11. Archaea – ecology; differences among archaea, eubacteria and eukaryotes

I. Archaea and their ecology

The **Archaea** (singular **archaeon**) constitute a domain or kingdom of single-celled microorganisms. These microbes are prokaryotes, meaning that they have no cell nucleus or any other membrane-bound organelles in their cells.

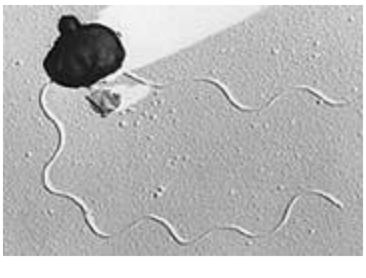
Archaea were initially classified as bacteria, receiving the name **archaebacteria** (in the Archaebacteria kingdom), but Archaeal cells have unique properties separating them from the other two domains of life, Bacteria and Eukaryota.

Then microbiologist Carl Woese devised an ingenious method of comparing genetic information showing that they could not rightly be called bacteria at all. Their genetic recipe is too different. So different Woese decided they deserved their own special branch on the great family tree of life, a branch he dubbed the Archaea.

Archaea and bacteria are generally similar in size and shape, although a few archaea have very strange shapes, such as the flat and square-shaped cells of *Haloquadratum walsbyi*. Archaea reproduce asexually by binary fission, fragmentation, or budding; unlike bacteria and eukaryotes, no known species forms spores.

Archaea were initially viewed as extremophiles living in harsh environments, such as hot springs and salt lakes, but they have since been found in a broad range of habitats, including soils, oceans, marshlands and the human colon, oral cavity, and skin. 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. Archaea are a major part of Earth's life and may play roles in both the carbon cycle and the nitrogen cycle. No clear examples of archaeal pathogens or parasites are known, but they are often mutualists or commensals. One example is the methanogens that inhabit human and ruminant guts, where their vast numbers aid digestion. Methanogens are used in biogas production and sewage treatment, and enzymes from extremophile archaea that can endure high temperatures and organic solvents are exploited in biotechnology.

There are three main types of archaea: the **crenarchaeota** (kren-are-key-oh-ta), which are characterized by their ability to tolerate *extremes in temperature and acidity*. The **euryarchaeota** (you-ree-are-key-oh-ta), which include *methane-producers and salt-lovers*; and **the korarchaeota** (core-are-key-oh-ta), a catch-all group for archaeans about which very little is known. Among these three main types of archaea are some subtypes, which include:



Methanogens (meth-an-oh-jins) — archaeans that produce methane gas as a waste product of their "digestion," or process of making energy.

Halophiles (hal-oh-files) — those archaeans that live in salty environments. Halophiles, including the genus *Halobacterium*, live in extremely saline environments such as salt lakes and outnumber their bacterial counterparts at salinities greater than 20–25%

Thermophiles (ther-mo-files) — the archaeans that live at extremely hot temperatures. Thermophiles grow best at temperatures above 45 °C (113 °F), in places such as hot springs; *hyperthermophilic* archaea grow optimally at temperatures greater than 80 °C (176 °F).[155] The archaeal *Methanopyrus kandleri* Strain 116 can even reproduce at 122 °C (252 °F), the highest recorded temperature of any organism

Psychrophiles (sigh-crow-files) — those that live at unusually cold temperatures. are extremophilic organisms that are capable of growth and reproduction in cold temperatures, ranging from −20 °C to +10 °C. Temperatures as low as −15 °C are found in pockets of very salty water (brine) surrounded by sea ice. Examples are *Arthrobacter* sp., *Psychrobacter* sp. and members of the genera *Halomonas*, *Pseudomonas*, *Hyphomonas*, and *Sphingomonas*. A

Acidophile and alkaliphile

Other archaea exist in very acidic or alkaline conditions. For example, one of the most extreme archaean acidophiles is *Picrophilus torridus*, which grows at pH 0, which is equivalent to thriving in 1.2 molar sulfuric acid.

