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T.Y.B.Sc. SEM-3 (CBCS)

SUBJECT: Microbiology

PAPER : 301

Unit 2

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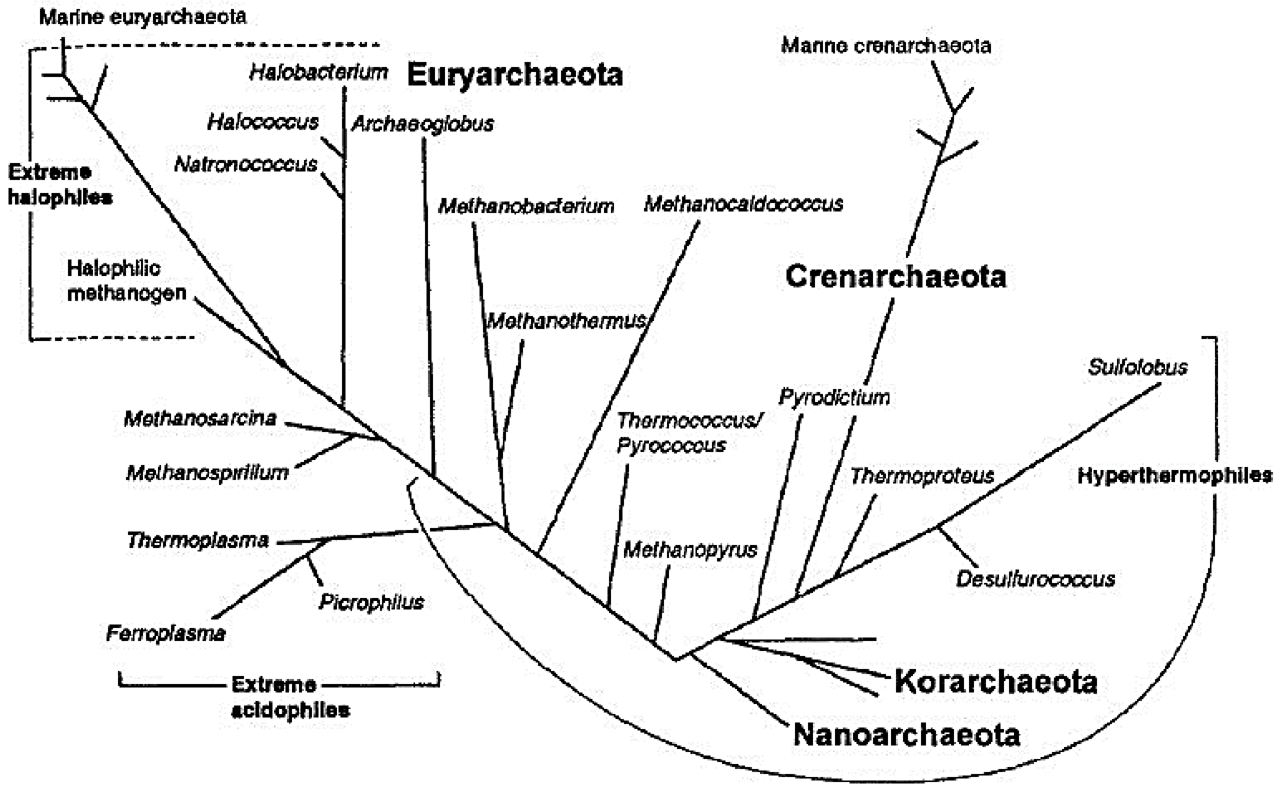
Table 19.4 Comparison of *Bacteria, Archaea,* and *Eukarya*			
Property	*Bacteria*	*Archaea*	*Eukarya*
Membrane-Enclosed Nucleus with Nucleolus	Absent	Absent	Present
Complex Internal Membranous Organelles	Absent	Absent	Present
Cell Wall	Almost always have peptidoglycan containing muramic acid	Variety of types, no muramic acid; some have pseudomurein	No muramic acid
Membrane Lipid	Have ester-linked, straight-chained fatty acids	Have ether-linked, branched isoprene-derived chains	Have ester-linked, straight-chained fatty acids
Gas Vesicles	Present	Present	Absent
Transfer RNA	Thymine present in most tRNAs	No thymine in T or TΨC arm of tRNA	Thymine present
	N-formylmethionine carried by initiator tRNA	Methionine carried by initiator tRNA	Methionine carried by initiator tRNA
Polycistronic mRNA	Present	Present	Present in some protists
mRNA Introns	Rare	Rare	Present
mRNA Splicing, Capping, and Poly-A Tailing	Absent	Absent	Present
Ribosomes			
Size	70S	70S	80S (cytoplasmic ribosomes)
Elongation factor 2 reaction with diphtheria toxin	Does not react	Reacts	Reacts
Sensitivity to chloramphenicol and kanamycin	Sensitive	Insensitive	Insensitive
Sensitivity to anisomycin	Insensitive	Sensitive	Sensitive
DNA-Dependent RNA Polymerase			
Number of enzymes	One	One	Three
Structure	Simple subunit pattern (6 subunits)	Complex subunit pattern similar to eukaryotic enzymes (8–12 subunits)	Complex subunit pattern (12–14 subunits)
Rifampicin sensitivity	Sensitive	Insensitive	Insensitive
RNA Polymerase II Type Promoters	Absent	Present	Present
Metabolism			
Similar ATP synthase	No	Yes	Yes
Methanogenesis	Absent	Present	Absent
Nitrogen fixation	Present	Present	Absent
Chlorophyll-based photosynthesis	Present	Absent	Present[1]
Chemolithotrophy	Present	Present	Absent

1 Present in chloroplasts (of bacterial origin).



ARCHAEA

The term Archaea (Greek archaios = ancient) is a group of prokaryotes which is quite different from Eubacteria in several morphological and biochemical traits. The archaebacteria are not a homogenous group but is a collection of disparate phenotypes: the methanogens, the extreme halophiles (organism that can grow in concentrated salt solutions) and extreme thermophilic sulphur metabolizing species.

Morphologically it can be spherical, rod-shaped, spiral lobed, plate shaped, irregularly shaped or pleomorphic. Some are single celled, whereas other form filaments or aggregates. They range in diameter from 0.1 to 15μm and some can grow in 200μm in length.

