# CHAPTER II: VARIOUS BACTERIAL and ARCHAEAL GROUPS

## 1. Introduction

Bacteria and archaea are two major groups of microorganisms that, despite their similarities as single-celled organisms, exhibit striking differences in terms of morphology**,** physiology, and ecology. These differences shape how they survive, interact with their environments, and contribute to the broader ecological systems they inhabit.

The classification presented in 9th eds. of *Bergey's Manual of Determinative Bacteriology* (1994) is different from the classification system presented in *Bergey's Manual of Systematic Bacteriology*. In *Bergey's Manual of Determinative Bacteriology* edition, bacteria have been characterized into 35 groups under above 4 major categories (**Fig. 01**):

- **Category 01:** include group 1 to 16 (Gram-negative bacteria: ex. Spirochaetes, sulphate and sulphur reducing bacteria, Rickethesias and Chlamydias);
- **Category 02:** include group 17 to 29 (ex. Gram positive cocci, endospore forming gram positive rods and cocci, non sporing gram-positive rods);
- **Category 03:** include the group 30 (*Mycoplasma*);
- **Category 04:** include group 31 to 35 (Ex. Methanogens, Archaeal sulphate reducers, extremely halophiles, cell wall less Archaebacteria).

The most recent revision of *Bergery's Manual of Systematic Bacteriology* divides bacteria into four division (or phyla) according to the <u>characteristics of cell wall</u>, which division is subdivided into sections based on: gram stain reactions, cell shape, cell arrangements, oxygen requirement, motility and nutritional and metabolic properties. Each section consists of a number of genera. In some sections, genera are grouped into families and orders in other sections, they are not. This edition has four volumes:

- **Volume 01:** include Gram negative bacteria (section 1-11) (1984)
- **Volume 02:** include Gram positive bacteria, phototrophic and other specialized bacteria including gliding bacteria (section 12-17) (1986)

- **Volume 03:** include bacteria with unusual cell wall like Archaea-bacteria (section 18-25) (1989)
- **Volume 04:** include Actinomycetes and other filamentous bacteria (section 26 - 33) (1991).