Similarities with eubacteria

- Archaea have generally the same shape, size, and appearance as eubacteria.
- Like bacteria, Archaea multiply by binary fission and move primarily by means of flagella.
- These morphological similarities can make it difficult to visually tell a bacterium and an archaean apart.
- Additionally, archaea are more phylogenetically similar to eukarya than bacteria is to either of them

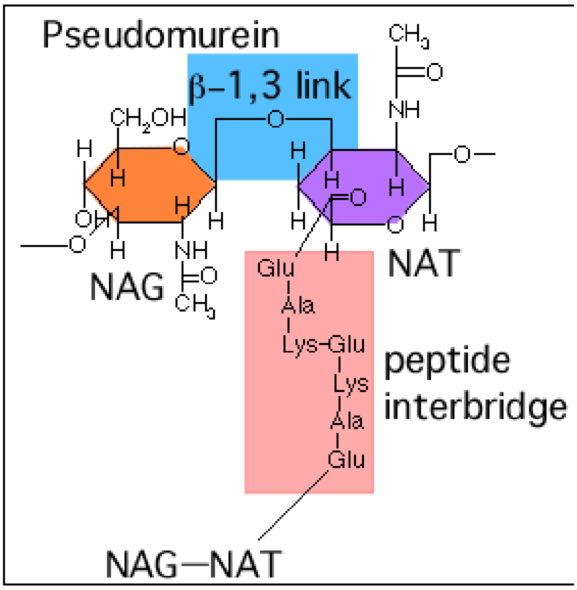
II. Archaea vs euacteria vs eukaryotes

	Archaea	Bacteria	Eukarya
	Methanosarcina	*E. coli*	*Amoeba*
Cell Type	Prokaryotic	Prokaryotic	Eukaryotic
Cell Wall	Varies in composition; contains no peptidoglycan	Contains peptidoglycan	Varies in composition; contains carbohydrates
Membrane Lipids	Composed of branched carbon chains attached to glycerol by ether linkage	Composed of straight carbon chains attached to glycerol by ester linkage	Composed of straight carbon chains attached to glycerol by ester linkage
First Amino Acid in Protein Synthesis	Methionine	Formylmethionine	Methionine
Antibiotic Sensitivity	No	Yes	No
rRNA Loop*	Lacking	Present	Lacking
Common Arm of tRNA†	Lacking	Present	Present

*Binds to ribosomal protein; found in all bacteria.
†A sequence of bases in tRNA found in all eukaryotes and bacteria: guanine-thymine-pseudouridine-cytosine-guanine.

Cell walls

Most Bacterial cell walls contain peptidoglycan, with N-acetyl muramic acid being the signature molecule for the presence of peptidoglycan. Archaea are considerably more diverse in the composition of their cell walls. They lack peptidoglycan, but some contain pseudomurein that has a similar structure as N-acetylalosaminuronic acid replaces N-acetylmuramic acid in the backbone of the molecule and each glycan unit is linked together using 1,3 glycosidic bonds, instead of the 1,4 glycosidic bonds seen in peptidoglycan. Many archaea do not contain a peptidoglycan molecule in any form, instead covering the outside of the membrane with proteins, glycoproteins or polysaccharides.



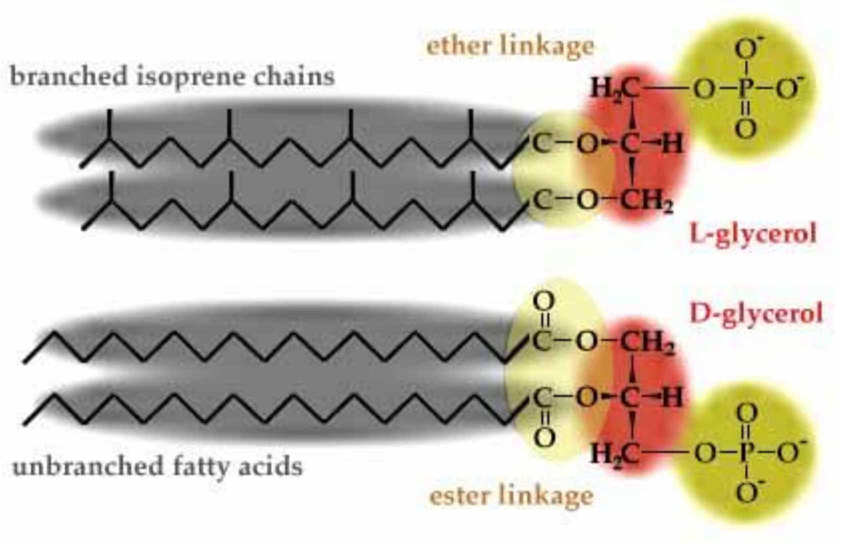
MEMBRANE LIPIDS

Archaeal membranes have features unlike those found in either eukaryotes or bacteria. In eukaryotes and bacteria the fatty acids are attached to the glycerol backbone by ester bonds, while in archaea ether linkages are used to link to their long chain alkyl groups. Also, the stereochemistry of lipids from archaea is primarily of the S form, while that of bacteria and eukaryotes is of the R form. In some archaea the hydrophobic chains attached to the glycerol backbone are twice normal length and pass completely through the membrane, attaching to a second backbone on the opposite side. This adds extra stability to the membrane and these dual lipids are often found in archaea living in extreme environments.