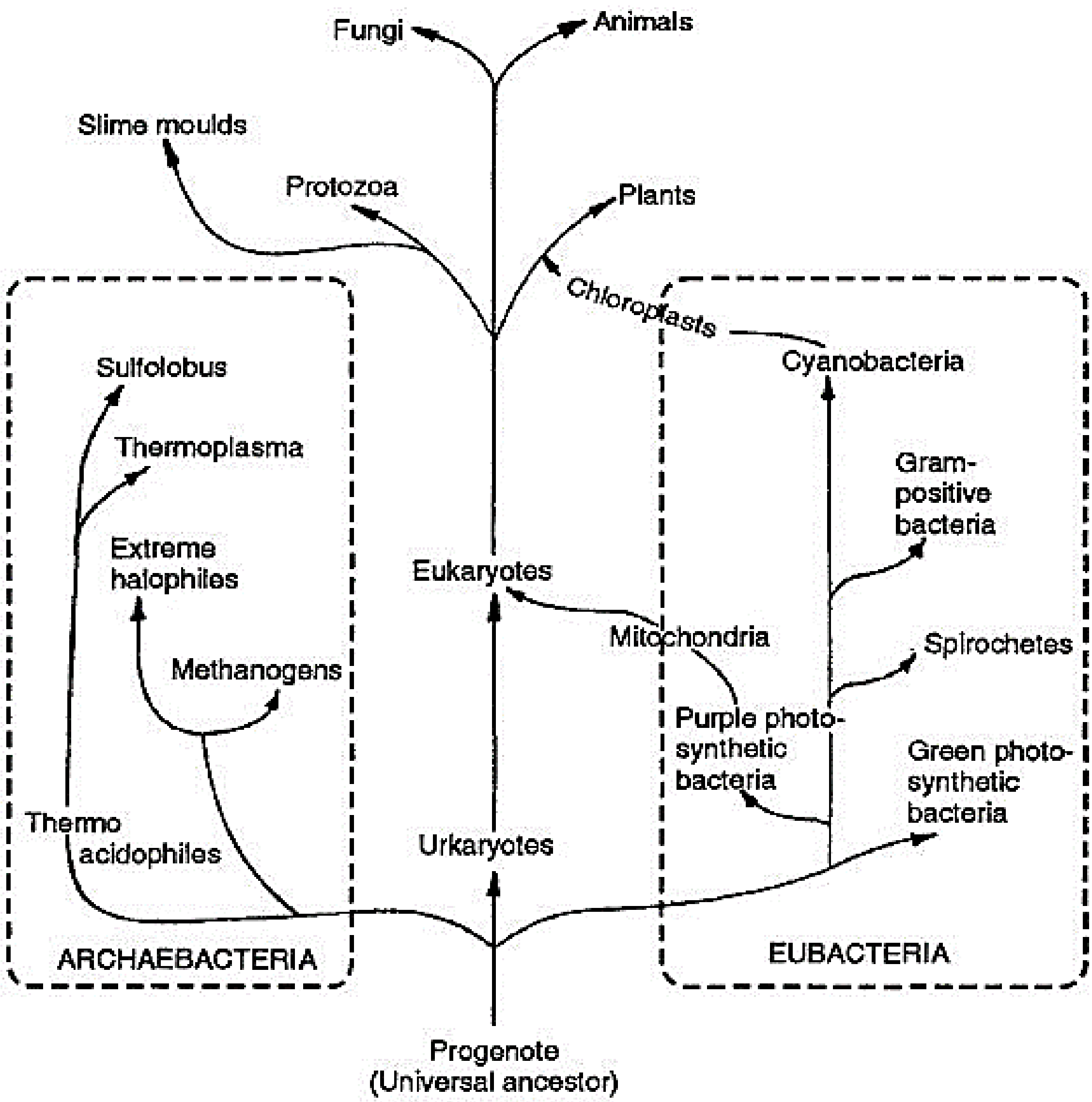
Archaea are generally found in extreme aquatic and terrestrial habitats. They are often present in anaerobic, hyper saline or high-temperature environments and also in cold environments. Archaea constitute up to 34% of prokaryotic biomass in Costa! Antarctic surface waters and few as a symbiont in animal digestive systems.

PHYLOGENY

Phylogenetic ally the domain Archaea tree splits into two major phyla called the Crenarchaeota and Euryarchaecota. Two other phyla called Korarchaeota and Nanoarchaeota branch of close to the root. Phyla Crenarchaeota contain mostly hyperthermophilic species whose optimum growth temperature is greater than 80°C. These hyperthermophiles are chemolithotrophic autotrophs and these organisms are, the only primary producers in these harsh environments. The 165 rRNA sequencing suggest that these organisms are more slowly evolving than other lineages in the domain.

Phyla Euryarchaeota includes methanogenic Archaea-whose metabolism is linked to the production of methane and extreme halophiles. Other groups of euryarchaeotes

Include hyperthermophiles *Thermococcus* and *Pyrococcus* and methanogen *Methanopyrus* and the cell wall less prokaryote *Thermoplasma.*



: The phylogenetic tree showing the evolution of archaebacteria, eubacteria and eukaryotes

The Korarchaeota was originally discovered by sampling of rRNA genes from organism inhabiting in unusual Yellowstone hot spring. This group is not yet officially recognized in taxonomy but clearly branch on the archaeae tree close to the root.

The Nanoarchaeota are the latest addition to the domain archaea. The only genus is *Nanoarchaeum* which is small parasitic prokaryote which lives attached to the cells of *Ignicoccus* (a crenarchaeote).

GENERAL CHARACTERISTICS

1. The archaebacteria (archaios = ancient and bakterion = a small rod) is a unique group which is diverse in its morphology and physiology from eubacteria and eukaryote.
2. They usually occur in extreme environments like highly saline or very high temperature conditions. Sometimes they are found in extreme cold environments. The extreme environment conditions include high temperature, low temperature, low acidic pH value, high alkaline value, high salt concentration, and low water

availability, high irradiation which include hot springs, salt lakes, and antarctic desert soils.

3. They are Gram positive or Gram negative and may be spherical, rod shaped, lobed, spiral or plate like or pleomorphic. The size ranges from 0.1-15 µm.
4. They multiply by binary fission, budding, fragmentation or other mechanisms.
5. Nutritionally they are either aerobic, facultative anaerobic or strictly anaerobic, chemolithoautotroph to organotrophs. The autotroph has the ability to fix $C0_2$ by reverse TCA cycle or by reductive acetyl CoA pathway-leading to production of glucose via pyruvate.
6. The Gram positive forms have a thick wall made up of N-acetyl glucosamine and L-amino acids while N-acetyl muramic acid and D-amino acids are absent and hence they are resistant to lysozyme and penicillin. The Gram negative archaebacteria have a relatively thick protein or glycoprotein cell wall but the outer membrane is absent.
7. The plasma membrane of archaea differs from that of eubacteria and eukaryote in having branched chain hydrocarbon attached to glycerol, connected by ether links (not straight chain fatty acids connected by ester links as in eubacteria).
8. The archaebacterial chromosome is a single circular DNA molecule as in eubacteria but smaller in length (mol. weight of 0.8 to 1.1 x 10^9 daltons, compared to 2.5 x 10^9dalton).
9. The TYC arm of archaeal tRNA lacks thymine and contains pseudouridine or 1-methyl pseudouridine.
10. The first amino acid to initiate a new polypeptide chain is methionine in archaebacteria where as it is N-formylmethionine in eubacteria.
11. The eubacteria are sensitive to chloramphenicol while the archaebacteria are not. While the diphtheria toxin affects archaebacteria but not eubacteria.
12. The variation in G + C content is great (21-68% of molecular weight)
13. The archaebacteria have few plasmids.
14. The archaebacterial mRNA is more similar to eubacteria than to eukaryotic mRNA.
15. Some methanogens have histone like protein that bends with DNA to form nucleosome like structure.
16. The archaebacteria, especially methanogens contain unusual coenzymes which do not occur in eubacteria like coenzyme F420, F430, Methanofuran, Methanopterin, and co-enzyme -M.
17. The extreme halophiles are only photosynthetic archaebacteria and convert light energy into chemical energy by means of a proton pump based on a pigment bacteriorhodopsin.

THE ARCHAEBACTERIAL CELL WALL

As we know that archaebacteria are either Gram + ve or Gram -ve. Thus there is considerable variety in the cell wall of archaebacteria. The cell wall structurally and chemically differ from that of eubacteria. The Gram positive archaebacteria have a single uniform thick homogenous cell wall layer like of eubacteria while the gram negative archaebacteria lack the outer membrane and complex peptidoglycan network like that of Gram negative eubacteria.

- Chemically the archaebacterial cell wall differ from eubacteria.
- They do not contain muramic acid and D-amino acid (characteristic feature of eubacterial peptidoglycan) but contain NAG (N-acetyl glucosamine) and L-amino

acid.

- Some methanogens like *Methanobacterium* contain a peptidoglyan like material called pseudopeptidoglycan or pseudomurien which contains an alternating repeats of N-acetyl glucosamine and N- acetyltalosamino uronic acid (unique to archaebacteria) which has L-amino acids in its cross links and 13 (1-3) glycosidic bonds instead of 13 (1-4) glycosidic bonds. Because of their structural difference the cell walls of archaebacteria are resistant to the action of lysozyme.
- *Methanosarcina* spp. contain a complex polysaccharide the major sugar in this being galactosamine, glucuronic acid and glucose. *Halococcus* an extreme halophile contains a sulphated polysaccharide made of sugars glucose, mannose and galactose.
- Along with this a great amount of negatively charged acidic amino acids which serve to balance the abundance of positive charges generated by the high concentration of sodium in the organism's environment (about 20-25% NaCl).
- *Methanococcus* and *Methanomicrobium* lack carbohydrates in the cell walls and contain only protein. *Sulfolobus* cell walls are made of glycoprotein and can remain, intact in boiling detergent solutions. The cell wall of *Pyrodictium* (which can with stand 110°C the most thermophilic organism) is also made of glycoprotein.
- In the Gram negative archaebacteria the outer membrane is absent and have a relatively thick protein and glycoprotein outside the plasma membrane.
- The layer is 20- 40 nm. The chemical content varies considerably some methanogens, *Halobacterium* and several extreme thermophiles viz. *Sulfolobus, Thennoproteus* have glycoproteins in their walls. In contrast, other methanogens *Metllanococcus, Methanomicrobium* and *Desulfurococcus* have protein walls.

