there is no such enlargement of the cell.

REPRODUCTION



Vegetative and asexual reproduction in Cyanophyceae : A. Cell division (*Synechococcus* sp.), B. Fragmentation of filament (*Cylindrospermum muscicola*), C. Hormospore (*Westiella lanosa*), D. Akinete (*Gloeotrichia natans*). E Endospore (*Dermocarpa prasina*), F. Exospore (*Chamaesiphon incrustans*), G. Akinete (*Anabaena* sp.) and H. Nannocytes (*Aphanothece*)

CLASSIFICATION

- ❖Historically, bacteria were first classified as plants constituting the class Schizomycetes, which along with the Schizophyceae (blue-green algae/Cyanobacteria) formed the phylum Schizophyta.
- ❖Then in the phylum Monera in the kingdom Protista by Haeckel in 1866, comprising *Protogens, Protamaeba, Vampyrella, Protomonae*, and *Vibrio*, but not *Nostoc* and other cyanobacteria, which were classified with algae, later reclassified as the *Prokaryotes* by Chatton.
- ❖The cyanobacteria were traditionally classified by morphology into five sections, referred to by the numerals I–V by the scientist Fritsch.
  - ❑ The first three – Chroococcales, Pleurocapsales, and Oscillatoriales – are not supported by phylogenetic studies.
  - ❑ The latter two – Nostocales and Stigonematales – are monophyletic, and make up the heterocystous cyanobacteria.
- ❖The members of Chroococales are unicellular and usually aggregate in colonies.
- ❖The classic taxonomic criterion has been the cell morphology and the plane of cell division.
- ❖In Pleurocapsales, the cells have the ability to form internal spores (baeocytes).
- ❖The rest of the sections include filamentous species.
- ❖In Oscillatoriales, the cells are uniseriately arranged and do not form specialized cells (akinetes and heterocysts).
- ❖In Nostocales and Stigonematales, the cells have the ability to develop heterocysts in certain conditions.
- ❖Stigonematales, unlike Nostocales, include species with truly branched trichomes.

❖Another system divide the class into two tribes:

❑ **Tribe Coccogoneae:** (unicellular and non filamentous colonia forms): reproduce chiefly by fission and colonial forms, in addition by fragmentation. This tribes included two orders;

- Order Chloroccocales
  - ✓Family Chloroccocaceae
  - ✓Family Entophysalidaeae
- Order Chamaesiphonales
  - ✓Family Pleurocapsaceae
  - ✓Family Dermaocarpaceae
  - ✓Family Chamaesiphonaceae

❑ **Tribes Hormogonae:** (filamentous): it includes which cells are united into definite trichomes which may be simple or branched, straight or coiled. Reproduction take place by hormogonia, akinetes, endospore and hormocysts. This tribes included five orders;

- Order Osillatoriales
  - ✓Family Osillatoriaceae
- Order Nostocales
  - ✓Family Nostocaceae
- Order Scytonematales
  - ✓Family Scytonemataceae
- Order Stigonematales
  - ✓Family Stigonematalaceae
- Order Rivenlanales
  - ✓Family Rivenlanaceae

Comparison Between Eubacteria And Archaea

Properties	Eubacteria	Archaea
Meaning	Bacteria are also single-cell but have the complex structure. All types of bacteria except archaea falls under this category.	Archaea are single-cell, simple microorganisms and are capable of surviving under extreme condition. They are considered as the most primitive cells, which originated on the earth 4 billion years ago.
Distribution	They are found everywhere like in the soil, water, living and non-living organisms.	Archaea are found in unusual environment like in hot spring, ocean depth, salt brine.
Cell Wall	The cell wall is made up of peptidoglycan with muramic acid or lipopolysaccharide.	The cell wall is said to be as pseudopeptidoglycan .
Lipid membrane	Eubacteria or bacteria have lipid membrane of ester bonds with fatty acids.	Archaea have ether bonds with the branching of aliphatic acids in their lipid membrane.
Metabolic pathway	Follow glycolysis pathway and Kreb's cycle to break down glucose.	Archaea do not follow glycolysis or Krebs cycle but uses similar pathway.
Types	Gram-positive and gram-negative.	Methanogens, Halophiles, Thermoacidophiles.
Reproduction	Bacteria can produce spores which allow them to live in unfavourable condition.	Archaea reproduce asexually by binary fission, fragmentation, or by the budding process.
Other features	Thymine is present in the tRNA.	Thymine is absent in the tRNA (transferase RNA).
	Introns are absent.	Introns are present.
	RNA polymerase is simple and contains 4 subunits.	RNA polymerase is complex and contains 10 subunits.
	Some bacteria are pathogens.	Archaea are non-pathogens.
Examples	Streptococcus pneumoniae., Yersinia pestis, Escherichia coli (E.coli).	Pyrolobus fumarii, Sulfolobus acidocaldarius, Pyrococcus furiosus.