(1) Chirality of glycerol : The basic unit from which cell membranes are built is the **phospholipid**. This is a molecule of glycerol which has a phosphate added to one end, and two side chains attached at the other end. When the cell membrane is put together, the glycerol and phosphate end of the molecules hang out at the surface of the membrane, with the long side chains sandwiched in the middle. This layering creates an effective chemical barrier around the cell and helps maintain chemical equilibrium.

The glycerol used to make archaeal phospholipids is a **stereoisomer** of the glycerol used to build bacterial and eukaryotic membranes. Two molecules that are stereoisomers are mirror-images of each other. Put your hands out in front of you, palms up. Both hands are oriented with fingers pointing away from you, wrists toward you, and with palms upwards. However, your thumbs are pointing different directions because each hand is a mirror image of the other. If you turn one hand so that both thumbs point the same way, that one will no longer be palm-up.

This is the same situation as the stereoisomers of glycerol. There are two possible forms of the molecule that are mirror images of each other. It is not possible to turn one into the other simply by rotating it around. While bacteria and eukaryotes have **D-glycerol** in their membranes, archaeans have **L-glycerol** in theirs. This is more than a geometric difference. Chemical components of the cell have to be built by **enzymes**, and the "handedness" (**chirality**) of the molecule is determined by the shape of those enzymes. A cell that builds one form will not be able to build the other form.



(2) Ether linkage: When side chains are added to the glycerol, most organisms bind them together using an **ester linkage**. The side chain that is added has two oxygen atoms attached to one end. One of these oxygen atoms is used to form the link with the glycerol, and the other protrudes to the side when the bonding is done. By contrast, archaeal side chains are bound using an **ether linkage**, which lacks that additional protruding oxygen atom. This gives the resulting phospholipid different chemical properties from the membrane lipids of other organisms.

(3) Isoprenoid chains: The side chains in the phospholipids of bacteria and eukaryotes are **fatty acids**, chains of usually 16 to 18 carbon atoms. Archaea do not use fatty acids to build their membrane phospholipids. Instead, they have side chains of 20 carbon atoms built from **isoprene**. Isoprene is the simplest member of a class of chemicals called **terpenes**.

(4) Branching of side chains: Not only are the side chains of achaeal membranes built from different components, but the chains themselves have a different physical structure. Because isoprene is used to build the side chains, there are side branches off the main chain (see diagram above). The fatty acids of bacteria and eukaryotes do not have these side branches (the best they can manage is a slight bend in the middle), and this creates some interesting properties in archaeal membranes.

For example, the isoprene side chains can be joined together. This can mean that the two side chains of a single phospholipid can join together, or they can be joined to side chains of another phospholipid on the *other side* of the membrane. No other group of organisms can form such **transmembrane** phospholipids.

Another interesting property of the side branches is their ability to form **carbon rings**. This happens when one of the side branches curls around and bonds with another atom down the chain to make a ring of five carbon atoms. Such rings are thought to provide structural stability to the membrane, since they seem to be more common among species that live at high temperatures. They may work in the same way that **cholesterol** does in eukaryotic cells to stabilize membranes. It's interesting to note that cholesterol is another terpene!

Role in chemical cycling

Archaea recycle elements such as carbon, nitrogen and sulfur through their various habitats. Although these activities are vital for normal ecosystem function, archaea can also contribute to human-made changes, and even cause pollution.