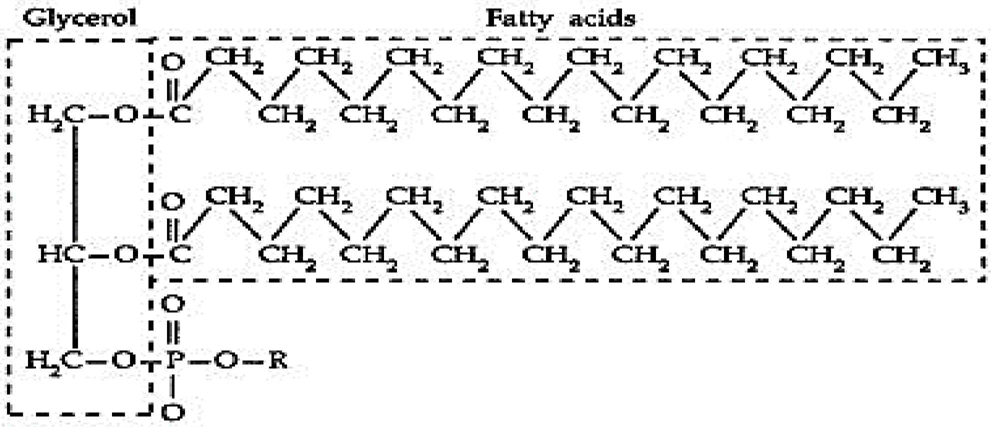
ARCHAEBACTERIAL LIPIDS AND MEMBRANE

The plasma membrane of archaebacteria differs from that of eubacteria and eukaryotes. The plasma membrane lipids of archaebacteria have branched chain hydrocarbon attached to glycerol by ether links rather than fatty acid connected by ester links as in eubacteria. Sometimes two glycerol groups are linked to form an extremely long tetra ethers. Glycerol diethers and glycerol tetra ethers are major classes of lipid present in archaebacteria.

The lipids are polar lipids which are present in archaebacterial membrane like phospholipids, sulfolipids and glycolipids. About 7-30% of membrane lipids are nonpolar lipids (the derivative of squalene). The C_{20} diethers can be used to make a regular bilayer membrane while a more rigid monolayer membrane is constructed of C_{40} tetra ethers lipids which increases the membrane's mechanical strength and resistance to chemical agent.

In thermoacidophiles one or two cyclopentane ring commonly occurs in C_{40} chains and two-OH (adjacent) groups on glycerol moiety are ether linked to these hydrocarbon chains. Thus archaebacterial membranes may contain a mix of diethers, tetra ethers and other lipids like thermoacidophiles contain many dibiphytanyl tetraethers, halophiles contain many diphytanyl diethers and methanagens contain both diphytanyl diethers and dibiphytanyl tetra ethers. The presence of ether linked lipid is such a unique characteristic of archaebacteria that this distinctive feature has been used as a biomarker for detecting archaebacteria in paleontological studies of rocks, sediments cores and other fossil materials.

(A)



(B)

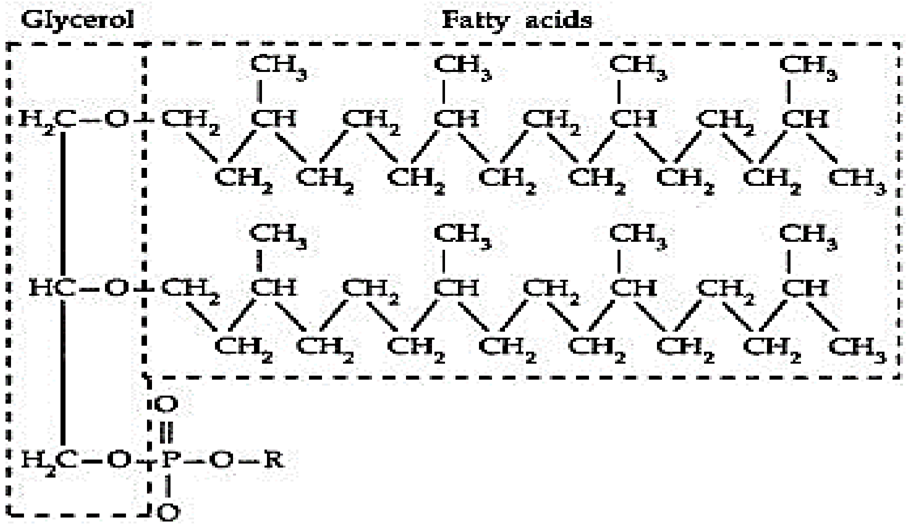


Fig. 3 : Structure of membrane lipids. A. Archaebacteria-Ester link
B. Eubacteria-Ether link

METABOLISM

1. Carbohydrate metabolism is best understood in archaea. They lack 6-phosphofructokinase enzyme and they do not appear to degrade glucose by EMP pathway. Extreme halophiles and thermophiles catabolize glucose using Entener duodoroff pathway.
2. (2) All archaea can oxidize pyruvate to acetyl CoA. They lack pyruvate dehydrogenase complex but have pyruvate oxidoreductase for this purpose.
3. Thermophiles and halophiles do have TCA cycle but methanogen lack it.
4. In protein synthesis the 1st_ NH_2 acid to initiate polypeptide chain is methionine in archaebacteria whereas it is N-formylmethionine in eubacteria.

Group	General characteristics	Representative Genera
Methanogenic archaea	Strict anaerobes. Methane is the major metabolic end product. S may be reduced to H_2S without yielding energy production. Cells possess coenzyme M, factors 420 and 430, and methanopterin.	*Methanobacterium* *Methanococcus* *Methanomicrobium* *Methanosarcina*
Archaea sulfate reducers	Irregular gram-negative coccoid cells. 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*
Extremely halophilic archaea	Coccoid or irregularly shaped rods. Gram-negative or gram-positive, primarily aerobic chemoorganotrophs. Require high sodium chloride concentrations for growth (>1.5 M). Colonies are various shades of red. Neutrophilic or alkalophilic. Mesophilic or slightly thermophilic. Some species contain bacteriorhodopsin and use light for ATP synthesis.	*Halobacterium* *Halococcus* *Natronobacterium*
Cell wall-less archaea	Pleomorphic cells lacking a cell wall. Thermoacidophilic and chemoorganotrophic. Facultatively anaerobic. Plasma membrane contains a mannose-rich glycoprotein and a lipoglycan.	*Thermoplasma*
Extremely thermophilic S^0-metabolizers	Gram-negative rods, filaments, or cocci. Obligately thermophilic (optimum growth temperature between 70-110°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* *Pyrodictium* *Pyrococcus* *Sulfolobus* *Thermococcus* *Thermoproteus*

Classification

The first edition of Bergey's manual divided the archaea into five major groups based on physiological and morphological difference (Table 1). The second edition of Bergey's Manual divides the archaea into two phyla the Crenarchaeota and Euryarchaeota each with several orders. The classification was based on rRNA data. The term Crenarchaeota [Greek Crene, spring or fount and archaeos) and Euryarchaeota [Greek
Eurus wide and = archaios = ancient or primitive) divided the archaea at the phyla level. The Crenarchaeote are thought to resemble the ancestor of the archaea and almost all the species are thermophiles or hyperthermophiles. The phylum Crenarchaeota is divided into one class. Thermoprotei and four order Thermoproteales, Sulfolobales, Desulfurococcales and Calidisphaerales.

Thermoproteales contains Gram-ve, anaerobic to facultative hyperthermophilic rods. They often grow chemolithoautotrophically by reducing sulphur to hydrogen sulfide. Members of the order Sulfolobales are coccus shaped thermoacidophiles. The order Desulfurococcales contain Gram negative coccoid or disk shaped hyperthermophiles. They grow either chemolithotrophically by hydrogen oxidation or organotrophically by either fermentation or respiration with sulphur as the electron acceptor.

The Euryarchaeotes are given the name because they occupy different ecological niches and have a variety of metabolic patterns. This phylum is very diverse with seven classes. (*Methanobacteria, Methanococci, Halobacteria, Thermoplasmata, Thermococci, Archaeglobi and Methanopyri*), nine orders and 15 families. Methanogens are the dominant physiological group and largest group with a great practical importance because methane is a clean burning fuel and an excellent energy source.