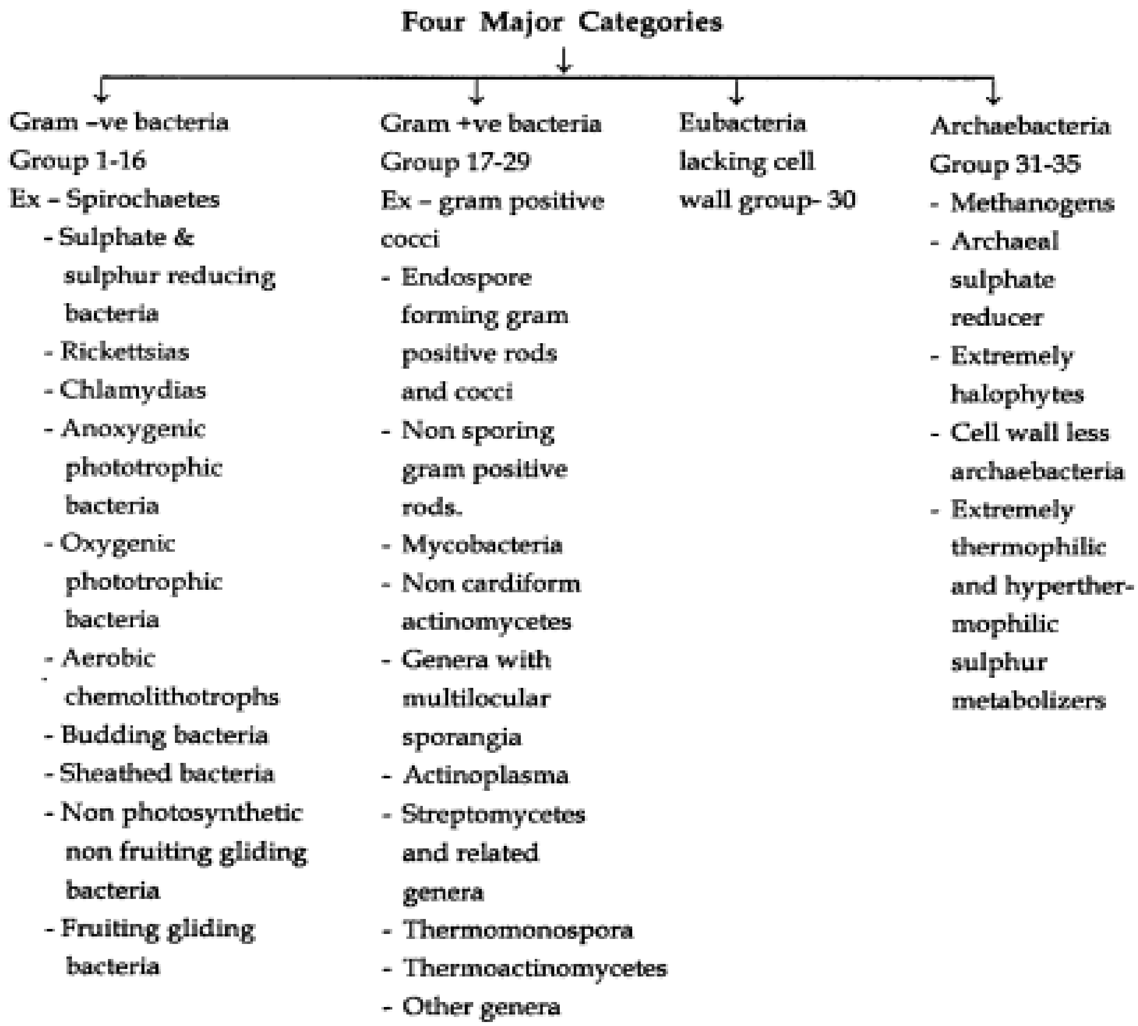


**Figure 01:** Four major categories of *Bacteria* and *Archaea*

After the details of above, the kingdom Prokaryotae, on the basic of presence or absence of cell wall, is divided on four divisions: (1) the ***Gracilicutes*** (gram -ve cell wall), (2) the ***Firmicutes*** (gram + ve cell wall other than actinomycetes), (3) the ***Tenericutes*** (bacteria lacking cell wall) and (4) the ***Mendoricutes*** (bacteria lacking peptidoglycan in their cell wall like Archaebacteria). On the other hand, prokaryotes can be organized on different groups focusing on physiology, morphology, and ecology. We'll categorize them into their respective groups, including key traits and their roles in various environments.

## 2. Bacterial groups

### 2.1. Firmicutes

Firmicutes are a vast and diverse group of Gram-positive bacteria, known for their thick peptidoglycan cell walls that give them their characteristic purple color under a Gram stain. This thick layer of peptidoglycan provides structural rigidity and protection. Firmicutes come in a range of shapes, primarily as cocci (spherical) or bacilli (rod-shaped), but some species may also form filamentous structures. A key feature of many Firmicutes is their ability to form endospores, a dormant and highly resistant form that can survive in extreme conditions like high heat, radiation, and dryness (eg. *Bacillus* and *Clostridium*).

Physiologically, many species are aerobic (requiring oxygen), but there are also anaerobic. A number of them, such as *Lactobacillus* and *Streptococcus* (lactic acid bacteria), are fermentative bacteria, converting sugars into lactic acid. On the other hand, some Firmicutes species can used aerobic respiration or anaerobic respiration.

Ecologically, Firmicutes are found in an array of environments, from soil and water to the gastrointestinal tracts of animals, including humans. In the human microbiome, they are integral to digestion, helping to break down complex carbohydrates and fermenting fiber and starches to produce short-chain fatty acids like butyrate. In the environment, Firmicutes play a critical role in decomposing organic matter, recycling nutrients, and contributing to biogeochemical cycles, particularly in the breakdown of plant material. Some species of Firmicutes, like *Bacillus,* also have significant applications in bioremediation, where they help break down pollutants like oil, pesticides, and other toxic chemicals in the environment.

However, some Firmicutes are **pathogenic** and cause diseases. For example, *Clostridium botulinum* (botulism), *Clostridium tetani* (tetanus), *Streptococcus pyogenes* (strep throat, necrotizing fasciitis), *Bacillus anthracis* (anthrax). These harmful species produce **toxins** that can disrupt cellular function and lead to severe health conditions.