Archaea carry out many **steps in the nitrogen cycle**. This includes both reactions that remove nitrogen from ecosystems (such as nitrate-based respiration and denitrification) as well as processes that introduce nitrogen (such as nitrate assimilation and nitrogen fixation). Researchers recently discovered **archaeal involvement in ammonia oxidation reactions**. These reactions are particularly important in the oceans. The archaea also appear crucial for ammonia oxidation in soils. They produce nitrite, which other microbes then oxidize to nitrate. Plants and other organisms consume the latter

In the sulfur cycle, archaea that grow by **oxidizing sulfur compounds** release this element from rocks, making it available to other organisms. However, the archaea that do this, such as *Sulfolobus*, produce **sulfuric acid as a waste produc**t, and the growth of these organisms in abandoned mines can contribute to **acid mine drainage and**

other environmental damage.

In the carbon cycle, **methanogen archaea remove hydrogen and play an important role in the decay of organic matte**r by the populations of microorganisms that act as decomposers in anaerobic ecosystems, such as sediments, marshes and sewage-treatment works.

Methanogens are the primary source of atmospheric methane, and are responsible for most of the world's methane emissions. As a consequence, these archaea contribute to global greenhouse gas emissions and global warming.

Global methane levels in 2011 had increased by a factor of 2.5 since pre-industrial times: from 722 ppb to 1800 ppb, the highest value in at least 800,000 years. Methane has an anthropogenic global warming potential (AGWP) of 29, which means that it's 29 times stronger in heat-trapping than carbon dioxide is, over a 100-year time scale

12. Systematic bacteriology - Bergey's manual of systematic bacteriology – outline only

Bergey's manual is the international standard for bacterial taxonomy. it is the main resource for determining the identity of prokaryotic organisms, emphasizing bacterial species, using every characterizing aspect. "*Systematic Bacteriology*" came in a new contract in 1980, whereupon the new style included "relationships between organisms" and had "expanded scope" overall. Many taxonomists define systematics as " The scientific studies of organisms with the ultimate object of characterizing and arranging them in an orderly manner." Thus it ecompasses disciplines such as 'morphology', 'ecology', 'epidemiology', 'biochemistry', 'molecular biology' and 'physiology'.

Bergey's Maual

- David .H.Bergey, published a first edition of **Bergey's manual of determinative bacteriology** from the Society of American Bacteriologists in 1923.
- Second edition was published in 1925, third edition in 1930 and subsequently five editions appeared.
- In 1974, 8th edition was published with international contributions.
- In,1984 major change occurred and the manual was prepared with information dealing with ecology, enrichment, isolation, preservation, characteristics of bacteria concerned with classification and identification.
- Then the manual came with rename as **Bergey's manual of systematic bacteriology.**
- This manual was published as four volumes.

1. Gracilicutes

Procaryotes with thin cell walls, implying a gram-negative type cell wall

2. Firmicutes

Procaryotes with thick and strong skin, indicating a gram-positive type cell wall

3. Tenericutes

Procaryotes of a pliable and soft nature, indicating the lack of a rigid cell wall

4. Mendosicutes

Procaryotes that lack conventional peptidoglycan (archaeobacteria)

The current volumes differ drastically from previous volumes in that many higher taxa are not defined in terms of phenotype, but solely on 16S phylogeny, as is the case of the classes within Proteobacteria.

The current grouping is:

Volume 1 (2001)
The Archaea and the deeply brancing and phototrophic Bacteria

Volume 2 (2005)
The Proteobacteria (in three parts)

Volume 3 (2006)
The low G + C Gram-positive Bacteria

Volume 4 (2007)
The high G + C Gram-positive Bacteria

Volume 5 (2007)
The Planctomycetes, Spriochaetes, Fibrobacteres, Bacteriodetes and Fusobacteria

Vol 1. Archaea, cyanobacteria, phototrophs and deeply branched genera

This volume has 3 important groups out of which, one is in different domain (Domain – archaea).

Archaea - divided into two kingdoms

a. *Crenarchaeota* - diverse kingdom that contains thermophilic and hyperthermophilic

. Hyperthermophiles - Ex. *Thermococcus, Sulfolobus, Thermosphaera*

. Thermoplasma - Ex. *Thermoplasma*

b. *Euryarchaeota* - contains primarily mathanogenic and halophilic bacteria and also

Methanogens - Ex. *Methanobacterium, Methanococcus, Methanosarcina*

Halobacteria - Ex. *Halobacterium, Halococcus, Natronomonas*

Eubacteria - complex with several small groups of phototrophs, cyanobacteria, and deeply branching eubacteria

Based on Bergeys' manual Domain Bacteria contains six phyla in volume 1

- • Phylum *Aquificiae*- earliest branch of bacteria that contain autotrophs which utilize hydrogen for energy production