PHYLUM-CRENARCHAEOTA

- Most of the Crenarchaeotes are extremely thermophilic and many are acidophilic and sulphur dependent.
- Almost all are strict anaerobes. They grow in geothermally heated water or soils that contain elemental sulphur. The sulphur may be used either as an electron acceptor in aerobic respiration or as an e- source by lithotrophs.
- The members are scattered all over the world for e.g. the sulphur rich hot springs in Yellowstone National park, Wyoming and water surrounding areas of submarine volcanic activity. Such habitats are called Solfatara.
- These archaea can be very thermophilic and often are classified as hyperthermophiles. The phylum include a single class Thermoprotei, with 4 orders, Thermoproteales, Calidisphaerales, Desulfurococcales and sulfolobales.
- *Thermoproteus* the member of order Thermoproteales is a long thin rod that can be bent or branched. Its cell wall is composed of glycoprotein. It is strict anaerobic and grows at temperature from 70-97°C and pH values between 2.5 to 6.5.
- It is found in hot springs and other hot aquatic habitats rich in sulfur. It can grow organotrophically and oxidize glucose, amino acids, alcohols and organic acids with elemental sulfur as the electron acceptor. CO or CO_2 act as sole carbon source

Some Characteristics of Representative Genera of Methanogens

Genus	Morphology	Motility	% G+C ratio	Wall composition	Gram reaction	Substrate used
1. *Methanobacterium*	Long rods often forming filaments	—	32 - 61%	Pseudomurin	+ to variable	H_2+CO_2, formate
2. *Methanococcus*	Pleomorphic, irregular cocci	Through one flagellar tuft	29 - 34%	Protein	—	H_2 + CO_2, formate
3. *Methanomicrobium*	Short rods	Through single polar flagellum	45 - 49%	Protein	Gram – ve	H_2 + CO_2, formate
4. *Methanogenium*	Pleomorphic cocci	Through peritrichous	52 - 61%	Protein or glycoprotein	Gram – ve	H_2 + CO_2, formate
5. *Methanospirillum*	Curved rods or spirilla	Through polar flagella	45 - 50%	Protein	Gram – ve	H_2 + CO_2, formate
6. *Methanosarcina*	Cocci in clusters	—	36 - 43%	Heteropolysacc harides or protein	Gram + ve or variable	H_2 + CO_2, methanol, methylamines, acetate
7. *Methanothermus*	Straight to slightly curved rods	+	33%	Pseudomurin with an outer protein sulphur layer	+	H_2 + CO_2

- For growth vary among isolates from 63-80°C, pH values 1-5 (Optimum 2). Although it can grow on organic compounds (organotrophically) but in its natural habitats it probably grows as a respirato ly chemoautotroph.
- Geothermal steam or hot water leaches much amounts of iron and sulphated which is rapidly oxidized to elemental sulphur by oxygen or ferric ion, either chemically or biologically: This bacterium rapidly oxidizes H S. This ability of *Sulfolobus* to oxidize Fe^{+2} to Fe^{+3} anaerobically has been used quite successfully in high temperature bioleaching of iron and copper ores.
- *Sulfolobus cells* are spherical, Gram – ve, aerobic irregularly lobed and cell walls are mainly composed of protein. Cells adhere tightly to sulphur crystals where

they can be visualized microscopically using fluorescent dyes.

- Their cell wall contains lipoprotein and carbohydrate but lacks peptidoglycan. Oxygen is the normal electron acceptor. Sugar and amino acid such as glutamate also serve as carbon and energy sources. They are generally classified as thermoacidophiles.
- *Pyrodictium:* It is a sub-marine volcanic extreme thermophile which is of great interest because of its ability to grow at temperature up to 110℃ (Optimum 105°C). Cells of *Pyrodictium* are irregularly disc-shaped and grow in cultures as a mold like layer upon sulphur crystals on the medium. The cell mass consists of a network of fibers to which cells are attached. The fibers are hollow and consist of proteinaceous subunits similar to that of flagellin protein of eubacterial flagellum. It is strict anaerobe that grows lithotrophically on H_2 and S at 82-110°C. The cell envelope consists of glycoprotein.
- *Picrophilus:* The genus was isolated from moderately hot solfataric fields in Japan. It lacks a regular cell wall but has an S-layer outside its plasma membrane. The cells grows as irregularly shaped cocci, 1.5 μm in diameter and have large cytoplasmic cavities that are not membrane bounded. The genus is aerobic and grows between 47-65°C. The optimum pH is 0.7

Phylum-Euryarchaeota

This phylum is very diverse phylum with many classes (nine according to 2nd edition of Bergey's manual), viz. *Methanobacteria, Methanococci, Methanomicrobia, Halobacteria, Thermoplasmata, Thermococci, Archaeoglobi, Methanopyri.*

- Methanogens occur in various anaerobic habitats rich in organic matter with non-- methanogenic bacteria ferment to produce H_2 and CO_2.
- Thus the methanogens form the consortia in association with other microorganisms which not only provide CO_2 and fatty acids required. The habitat like marshes, swamps, pond and lake mud marine sediments, the intestinal tract of human and animals, the rumen of cattle and anaerobic sludge digesters in sewage treatment systems are ideal for these archaebacteria. These microbes are unable to use carbohydrate, proteins or other complex organic substrates.
- The methanogens obtain energy by converting CO_2, formate, methanol, acetate and other compounds to produce either methane or CO_2•
- This is the largest group of archaea which differ greatly in overall shape, 16srRNA sequence, cell wall chemistry and structure, membrane lipids.
- For example methanogens construct three different types of cell wall. The most complex is that of group I which is rigid and composed chiefly of pseudomurin (it contain N-acetyl talosaminuronic acid instead of N-acetylmuramic acid and lack D-amino acids). In appearance the wall resembles those of Gram + ve eubacteria. In groupes II the wall is flexible and composed chiefly of proteins with traces of glucosamine.
- While the group III has the most complex cell wall. It is flexible composed of at least two layers, an inner electron dense of unknown chemistry and outer one appearing like a membrane in cross section but composed entirely of protein.
- The order Methanobacteriales consists of the genera *Methanobacterium, Metlumobrevibacter, Metlumosphaera* and *Methanotlzennus.*
- The Methanomicrobiales contains sarcinoid forms and some spirilla. The sarcinae can utilize acetate and sometimes methyl amines for methane production. They contain cytochrome b or c or both. The most unusual methanogenic group is the genus

Methanopyrus which is extremely thermophilic, rod shaped methanogen from marine hydrothermal vent. This genus occupies the deepest and most ancient branch of euryarchaeotes.

- The metabolism of these methanogen is unusual. They contain unique cofactors tetrahydromethanopterin, methanofuran, coenzyme M (all three not found in eubacteria) coenzyme F_{4201} and coenzyme F_{430}• It is suggested that ATP synthesis is linked with methanogenesis by electron transport, protein pumping and a chemiosmotic mechanism.
- The group methanogenic archaea are potentially of great practical importance because methane is a clean burning fuel and an excellent energy source. The sewage treatment plants uses the methane, produced as a source of energy for heat and electricity.
- In contrast the methanogenesis can also be a ecological problem. It absorb IR radiation and is a green house gas and this significantly promote future global warming.

Halobacteria

- The extreme halophiles or halobacteria (class Halobacteria) is another group of archaea, currently with 15 genera.
- It has a single family Halobacteriaceae. They are aerobic chemoheterotrophs and require complex nutrients usually proteins and amino acids for growth. All the members of this family are obligate halophiles growing in media containing at least 15% NaCl.
- These members are found in the ecosystem which have extremely high NaCl concentration like salt lakes, the dead sea and salt preserved foods. The salt lakes occur in arid regions where evaporation exceeds fresh water inflow, or a lake which is fed by a salt spring.
- The cell wall of these organism is so dependent on the presence of NaCl that it disintegrate when NaCl concentration drops to about 1.5 M.
- The cell wall of *Halococcus* are composed of a complex heteropolysaccharide which is stable even at low salt concentration.
- The major component of cell wall of *Halobacterium* is a large acidic glycol protein. Its glycan component consist of 22-24 disaccharide linked via – O – glycosidic bond to threionine residues, 12-14 trisaccharide. Also o-li"lked to thrionine and a single heterooligosaccharide in N-glycosidic linkage to aspargine. In addition to the glycoprotein the cell envelope contains nonglycosylated protein and glycolipid.
- They can also grow in food products such as salted fish and cause spoilage. They can reach such high population levels that salts lakes, salterns and salted fish actually turn red.
- The best studied member of the family is *Halobacterium salinarium* which is especial because it can trap light energy photosynthetically with the help of a special pigment called bacteriorhodopsin.
- Bacteriorhodopsin is a protein pigment, because · of its functional similarity to the visual pigment of eye called rhodopsin, conjugated to bacteriorhodopsin is a molecule of retinal, a carotene like molecule which can absorb light and catalyse

the transfer of protons across the cytoplasmic membrane.