### 2.2. Gracilicutes

Gracilicutes, a group of Gram-negative bacteria, possess a distinctive cell structure, where the thin peptidoglycan layer is surrounded by an outer membrane rich in lipopolysaccharides, which contributes to their resistance to certain antibiotics. These bacteria can take various forms, including rod-shaped, spherical (cocci), or spiral (spirilla), and are often motile, using flagella that can be arranged in different configurations, either at one or both ends (polar) or distributed across the surface (peritrichous). Some also produce pili or fimbriae, which help them adhere to surfaces, enhancing their ability to colonize hosts or environments.

The physiological versatility of Gracilicutes allows them to thrive in diverse environments. Many are facultative anaerobes, meaning they can switch between aerobic and anaerobic metabolism, allowing them to adapt to fluctuating oxygen levels. Their ability to ferment or undergo aerobic/anaerobic respiration enables them to metabolize a wide range of substrates, including organic compounds and some inorganic compounds like nitrogen and sulfur.

Ecologically, Gracilicutes occupy a vast array of niches. They can be found in soil, water, sediments, and within animal and plant tissues. Many are integral to nutrient cycling, particularly in decomposing organic matter and recycling nitrogen. For example, species like *Pseudomonas* are known for their role in bioremediation, breaking down pollutants like oil, pesticides, and heavy metals, which aids in environmental cleanup efforts. Some Gracilicutes, such as *Rhizobium*, form symbiotic relationships with plants, especially legumes, where they fix nitrogen in the soil, enriching it with essential nutrients.

On the other hand, several Gracilicutes are **pathogenic**, causing diseases in humans, animals, and plants. Notably, species like *Escherichia coli*, *Salmonella*, *Pseudomonas aeruginosa*, and *Vibrio cholerae* are significant pathogens known for causing gastrointestinal, respiratory, and systemic infections.

### 2.3. Tenericutes

Tenericutes are a distinctive group of bacteria characterized by their unique physiological, morphological, and ecological traits. Morphologically, the defining feature of Tenericutes is the **absence of a cell wall**, which gives them flexibility in shape. These bacteria are **pleomorphic**, meaning they can take on various forms, including spherical, filamentous, or even spiral shapes. This flexibility allows them to adapt to different environments, especially within host organisms. Their small size, often ranging from 0.1 to 0.5 µm, further distinguishes them as some of the smallest free-living bacteria. The lack of a rigid structure is compensated by specialized membrane lipids and sterols, which help maintain cell membrane stability. Some species, such as *Spiroplasma*, adopt a helical shape that allows them to move through viscous fluids, while others glide across surfaces without flagella.

Physiologically, Tenericutes are primarily obligate parasites or symbionts, meaning they rely heavily on host organisms for survival. These bacteria have **reduced metabolic pathways**, rendering them incapable of synthesizing essential nutrients like amino acids, vitamins, and nucleotides, which they obtain directly from their hosts. Due to the absence of a cell wall, Tenericutes are naturally resistant to antibiotics that target cell wall synthesis, such as **penicillin** and **cephalosporins**. They can metabolize a variety of organic compounds, such as urea in the urinary tract, and are often aerobic or facultative anaerobes, capable of adjusting their metabolism to different oxygen conditions.

Ecologically, Tenericutes are often found in highly specialized habitats. Many species are **obligate intracellular parasites**, living in the tissues or cells of their host organisms. They inhabit areas like the respiratory, urogenital, and gastrointestinal tracts of animals and humans, where they can thrive on mucosal surfaces. Some species, like *Mycoplasma*, are responsible for causing diseases such as pneumonia and urinary tract infections in humans and animals. In addition to parasitic relationships, some Tenericutes species have **mutualistic** relationships with their hosts (e.g. *Spiroplasma* and insects like leafhoppers**)**. They are also capable of surviving in extreme conditions, such as high salinity or acidity, and can be found in environments ranging from soil and water to plant tissues.

Tenericutes' **virulence factors** are key to their survival and pathogenicity. They can adhere tightly to host tissues using surface proteins known as **adhesins**, which are critical for colonization and infection. Some species also produce **toxins** as *Mycoplasma pneumoniae* that produces hydrogen peroxide.