Comparison Between Eubacteria And Cynobacteria

Characters	Eubacteria	Cyanobacteria
Size	Comparatively smaller.	Comparatively larger.
Distribution	Found every possible places in earth.	Only found in presence of sunlight and moisture.
Flagella	May bear flagella.	Flagella always absent.
Cell wall	1-2 layered.	4 layered.
Composition of cell wall	Glycolipids and peptidoglycan.	Glucosamine, diaminopimelic acid, amino acids and muramic acid with some amino sugar
Nutrition	May be autotrophic or heterotrophic.	Usually autotrophic.
Photosynthetic pigments	Bacteriochlorophyll.	Photosynthetic pigments is chlorophyll a.
Accessory pigment	Absent	Phycocyanin and phycoerythrin
Reserve food	Glycogen	Cyanophycean starch
Spore formation	Endogenous.	Endogenous and exogenous
Hydrogen donor	During photosynthesis hydrogen donor is not water; as a result oxygen is not evolved.	Hydrogen donor is water, oxygen is evolved. Process is oxygenic.
Heterocyst	Absent	Present.
Sexual reproduction	conjugation, transformation, transduction.	Totally absent.

KEY POINTS OF THE LECTURE

- Eubacteria are called true bacteria. These are single-celled prokaryotic relatively more complex domain of kingdom monera.
- They are cosmopolitan in their distribution and found in most of the habitats on earth like soil, water and inside or outside of large organisms.
- Eubacteria exhibit a variety of shapes and arrangements. Cocci and bacilli are the major shapes. Vibrio, rods, filaments and spirochetes are the other shapes of eubacteria.
- The cell wall is made up of peptidoglycans in a cross-linked chain pattern. This gives the wall of the bacteria the strength needed to maintain its shape and size during changing environments.
- Depending on the cell wall thickness, eubacteria can be divided into two categories: gram positive and gram negative bacteria.
- The cell wall structure of gram negative bacteria is more complex than gram positive bacterial cell wall and incapable of binding with gram stain.
- Some bacteria have a flagella, or a projection composed of protein, that is used for movement.
- Within the cytoplasm, free floating genome, or bacterial DNA, found in the nucleoid. Bacterial chromosomes are often circular but can also be linear in shape.
- Eubacteria, diversity in the modes of metabolism is also due to the wide variety of chemical compounds that serve as substrates as well as the ability to produce energy in different environmental conditions.

KEY POINTS OF THE LECTURE

- Some of the main nutritional modes of different species in the domain Eubacteria include: Autotrophic, Heterotrophic, Strictly or facultatively aerobic, Strictly or facultatively anaerobic
- Bacteria asexually reproduce through binary fission, fragmentation, budding and endospore.
- Pasmids are also found within bacteria separate from the bacteria's circular DNA. Also referred to as "replicons", plasmids are autonomous replicating DNA molecules.
- Eubacteria, the taxonomic domain that contains the single kingdom Bacteria, comprising the true bacteria. There are 11 main groups.
- This metabolic diversity also permits them to occupy a wide range of habitats. Bacteria can thrive in extremes of temperature, pH, salt, pressure, or toxic substances.
- The most bacteria are free living at some point of their life cycles, many bacteria are capable of living in close associations with other organisms, including eukaryotes.
- Some of these symbiotic associations are so highly evolved as to be obligate, while other associations are facultative, meaning the symbiotic partners can live apart from each other.
- Archaea constitute a domain of prokaryotes, single-celled microorganisms.
- Archaea and bacteria are generally similar in size and shape, although a few archaea have very different shapes.
- Their cell membrane including archaeols.

KEY POINTS OF THE LECTURE

- Archaea use more energy sources than eukaryotes: these range from organic compounds, such as sugars, to ammonia, metal ions or even hydrogen gas.
- Archaea are diverse but share some common features with eubacteria.
- Archaeal cells, like bacterial cells, exhibit a variety of shapes. cocci and rods are common.
- Curved rods, spiral shapes, and pleomorphic (many shaped) archaea have also been observed.
- The filament of archaeon coated with a biofilm formed by a bacterium. The nature of this interaction is unknown, but it is thought that the archaeon is host and bacteria are symbionts.
- Archaeal cell envelopes usually consist of only the plasma membrane and the cell wall.
- Archaeal membranes are composed of glycerol diether and diglycerol tetraether lipids.
- Archaeal membrane lipids are attached to glycerol by ether linkages instead of ester linkages, as found in bacteria and eukaryotes.
- The stereochemistry also differs. In archaeallipids, the stereoisomer of glycerol is sn-glycerol-1-phosphate; in bacterial lipids, the stereoisomer is sn-glycerol-3-phosphate. Thus in archaeal lipids, the side chains are attached to carbons 2 and 3 of glycerol, and in bacterial lipids, the side chains are attached to carbons 1 and 2.
- Membranes composed of glycerol diether are lipid bilayers. Membranes composed of diglycerol tetraethers are lipid monolayers.