- The cell membrane of *Halobacterium* appears purple due to the presence of the pigment bacteriorhodopsin. When a cell containing the pigment are exposed to light the pigment bleaches.
- During this bleaching H+ (protons) are extruded to the outside of the membrane and generate a proton motive force which drives ATP synthesis. The absorption spectra of bacteriorhodopsin appears at 570 nm.
- The *Halobacteria* also contain cytochrome and ferredoxins. The genus *Halobacterium* has four rhodopsins each with separate function.
- Halorhodopsin uses light energy to transport chloride ions into the cell and maintain a 4-5 M intracellular KCl concentration. Two other rhodopsin act as photoreceptor one for red and one for blue light.

The halobacteria are Gram negative with the shape ranges from rod to disc shaped, polarly flagellated cells viz. *Halobacterium* or immotile cocci *(Halococcus).* The colonies are red to orange in colour because of carotene like pigments.

The genome of *Halobacteriwn* and *Halococcus* contain two components with different percentage of G + C values. Majority of DNA has a G + C content of 66-68%. The total genome size of *Halobacterium* is 2.5 x 10^9 which contains a large number of different repeated sequences upto 5,000 bp in length.

The group thermococcales are strictly anaerobic and can reduce sulfur to sulfide. They are motile and have optimum growth temperature 88-100°C. It contains two genera *Thermococcus* and *Pyrococcus.* This group is also known as extremely thermophilic s°metabolizers.

The group Archaeoglobales has a single family with single genus *Arcl1aeoglobus.* This group is also known as sulfate reducing archaea. The organism is Gram -ve, irregular coccoid. Cells with cell wall containing glycoprotein subunits. It can extract electron from a variety of electron donors (like H_2 lactate, glucose) and reduce sulfate, sulfite or thiosulfate to sulfide. The species is extremely thermophilic (optimum 83°C). It possess the methanogen, coenzyme F_{420} and methanopterin.

EVOLUTION

Evolutionarily all the organism of the group archaea is assumed to be descendent from a common ancestor the progenitor (the organism might be primitive, cellular, with rudimentary not well coordinated translation apparatus or might be an archaebacterium). As a group they are collection of diverse groups of organism. The unifying feature being their adaptation to extremes of environmental conditions like extreme pH, temperature, salinity. Considering that early earth had such extreme environmental condition archaebacteria appears to be the early forms of life on earth. It is suggested that archaebacteria are more primitive than eubacteria and evolved at slower rate than both i.e. the eubacteria and eukaryotes.

MYCOPLASMA

In living organisms, some diseases are caused by very small microorganism called Mycoplasma. These organism are the smallest free living cell known much similar to other microorganism like bacteria, chlamydea, rickettsia and viruses.

Mycoplasmas and prokaryotes, without cell wall have been placed under the class mollicutes (Latin mollis = soft, pliable + cutis = stain) and the order Mycoplasmatales. Mycoplasmas or mollicutes (soft skin) are without cell wall and are ·bounded by triple layered membrane. They are smallest microorganism which have been known to cause a number of diseases in animals and human being. Louis Pasteur first noticed them while observing the causative agent of pleuropneumonia in culture. He was unable to isolate them in a pure culture medium. Nocard and Roux (1898) of Pasteur's laboratory cultured the microorganism in media containing serum and demonstrated that the pleomorphic microbes could produce the disease in inoculated healthy cattle. These were pleomorphic and were called PPLO (Pleuropneumonia like organism). This organism was later on given the name *Asterococcus mycoides* by Borre!*et al* (1910). Nowak (1929) put *Asterococcus mycoides* under the genus *Mycoplasma.* All such organisms are now called mycoplasmas.

In 1967 Japanese scientists Doi, Teranaka, Yora and Asuyama surprised the plant pathologists stated that Mulberry dwarf, Potato witches broom, Aster yellows or Paulownia witches broom which were suspected to be the virus diseases, were infact caused by Mycoplasma. In 1976 as many as 150 plant species were known in which Mycoplasmas could be detected.

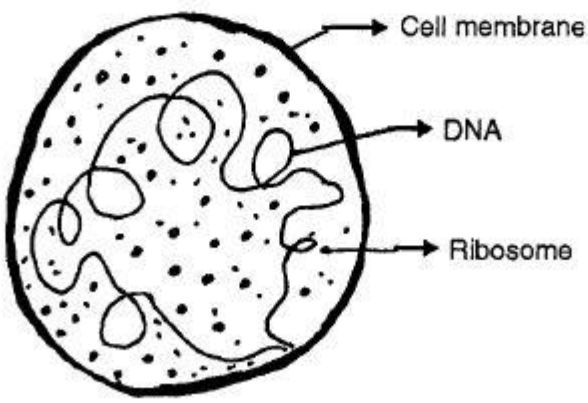


Fig. 1 : Diagrammatic representation of single cell of Mycoplasma

TABLE 1

Characters of Mycoplasmas and Viruses

Properties	Virus	Mycoplasma
1. Growth on culture medium	-	+
2. Cell wall/cell wall Peptidoglycan lack	+	+
3. Generate metabolic energy	-	+
4. Depends on host cell nucleic acid for multiplication	+	-
5. Can synthesize protein by own enzyme	-	+
6. Require sterols	-	+
7. Visible in optical microscope x 1500	-	+
8. Filterable through 450 nm filters	+	+
9. Contains both RNA and DNA	-	+
10. Growth inhibited by antibody alone	-	+
11. Growth inhibited by antibiotics	-	+
12. Action on protein synthesis + positive action, negative action	-	+

GENERAL CHARACTERISTICS OF MYCOPLASMA

1. They are very small, non-motile (except *Spiroplasma*) and prokaryotic which may
2. be parasitic or saprophytic.
3. They lack cell wall and the outer boundary of the cells being the cytoplasmic membrane which is three layered unit membrane structure.
4. Their cells possess plasticity (pleomorphic) and can assurp.e various shapes ranging from spheres to branched filaments.
5. The plasticity allows the cells to pass through bacteriological filters even though the 1.mallest cells are about 0.3 nm in diameter.
6. They require sterols for their growth. They are sensitive to supersonic vibrations desiccations and most of the physical environment factors.
7. The colony of mycoplasma on solid agar medium appears as just like fried egg
8. under stereomicroscope. The colony shows spherical or hemispherical portion in the centre, which is surrounded by sll.rface growth towards periphery. The typical colony is biphasic with a fried egg appearance {characterized by opaque, granular central area with a transleucent peripheral zone).
9. They are susceptible to lysis by osmotic shocks caused by sudden dilution of the medium with water.
10. They can be cultivated *in vitro* on non-living media of rich composition as facultative anaerobes or obligate anaerobes.
11. The genome size of mycoplasmas are about size of those of bacteria.
12. Genetic material is naked circular chromosome of fibrillar (double stranded) DNA, about 3 nm thick with a molecular weight ranges from 44 x 10 to 1200 x 10 daltons. Guanine : cytosine ratio of DNA ranges from 24-10%.
13. The mode of multiplication is presumed to be by budding or binary fission.
14. Chemically they are much closer to bacteria because they possess 4% DNA and 8% RNA, 70s ribosomes are present in the cytoplasm.
15. Cells are non-motile but gliding motility has been observed in a few species.
16. Mesosomes are not found in the cells of mycoplasma, but plasmids are found on the basis of dry matter 50-80% proteins, 8-17% RNA and 4-7% DNA is present.
17. They do not show response towards Gram staining i.e. they are Gram negative in nature. Stevens & Fox (1979) suggested a rapid and simple technique called Dien's stain for staining technique.
18. They are insensitive to penicillin, vancomycin and cephaloridine (which effect on cell wall) but are sensitive toward tetracycline & chloremphenicol (which effect on metabolic activities) and they have harmful effect on them

CLASSIFICATION

In 1966, International Committee of Nomenclature of Bacteria, separated mycoplasma from bacteria and placed them in class-Mollicutes. (Mollis = flexible, + cutis = stain). Edward & Friendt (1970) have classified *Mycoplasma* or PPLO under different groups on the basis of sterol requirement.