  • Phylum *Thermotogae* - anaerobic, thermophilic, and fermentative Gram negative bacteria

  • Phylum “ *Deinococcus Thermus* ” - radiation resistant bacteria

• Phylum *Chloroflexi* - green non-sulfur bacteria that carries out anoxygenic photosynthesis

• Phylum *Cyanobacteria* – filamentous, oxygenic photosynthetic bacteria. They have special cells called heterocyst in which nitrogenase enzyme is present. The nitrogenase enzyme is responsible for fixing atmospheric N_2 into ammonia.
Cyanbobacteria exist in three forms,

- Single celled - *Chrococcus, Gleotheca, Gleocapsa*
- Filamentous non-heterocystous - *Oscillatoria, Lyngbya*
- Filamentous heterocystous - *Anabaena, Nostoc, Tolypothrix*

• Phylum *Chlorobi* - green sulfur bacteria that carry out anoxygenic photosynthesis

Vol 2. Proteobacteria

The **Proteobacteria** are a major group (phylum) of gram-negative bacteria. They include a wide variety of pathogens, such as *Escherichia*, *Salmonella*, *Vibrio*, *Helicobacter*, and *Yersinia*, and many other notable genera. Others are free-living (nonparasitic), and include many of the bacteria responsible for nitrogen fixation.

Because of the great diversity of forms found in this group, the Proteobacteria are named after Proteus, a Greek god of the sea capable of assuming many different shapes; it is not named after the genus *Proteus*.

α Alphaproteobacteria: grow at very low levels of nutrients and have unusual morphology such as stalks and buds. They include agriculturally important bacteria capable of inducing nitrogen fixation in symbiosis with plants. An example of alphaproteobacteria is *Wolbachia* which is the most common infectious bacterial genus in the world that lives only inside the cells of their hosts, usually insects.

β Betaproteobacteria often use nutrient substances that diffuse away from areas of anaerobic decomposition of organic matter (hydrogen gas, ammonia, methane) and includes chemoautotrophs. An example of betaproteobacteria is *Bordetella pertussis* which causes pertussis, or whooping cough.

γ Gammaproteobacteria are the largest subgroup which include *Acinetobacter*, *Pseudomonas*, *Escherichia coli*, *Salmonella*, and *Serratia marcescens*.

δ Deltaproteobacteria include bacteria that are predators on other bacteria and are important contributors to the sulfur cycle. An example is *Desulfovibrio* which is found in anaerobic sediments and in the intestinal tracts of humans and animals.

ε Epsilonproteobacteria are slender gram-negative rods that are helical or curved. They are also motile by flagella and are microaerophilic. An example is *Helicobacter* which has been identified as the most common cause of peptic ulcers in humans and a cause of stomach cancer.

S.No.	Important Bacteria	Characters	Example
α Proteobacteria			
1.	Purple bacteria	Anoxygenic Photosynthetic – sulphur bacteria	*Rhodospirillum, Rhodobacter, Chromatium*
2.	Associative Nitrogen fixing bacteria	These bacteria present in the rhizosphere of graminaceous plants and symbiotically fix atmospheric nitrogen.	*Azospirillum*
3.	Symbiotic Nitrogen fixing bacteria	Form nodules in legume roots and fix atmospheric nitrogen.	*Rhizobium, Bradyrhizobium,*
		Some form galls in the roots	*Agrobacterium*
4.	Free living Nitrogen fixing bacteria	Present in the soil as heterotrophs – use verity of carbon sources in soil and fix atmospheric nitrogen	*Azotobacter, Beijerinkia*
5.	Pseudomonas group	Some are Plant Growth Promoting Rhizobacteria	*Pseudomonas*
		Some are pathogens	*Xanthomonas*
		Some produce alcohol	*Zymomonas*
6.	Rickettsia	Endoparasites	*Rickettsia*
7.	Sulphur oxidizing bacteria	Uses S as electron donor – Chemolithotrophs – Strict aerobes	*Thiobacillus*
8.	Acetic acid producing bacteria	Fermentative bacteria	*Acetobacter, Gluconobacter*
9.	Budding bacteria	Reproduction by budding like yeast	*Caulobacter*
10.	Hydrogen bacteria	Hydrogen producing bacteria	*Alkaligenes*
βProteobacteria			
1.	Nitrifying bacteria	Chemolithotroph – strict aerobe – soil bacteria – important	*Ammonia to nitrite – Nitrosomonas* *Nitrite to nitrate –*