### 2.4. *Actinobacteria*

*Actinobacteria* are a diverse and ecologically significant group of Gram-positive bacteria characterized by their high G+C content in DNA, typically ranging from 50% to 75%. These bacteria exhibit a broad metabolic range, thriving in various environments as aerobes or facultative anaerobes, and are often involved in the decomposition of complex organic compounds like cellulose and lignin. Morphologically, they can be rod-shaped, coccoid, or filamentous, with some species, such as *Streptomyces*, forming branching hyphal structures resembling fungal mycelium, and producing spores (conidia) for dispersal. Some genera, like *Mycobacterium*, possess mycolic acids in their cell walls, making them acid-fast.

Ecologically, *Actinobacteria* play key roles in soil, where they break down organic matter, cycle nutrients, and even form symbiotic relationships with plants, such as nitrogen fixation in *Frankia*. While many are beneficial, some species are **pathogenic**, such as *Mycobacterium tuberculosis*, which causes tuberculosis. Additionally, *Actinobacteria* are renowned for their ability to **produce antibiotics**, contributing significantly to pharmaceutical industries. Their adaptability to extreme conditions, including high salinity, temperature, and oxygen scarcity, highlights their ecological resilience and importance in diverse habitats.

### 2.5. *Cyanobacteria*

*Cyanobacteria*, also known as blue-green algae, are a diverse group of photosynthetic bacteria that play essential roles in various ecosystems. These bacteria are primarily **photoautotrophic**, utilizing light energy to produce glucose and releasing oxygen as a byproduct through oxygenic photosynthesis, similar to plants. They contain **chlorophyll a**, along with other pigments like **phycocyanin** and **phycoerythrin**, which contribute to their blue-green color and help them capture light. Many *Cyanobacteria* also possess the ability to fix atmospheric nitrogen into ammonia, a process carried out by specialized cells called **heterocysts**, making them crucial contributors to nitrogen cycling in ecosystems. *Cyanobacteria* exhibit a wide range of morphologies, from unicellular forms to multicellular filaments, some of which form large colonies or mats. They may also produce **gas vesicles** that help them regulate buoyancy in aquatic environments. Additionally, they often secrete mucilaginous sheaths around their cells, providing protection from environmental stress.

Ecologically, they are found in diverse environments, including nutrient-poor waters, hot springs, and deserts, demonstrating their resilience to extreme conditions. They play a vital ecological role as primary producers, converting solar energy into chemical energy, and are key players in the nitrogen cycle. Their ability to fix nitrogen enriches both aquatic and terrestrial ecosystems. However, in nutrient-rich environments, *Cyanobacteria* can form harmful algal blooms that produce toxins, posing risks to water quality and human health. Despite this, their contributions to symbiotic relationships with plants and corals, as well as their ability to survive in extreme habitats, highlight their ecological importance.