Class - Mollicutes

Order - Mycoplasmatales Family –

includes 3 families

(i) Mycoplasmataceae - e.g. *Mycoplasma*

(ii) Acholeplasmataceae – e.g. *Aclzoleplasma*

(iii) Spiroplasmataceae – e.g. *Spiroplasma*

CELL STRUCTURE

The ultra structure of cell of *Mycoplasma* appears as prokaryotic unicellular microorganism. The outer most boundary of cell is a unit plasma membrane which is three layered made up of lipoprotein. The chemical nature of lipoprotein consist of phospholipids and cholesterol. This unit membrane is 80-100A in thickness and selectively permeable. The membrane surrounds the cytoplasm which is packed with 70s ribosomes, RN.A., naked circular chromosome of fibrillar double stranded DNA of about 3 nm thick, one or more electron dense areas and some empty vacuoles.

On the basis of dry weight the chemical composition of *Mycoplasma* is as follows:-

Protein – 50-80%

Lipid - approx 40% RNA – 8-15%

DNA – 4-6%

Mesosomes are not found in the cells of *Mycoplasma* but plasmids are found 40 different types of enzymes are found in cytoplasm.

Because the *Mycoplasma* are able to pass through many filters and grow in media which do not contain living tissue. They are therefore considered to be microorganism intermediate between bacteria and viruses chemically they are much closer to bacteria. Because of their special cell structure and physiology various scientist has named *Mycoplasmas* with different nomenclature viz. Joker of microbiology, jocker of plant kingdom, Prokaryote without cell wall, and Bacteria with their coats off.

Reproduction

Morowitz and Tourtelotte (1962) reported the absence of sexual and asexual reproduction in *Mycoplasma,* but they reproduce by (i) Fragmentation (ii) Budding (iii) Young elementary bodies

Formation of elementary body is an important mode of reproduction in *Mycoplasma.* The cells of *Mycoplasma laidlawii* show unequal division at the time of multiplication, as a result of which elementary bodies of 330-450 μm size are formed. They are very minute and can live freely. They are known as primary bodies. These primary bodies increases in size and shape accordingly called as secondary and tertiary structures. Inside these larger bodies the elementary bodies are formed and this stage is known as quarternary structure and after the rupturing of larger bodies these are released and this quarternary structure develops into complete mycoplasma cell.

ECONOMIC IMPORTANCE OF MYCOPLASMA

Mycoplasma causes many diseases in plants animals and human beings. The important ones, caused in plants are as follows:

Mycoplasmal Plant Diseases :

- Little leaf disease of Brinjal.
- Bunchy top of Papaya.
- Witches broom of Legumes.
- Yellow dwarf of Tobacco.
- Sandal spike disease.
- Sesamum Phyllody.
- Stripe disease of Sugarcane.
- Witches broom of Potato.
- Clover virescence.
- Clover phyllody disease.
- Cotton virescence.

Symptoms of Mycoplasmal Plant Diseases

(i) Plant associated with mycoplasma are infected in the sieve tubes of the plants causes upsetting the hormonal balance resulting in witchs broom growth (all the axillary buds grows and convert into bunch).

(ii) In some cases flower leaf assume the shape of foliage leaves (phyllody) and various intermediate stage between flowers and leafy sprouts can be found (antholysis). In many cases no anthocyanin are formed in petal.

(iii) Degenerative processes in the sieve tubes of infected plant causes plant stunting, wilting or leaf yellowing and reduction of leaf size.

(iv) Colour breaking in the calyx portion of infected flower causes greening of all flower parts (virescence) and transferred into green leaf like structure (Phyllody).

(v) Stem become flat in infected plant.

(vi) Excessive callose formation and cell necrosis occurs in the sieve tubes of infected plant which can be visible under a fluorescence microscope after staining with aniline blue (serves as indirect indication for the presence of mycoplasma).

Transmission of Disease

(i) Plant mycoplasmas are known to be transmitted by certain insect vectors (leaf hopper) of cicadellidae and psyllidae. Once mycoplasma invade the insects salivary glands the vectors can transmit these organisms with the help of their saliva to healthy plants.

(ii) By graf ting, mycoplasma can be transferred to healthy plant.

(iii) With the aid of *Cuscuta,* mycoplasma can be transferred from diseased to healthy plants. (with the help of haustoria) but this type of. transmission does not occur in nature.

(iv) An aphid named *Acŋthosiphon pisum* transmit mycoplasma in *Pisum sativum.*

Mycoplasmal Human Diseases

(i) *Mycoplasma pneumoniae* causes the disease primary atypical pneumonia (PAP) in the mouth, pharynx and genitourinary tract.

(ii) *Ureaplasma ueralyticum* have been found in women experiencing repeated or habitual reproduction failure.

(iii) Two species of mycoplasma viz. *M . hominis* and *M .fermentants* has been found responsible for infertility in men.

(iv) *M. orale* and *M. salivarium* are found responsible for respiratory tract infection.

(v) Mycoplasma have also been found in cases of arthritis and inflammation of the middle ear. Mycoplasmal

Animal Diseases:

(i) Inflammation of genitals in animals is caused by *Mycoplasma bovigenitalium.*

(ii) Bovine pleuropneumonia in animals is caused by *Mycoplasma mycoides.*

(iii) Agalactia of sheep and goat is caused by *Mycoplasma agalactiae.*

(iv) Sinubitis in hen is caused by *Mycoplasma melegridis.*

Thermoplasmas are heat loving mycoplasma. The optimum temperature for growth is 59°C. They are Gram variable.

The genus *Thermoplasma* grows at a temperature of 55-59°C (max. 62°C) and pH 2 (minimum 1 to max. 4). The genus is distinct from other extreme thermophiles as it resembles the eubacterial genus *Mycoplasma* in lacking a cell wall and forming fried egg colony. It grows in refuse piles of coal mines which contain iron pyrites (FeS) which oxidized to sulphuric acid by lithotrophs. *Thennoplasma* lacks a cell wall but cell membrane contains large amounts of lipopolysaccharide and glycoprotein (diglycerol tetraethers). The DNA is stabilized with a histone like protein, thus resembling the chromosome of eukaryote.

Spiroplasma are spiral form mycoplasmas. The helical filamentous forms are motile and show rapid rotary or screw motion and slow undulation motion. They are gram positive.

Mycoplasma resembles L-form in (i) having similar ultrastructure (ii) soft pleomorphic cells devoid of mucopeptide wall (iii) not osmotically fragile (iv) growth on media without osmotic protection. They differ from L-forms in the following characters : (i) while the L-forms revert to normal cells when the antibiotic is removed, mycoplasma never synthesizes the wall and (ii) while L-forms are non-pathogenic, mycoplasmas are important pathogens.

L- form was isolated by Kleinberger Nobel in 1935. The cells were called L- forms after Lister Institute in London where they were isolated. L-forms are spheroplast like structure lacking cell wall. These naked protoplast can also be isolated from *Salmonella, E. coli* and *Proteus* (both Gram positive and Gram negative) as well as from other bacteria by cultivation on serum agar with penicillin (100 μg/ ml) in laboratory conditions. They produce fried egg type colonies which resemble those of mycoplasma species. Two types of L-forms have been isolated.

The L-form colonies can be lifted and cultured at higher concentration of penicillin as at lower concentrations the L-forms revert to normal bacterial cells with walls. L forms resemble protoplasts and sphaeroplasts in (a) lack of flagella. (b) inability to sporulate (c) lack of some or all cell wall antigens (d) reverson to normal cells when antibiotic treatment is stopped.

The L-forms do not multiply by binary fission. They increase in size (upto 50μ) and than form large number of small (0.1-0.3μ) units called elementary corpuscles by fission or budding.