		form N cycle	*Nitrobacter*
2.	Neisseria & relatives		Neisseria
3.	Spirillum	Aerobes & facultative aerobes	*Spirillum sp.*
4.	Sheathed bacteria		*Sphaerotilus*
γProteobacteria			
1.	Purple sulphur bacteria	Anoxygenic photosynthetic – sulphur bacteria	*Thiobacillus, Thiospirillum*
2.	Methylotrophs	Uses methane and methanol as carbon source	*Methylomonas, Methylobacter, methylococcus*
3.	Coliforms	Present in the intestinal track of mammals	*Escherichia, Salmonella*
δProteobacteria			
1.	Sulphur reducing bacteria	Anaerobes – use S as terminal electron acceptor	*Desulfovibrio, Desulfomonas*
2.	Glding bacteria	Gliding movement	*Myxobacteria*
3.	Vibrio group	Most are pathogenic	*Vibrio, Erwinia*

Vol 3. Low G+C gram positives

This is an ecologically and industrially important group of microorganisms. The group name refers to a phylum of Bacteria, also known as the Firmicutes, which share a common evolutionary history. Many have certain distinct cellular characteristics. Gram-positive organisms stain purple with a differential staining procedure developed in 1884 by Christian Gram. This procedure identifies cells that have a thick cell wall of peptidoglycan. While many Firmicutes stain Gram-positive, some do not. In fact, some Firmicutes have no cell wall at all! They are called "low G+C" because their DNA typically has fewer G and C DNA bases than A and T bases as compared to other bacteria. Exceptions have been identified and some Firmicutes have G+C content as high as 55% (*Geobacillus thermocatenulatus*). Certain Firmicutes make resistant progeny called endospores, while others can only reproduce through binary fission. It is evident that Firmicutes are as diverse as they are important.

S.No	Group	Characters	Example
1.	Clostridia group	Strict anaerobes – mostly fermentative nutrition – few	*Clostridium, Thermoanaerobacteriu, Thermoanaerobium*

		thermotolerant – endospore producers	
2.	Mycoplasma group	Absence of cell wall	*Mycoplasma, Mesoplasma, Spiroplasma*
3.	Bacilli and Lactobacilli group	Lactic acid producing bacteria – endospore producers – aerobes – aerotolerant – fermentative nutrition	*Leuconostoc, Lactococcus, Streptococcus*

Vol 4. High G+C gram positives

This group includes the member with diverse morphological assemblage having pathogenic and economical important member. The important character giving bellow:

1. Morphology they are of various types ranging from cocci, rods with rudimentary branching to elaborate mycelia forms.
2. They are of gram-positive types.
3. G+C content of DNA is moles % or more, designated as high G+C group.

The phylum includes both useful and harmful bacteria.

Useful member:

1. Many species of Streptomyces are useful in the commercial production of antibiotic.
2. *Propiniobacterium* and *Brevibacterium* are useful in diary industry.
3. *Frankia spp.*are able to infect many non-leguminous plants like Casuarina, Myrica, Alnus, Coriaria, and produce nitrogen-fixing root nodules.

Harmful bacteria:

1. *Mycobacterium leprae* causes leprosy.
2. *Corynebacterium diphtheria* causes diphtheria in humans.
3. *Actinomyces israelii* causes abscesses of connective tissue in man.

S.No	Group	Characters	Example
1.	Actinomycetes	Filamentous – sporangiospores – conidiospores – soil habitat – antibiotics	*Actinomyces, Nocardia, Sreptomyces*

		producers	
		Symbiotic with *Casuarina* – form root nodules – N2 fixation	*Frankia*
2.	Mycobacterium	Presence of mycolic acid in the cell wall – acid fast staining – human pathogens	*Mycobacterium lepri*
3.	Corynebacterium	Human pathogens	*Corynebacterium diptheriaea*

Vol 5. Plancomycetes, Spirochetes, Bacteroides and Fusobacteria

S. No	Group	Characters	Example
1.	Chlamydia group	Obligate parasites to man, animal and birds	*Chlamydia*
2.	Bacteroides	Obligate anaerobes	*Bacteroides*
3.	Spirochete	Gram negative – flexile – endoflagella presence	*Spirocheta, Leptospira*