KEY POINTS OF THE LECTURE

- The cytoplasm of archaeal cells is very similar to that of bacteria.
- Within it can be found inclusions—polyhydroxyalkonates, polyphosphate granules, glycogen granules, and gas vacuoles, ribosomes, a nucleoid, and plasmids.
- Many archaea have pili. Some archaeal pili are similar to bacterial type IV pili.
- Cannulae and hami are external structures that are unique to archaea. Their function is not known, but it is likely that they help cells attach to surfaces, including other cells.
- Bergey's Manual of Systematic Bacteriology (2001) divides Archaea into three phylum.
- Cyanobacteria consisting of free-living photosynthetic bacteria.
- They obtain their energy through oxygenic photosynthesis. The oxygen in the atmosphere is produced by cyanobacteria, either as free-living bacteria or as the endosymbiotic plastids.
- Cyanobacteria are arguably the most successful group of microorganisms on earth. They are the most genetically diverse; they occupy a broad range of habitats across all latitudes, widespread in freshwater, marine, and terrestrial ecosystems, and they are found in the most extreme niches such as hot springs, salt works, and hypersaline bays.
- They range of cynobacteria from unicellular to filamentous and include colonial species, Free living to colonial. Colonies may form filaments, sheets, or even hollow spheres.
- They can be found growing as epiphytes on the surfaces of the green alga

KEY POINTS OF THE LECTURE

- Cell wall divided into four layers (L1 to L4). Overall, the cell wall is lack of microfibrils. Its principal components are glucosamine, diaminopimelic acid, amino acids and muramic acid with some amino sugar. Cellulose is absent in the cell wall.
- Plasma membrane is to selective permeable and regulate movement of molecules within the cell.
- Elongated, flattened closed sac or disk shaped structure called thylakoids are presentas photosynthetic apparatus.
- The chlorophyll-α (but not chlorophyll-β) and a number of other pigments such as B-carotene, xanthophyll and phycobilins are present in this group.
- Nucleus are absent. Genome is the word suggested for this type of primitive nucleus.
- Sexual reproduction including gametes formation, fertilization and zygote formation is absent.
- Like bacteria, the cyanobacteria also reproduce asexually and the commonest mode of reproduction in them is transverse binary fission.
- In addition, there are certain specialized structures such as akinetes, hormogonia, hormocysts and spores, which are partly involved in the process of reproduction.
- Cynobacteria can be divide into total two tribes, 7 orders and 10 families.
- The cyanobacteria show potential applications in biotechnology for bioethanol production, food colorings, as a source of human and animal food, dietary supplements and raw materials.

TERMINOLOGY

- **Aerobes (aerobic):** Microorganisms that require oxygen to live and grow
- **Anaerobes (anaerobic):** Microorganims that do not require the presence of oxygen to live
- **Autotrophic:** Self-nourishing. Pertains to green plants and bacteria which form protein/carbohydrates from inorganic salts/ carbon dioxide
- **Bacteria:** Most common group of microbes. Essential to life; many reside naturally in the body. Cause disease when a person is compromised
- **Binary fission:** The process by which bacteria reproduce
- **Fungi:** Eucaryotic organisms including mushrooms, molds and yeasts
- **Gram negative bacteria:** Bacteria which appear red/pink following a staining process
- **Gram positive bacteria:** Bacteria which retain a purple color when subjected to a staining
- **Heterotrophic:** Organisms which require complex organic food to grow and develop
- **Host:** The organism from which a parasite gets its nourishment
- **Infection:** Term used when nonresident flora invade a susceptible area/host
- **Microorganisms:** Living organisms to small to be seen with the naked eye
- **Parasite:** Organism that lives within, upon or at the expense of a host
- **Pathogenic microorganism:** A disease causing/producing microorganism
- **Primary disease:** First disease or infection
- **Protozoa:** Eucaryotic, usually single-celled, animal like microorganism
- **Saprophyte:** Microorganism whose main source of foof is dead and decaying organic matter
- **Spores:** Formed by some bacteria as a means of survial
- **Toxin:** Poisons released by microorganisms

SOME QUESTIONS RELATED TO THE LECTURE

- **Question 1:** What are the eubacteria? Illustrate the well labeled diagram of eubacteria.
- **Question 2:** Highlight the characteristics of eubacteria.
- **Question 3:** Explain the metabolism of eubacteria in detail.
- **Question 4:** What is the mode of reproduction in eubacteria? Explain the various methods of reproduction in eubacteria.
- **Question 5:** Write a note on origin and taxonomy of eubacteria.
- **Question 6:** What do you understand by diversity and association of eubacteria?
- **Question 7:** What are the archaebacteria? Explain in detail.
- **Question 8:** Write a short note on shape, size and arrangement of archaebacteria.
- **Question 9:** How the archaebacteria are differ from the true bacteria?
- **Question 10:** What are the cynobacteria? Explain in detail.
- **Question 11:** Discuss the classification of cynobacteria in detail.
- **Question 12:** Write the morphological features of cynobacteria.
- **Question 13:** What are the modes of reproduction in cynobacteria?

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श्रद्धावाँल्लभते ज्ञानं