These similarities suggest that in nature, mycoplasma might have originated from L-forms by loss of the capacity of reversion to normal cells. Thus L-forms are closest to mycoplasma, could be thought of as their proginator.

APPENDIX 1

Prokaryotes Notable for their Environmental Significance

Group/Genera	Characteristics
Metabolic Diversity	
Anaerobic Chemolithotrophs	
Methanogens *Methanococcus, Methanospirillum*	Members of the Archaea that oxidize hydrogen gas, using CO_2, as a terminal electron acceptor to generate methane.
Anaerobic Chemoorganotrophs-Anaerobic Respiration	
Sulfur-and sulfate-reducing bacteria *Desulfovibrio*	Use sulfate as a terminal electron acceptor, generating hydrogen sulfide. Found in anaerobic muds that are rich in organic material. Gram-negative.
Anaerobic Chemoorganotrophs-Fermentation	
Clostridium	Endospore-forming obligate anaerobes. Common inhabitants of soil. Some species are medically important. Gram-positive.
Lactic acid bacteria *Streptococcus, Enterococcus, Lactococcus, Lactobacillus, Leuconostoc*	Produce lactic acid as the major end product of their fermentative metabolism. Although most can grow in the presence of O_2, they can only ferment. Several genera are exploited by the food industry; some species are medically important. Gram-positive.
Propionibacterium	Obligate anaerobes that produce propionic acid as their primary fermentation end product. Used in the production of swiss cheese. Gram-positive.
Anoxygenic Phototrophs	
Purple sulphur bacteria *Chromatium, Thiospirillum, Thiodictyon*	Grow in coloured masses in sulfur springs and other sulfur-rich habitats, using sulfur compounds as a source of electrons when making reducing power. Most accumulate sulfur granules contained within the cell. Gram-negative.
Purple non-sulphur bacteria *Rhodobacter, Rhodopseudomonas*	Grow in a wide variety of aquatic habitats, preferentially using organic compounds as a source of electrons for reducing power. Many are metabolically versatile. Gram-negative.
Green Sulphur bacteria *Chlorobium, Pelodictyon*	Found in habitats similar to those preferred by the purple sulfur bacteria. Those that accumulate sulfur form granules outside of the cell. Gram-negative.
Green non-sulphur bacteria *Chloroflexus*	Characterized by their filamentous growth. Metabolically similar to the purple non-sulfur bacteria. Gram-negative.
Others *Heliobacterium*	Other types of anoxygenic photographs have not been studied extensively.
Oxygenic Phototrophs – Cyanobacteria	
Anabaena, Synechococcus, Trichodesmium	Photosynthetic bacteria that were once thought to be algae. Important primary producers. Those that fix N_2, support the growth of unrelated organisms in environments that would otherwise be nitrogen-deficient. Gram-negative.
Aerobic Chemolithotrophs	
Filamentous sulfur oxidizers	Oxidize sulfur compounds as an energy source. Found in sulfur

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Group/Genera	Characteristics
Beggiatoa, Thiothrix	springs, sewage-polluted waters, and on the surface of marine and freshwater sediments. Their overgrowth causes bulking in sewage at treatment facilities. Gram-negative.
Unicellular sulfur oxidizers *Thiobacillus*	Oxidize sulfur compounds as an energy source. Some species can produce enough acid to lower the pH to 1.0. Oxidation of metal sulfides causes bioleaching. Gram-negative.
Nitrifiers *Nitrosomonas, Nitrosococcus, Nitrobacter, Nitrococcus*	Oxidize ammonia or nitrate as an energy source. In so doing, they convert certain fertilizers to a form that is readily leached from soils, and deplete O_2 in waters polluted with ammonia-containing wastes. Genera that oxidize nitrite prevent the toxic buildup of this compound in soils. Gram-negative.
Hydrogen-oxidizing bacteria *Aquifex, Hydrogenobacter*	Thermophilic bacteria that oxidize hydrogen gas as an energy source. According to 16S rRNA studies, they were one of the earliest bacterial forms to exist on earth.
Aerobic Chemoorganotrophs – Obligate Aerobes	
Micrococcus	Widely distributed, common contaminants on bacteriological media. Gram-positive
Mycobacterium	Waxy cell wall resists staining; acid-fast. Some species are medically important.
Pseudomonas	Common environmental bacteria that, as a group, can degrade a wide variety of compounds. Some species are medically important. Gram-negative.
Thermus	*Thermus aquaticus* is the source of *Taq* polymerase, the heat-resistant polymerase used in PCR. Unusual cell wall stains gram-negative.
Deinococcus	Extraordinarily resistant to the damaging effects of gamma radiation. Unusual cell wall stains gram-positive, but has multiple layers.
Aerobic Chemoorganotrophs-Facultative Anaerobes	
Corynebacterium	Widespread in nature; form metachromatic granules. Some species are medically important. Gram-positive.
The Enterobacteriaceae *Escherichia coli, Enterobacter, Klebsiella, Proteus, Salmonella, Shigella, Yersinia*	Most reside in the intestinal tract. Those that ferment lactose are coliforms; their presence in water serves as an indicator of fecal pollution. Some species are medically important. Gram-negative.
ECOPHYSIOLOGY	
Thriving in Terrestrial Environments	
Endospore-formers *Bacillus, Clostridium*	Endospores are the most resistant life form known. *Bacillus* species include both obligate aerobes and facultative anaerobes; *Clostridium* species are obligate anaerobes. Some species are medically important. Gram-positive.

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Group/Genera	Characteristics
Azotobacter	Form a resting stage called a cyst. Notable for their ability to fix nitrogen in aerobic conditions. Gram-negative.
Myxobacteria *Chondromyces, Myxococcus, Stigmatella*	Congregate to form a fruiting body; cells within this differentiate to form dormant microcysts. Gram-negative.
Streptomyces	Resemble fungi in their pattern of growth, forming dormant conidia. Naturally produce a wide array of medically useful antibiotics. Gram-positive.
Agrobacterium	Cause plant tumors. Scientists use their plasmid to introduce desired genes into plant cells. Gram-negative.
Rhizobia *Rhizobium, Sinorhizobium, Bradyrhizobium, Mesorhizobium, Azorhizobium*	Fix nitrogen, form a symbiotic relationship with legumes. Gram-negative.
Thriving in Aquatic Environments	
Sheathed bacteria *Sphaerotilus, Leptothrix*	Form chains of cells enclosed within a protective sheath. Swarmer cells move to new locations. Gram-negative.
Prosthecate bacteria *Caulobacter, Hyphomicrobium*	Appendages increase their surface area. *Caulobacter* species serve as a model for cellular differentiation. *Hyphomicrobium* species have a distinctive method of reproduction. Gram-negative.
Bdellovibrio	Predator of *E. coli* and other bacteria, multiplying within the periplasm of the prey. Gram-negative.
Bioluminescent bacteria *Photobacterium, Vibrio fischeri*	Some bioluminescent species form a symbiotic relationship with specific-species of squid and fish.
Legionella	Often reside within protozoa. Some species are medically important. Gram-negative.
Free-living spirochetes *Spirochaeta, Leptospira* (some species)	Long spiral-shaped bacteria that move by means of an axial filament. Some species are medically important. Gram-negative.
Magnetospirillum	Contain a string of magnetic crystals that enable them to move up or down in water and sediments. Gram-negative.
Spirillum	Spiral-shaped, microaerophilic bacteria, some species form metachromatic granules. Gram-negative.
Sulfur – oxidizing, nitrate-reducing marine bacteria *Thioploca, Thiomargarita*	Use novel mechanisms to compensate for the fact that their energy source (reduced sulfur compounds) and terminal electron acceptor (nitrate) do not coexist.
ARCHAEA	
Methanogens *Methanococcus, Methanospirillum*	Generate methane when they oxidize hydrogen gas as an energy source, using CO_2 as a terminal electron acceptor.
Extreme halophiles *Halobacterium, Halorubrum, Natronobacterium, Natronococcus*	Found in salt lakes, soda lakes, and brines. They produce pigments and can be seen as pink blooms in concentrated salt water ponds.

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Group/Genera	Characteristics
Methane-generating thermophiles *Methanothermus*	Found near hydrothermal vents; can grow at temperatures near 100°C.
Sulfur and sulfate-reducing hyperthermophiles *Thermococcus, Archaeoglobus, Thermoproteus, Pyrodictium, Pyrolobus*	Obligate anaerobes that use sulfur or, in one case, sulfate as a terminal electron acceptor, generating hydrogen sulfide. *Thermococcus* and *Archaeoglobus (Euryarchaeota)* oxidize organic compounds as an energy source; *Thermoproteus, Pyrodictium,* and *Pyrolobus* (*Crenarchaeota*) oxidize H_2 as an energy source.
Sulfur oxidizers *Sulfolobus*	Oxidize sulfur as a source of energy, using O_2 as a terminal electron acceptor to generate sulfuric acid. They grow only at a temperature above 50°C and at a pH between 1 and 6.
Thermophilic extreme acidophiles *Thermophilus, Picrophilus*	Grow only in extremely hot, acidic environments.

APPENDIX 2

Medically Important Chemoorganotrophs

Organism	Medical Significance
Gram-Negative Rods	
Bacteroides	Obligate anaerobes that commonly inhabit the mouth, intestinal tract, and genital tract. Causes abscesses and bloodstream infections.
Enterobacteriaceae	
Enterobacter species	Normal flora of the intestinal tract.
Escherichia coli	Normal flora of the intestinal tract. Some strains cause urinary tract infections; some strains cause specific types of intestinal disease. Causes meningitis in new borns.
Klebsiella pneumoniae	Normal flora of the intestinal tract. Causes pneumonia.
Proteus species	Normal flora of the intestinal tract. Causes urinary tract infections.
Salmonella enteritidis	Causes gastroenteritis. Grows in the intestinal tract of infected animals, acquired by consuming contaminated food.
Salmonella typhi	Causes typhoid fever. Grows in the intestinal tract of infected humans; transmitted in feces.
Shigella species	Causes dysentery. Grows in the intestinal tract of infected humans; transmitted in feces.
Yersinia pestis	Causes bubonic plague, which is transmitted by fleas, and pneumonic plague, which is transmitted in respiratory droplets of infected individuals.

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Organism	Medical Significance
Haemophilus influenzae	Causes ear infections, respiratory infections, and meningitis in children.
Haemophilus ducreyi	Causes chancroid, a sexually transmitted disease.
Legionella pneumophila	Causes legionnaires' disease, a lung infection. Grows within protozoa, acquired by inhaling contaminated water droplets.
Pseudomonas aeruginosa	Causes burns, urinary tract, and bloodstream infections. Ubiquitous in the environment. Grows in nutrient-poor aqueous solution and is resistant to many disinfectants and antimicrobial medications.
Gram-Negative Rods-Obligate Intracellular Parasites	
Chlamydia pneumoniae	Causes atypical pneumonia, or "walking pneumonia". Acquired from an infected person.
Chlamydia psittaci	Causes psittacosis, a form of pneumonia. Transmitted by birds.
Chlamydia trachomatis	Causes a sexually transmitted disease that mimics the symptoms of gonorrhea. Also causes trachoma, a serious eye infection, and conjunctivitis in newborns.
Coxiella burnetii	Causes Q fever. Acquired by inhaling organisms shed by infected animals.
Ehrlichia chaffeenis	Causes human ehrlichiosis. Transmitted by ticks
Orientia tsutsugamushi	Causes scrub typhus. Transmitted by mites.
Rickettsia prowazekii	Causes epidemic typhus. Transmitted by lice.
Rickettsia rickettsii	Causes rocky mountain spotted fever. Transmitted by ticks.
Gram-Negative Curved Rods	
Campylobacter jejuni	Causes gastroenteritis. Grows in the intestinal tract of infected animals, acquired by consuming contaminated food.
Helicobacter pylori	Causes stomach and duodenal ulcers. Neutralizes stomach acid by producing urease, resulting in the breakdown of urea to form ammonia.
Vibrio cholerae	Causes cholera, a severe diarrheal disease. Grows in the intestinal tract of infected humans; acquired by drinking contaminated water.
Vibrio parahaemolyticus	Cause gastroenteritis. Acquired by consuming contaminated seafood.

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Organism	Medical Significance
Gram-Negative Cocci	
Neisseria meningitidis	Causes meningitis.
Neisseria gonorrhoeae	Causes gonorrhea, a sexually transmitted disease.
Gram-Positive Rods	
Bacillus anthracis	Causes anthrax. Acquired by inhaling endospores in soil, animal hides, and wool. Bioterrorism agent.
Bifidobacterium species	Predominant member of the intestinal tract in breast-fed infants. Thought to play a protective role in the intestinal tract of infants by excluding pathogens.
Clostridium botulinum	Causes botulism. Disease results from ingesting toxin-contaminated food, typically canned foods that have been improperly processed.
Clostridium perfringens	Causes gas gangrene. Acquired when soil-borne endospores contaminate a wound.
Clostridium tetani	Causes tetanus. Acquired when soil-borne endospores are inoculated into deep tissue.
Corynebacterium diphtheriae	Toxin-producing strains cause diphtheria, a frequently fatal throat infection.
Gram-Positive Cocci	
Enterococcus species	Normal intestinal flora. Causes urinary tract infections.
Micrococcus species	Found on skin as well as in a variety of other environments; often contaminates bacteriological media.
Staphylococcus aureus	Leading cause of wound infections. Causes food poisoning and toxic shock syndrome.
Staphylococcus epidermidis	Normal flora of the skin.
Staphylococcus saprophyticus	Causes urinary tract infections
Streptococcus pneumoniae	Causes pneumonia and meningitis.
Streptococcus pyogenes	Causes pharyngitis (strep throat), rheumatic fever, wound infections, glomerulonephritis, and streptococcal toxic shock.
Acid-fast Rods	
Mycobacterium tuberculosis	Causes tuberculosis, typically a chronic respiratory infection.
Mycobacterium leprae	Causes Hansen's disease (leprosy); peripheral nerve invasion is characteristic.
Spirochetes	
Treponema pallidum	Causes syphilis, a sexually transmitted disease that can spread throughout the body. The organism has never been grown in culture.

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Organism	Medical Significance
Borrelia burgdorferi	Causes lyme disease, a tick-borne disease that initially causes a rash and then spreads throughout the body.
Borrelia recurrentis and B. hermsii	Causes relapsing fever. Transmitted by arthropods.
Leptospira interrogans	Causes leptospirosis, a waterborne disease that can spread throughout the body. Excreted in urine of infected animals.
Cell Wall-less	
Mycoplasma pneumoniae	Causes atypical peneumonia or walking pneumonia. Not susceptible to penicillin because it lacks a cell wall.

APPENDIX 3

Terms Used to Describe Microorganisms According to Their Metabolic Capabilities

Terms	Definition	Comments
Chemotroph	An organism that obtain energy by oxidizing chemicals, the same process provides reducing power for biosynthesis.	Aerobic respiration uses O_2 as a terminal electron acceptor, anaerobic respiration uses an inorganic compound other than O_2 as a terminal electron acceptor, and fermentation uses an organic compound such as pyruvate as a terminal electron acceptor.
Chemolithotroph	Inorganic chemicals such as H_2S are used as an energy source (*litho*-means "rock")	Generally, a chemolithotroph obtains carbon from CO_2 and is therefore a chemoautotroph, because of this, the terms chemolithotroph and chemoautotroph are often used interchangeably. Alternatively, and more correctly, the term chemolithoautotroph is used.
Chemoorganotroph	Organic compounds such as glucose are used as an energy source.	A chemoorganotroph obtains carbon from organic compounds and is therefore a chemoheterotroph; because of this, the terms chemoorganotroph and chemoheterotroph are often used interchangeably. The term chemoorganoheterotroph is rarely used, although it is technically more correct.

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Terms	Definition	Comments
Phototrophs	Organisms that harvest energy from sunlight, cells need a source of electrons to make reducing power for biosynthesis.	Anoxygenic phototrophs use reduced compounds such as H_2S as a source of electrons for reducing power. Oxygenic phototrophs use H_2O as a source of electrons for reducing power, generating O_2.
Photoautotroph	Energy is harvested from sunlight, carbon is obtained from CO_2	
Photoheterotroph	Energy is harvested from sunlight, carbon is obtained from organic compounds.	

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