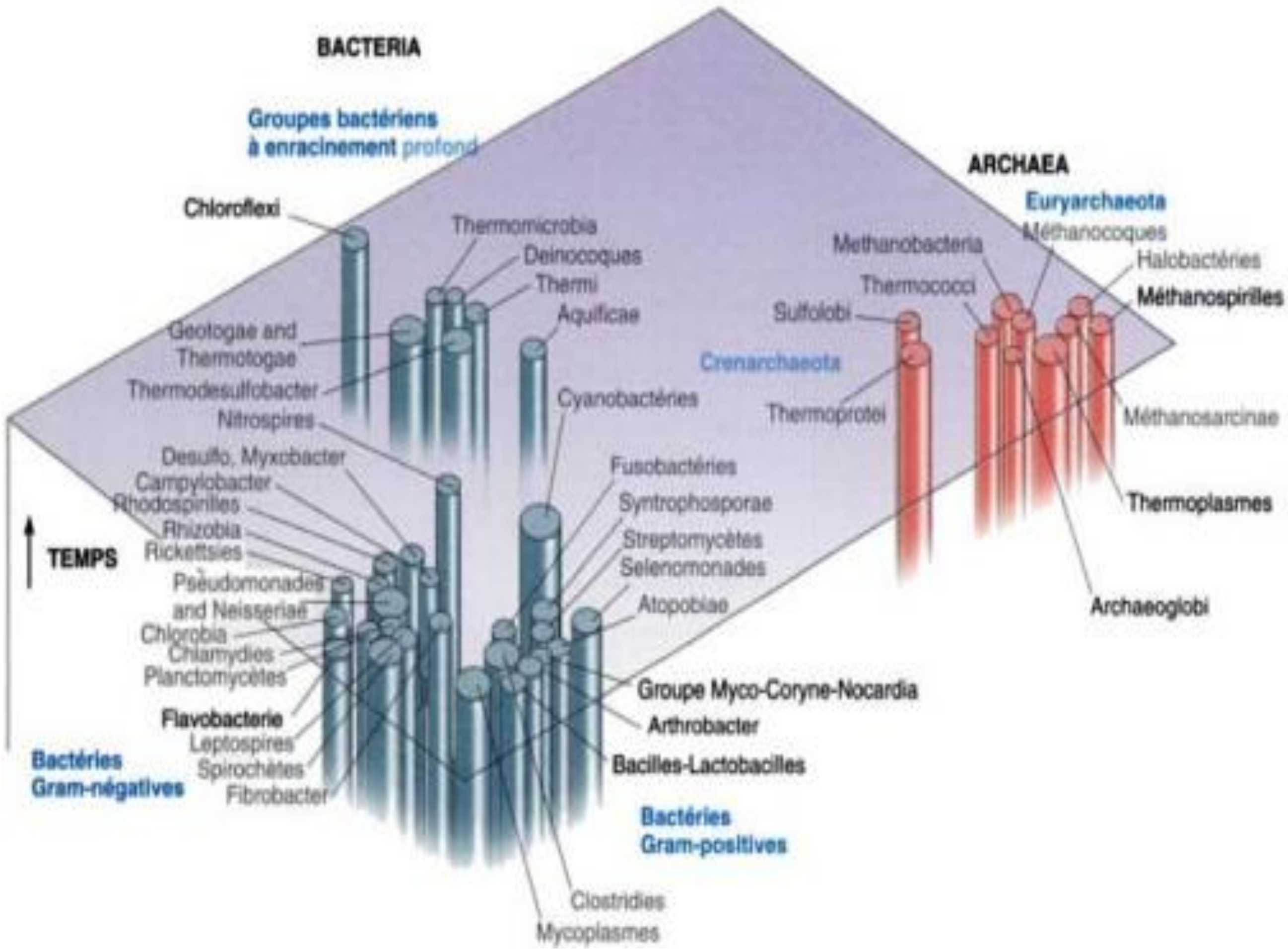


**Figure 02:** Main groups of prokaryotes and their relationships.

(The size of the disks is approximately proportional to the number of sequenced prokaryotes in the group. The prokaryote groups are tightly clustered. Note that the two prokaryote domains (*Bacteria* and *Archaea*) are clearly separate. The cylinders are superimposed to show that the antiquity of these groups is uncertain).

## 3. Archaeal groups

Archaeal groups exhibit distinct morphological, physiological, and ecological characteristics that allow them to thrive in various environments.

### 3.1. *Crenarchaeota*

*Crenarchaeota* are primarily **thermophiles** and **acidophiles**, with a variety of shapes such as cocci and rods. These *Archaea* possess unique cell walls made of pseudopeptidoglycan, which help them withstand extreme conditions. They are often found in extreme environments like hot springs, geysers, and deep-sea hydrothermal vents**.** Many species in this group are **chemolithotrophic**, using inorganic compounds like sulfur, iron, and hydrogen for energy. They play important roles in sulfur cycling and thrive in environments with high temperatures and low pH.

### 3.2. *Euryarchaeota*

The *Euryarchaeota* group is highly diverse, including **methanogens**, **halophiles**, and **thermophiles**. Methanogens produce methane as a metabolic byproduct in anaerobic environments such as swamps, marshes, and the digestive tracts of animals like ruminants. Halophiles thrive in saline environments such as salt lakes, salt mines, and brines, while some thermophiles are found in hot springs and other high-temperature habitats. *Euryarchaeota* are involved in carbon cycling, particularly through methane production, and play roles in salt cycling in hypersaline ecosystems.

### 3.3. *Korarchaeota*

*Korarchaeota* are considered primitive *Archaea* and are primarily **thermophilic**. They have been found in hot springs but are not well studied in terms of their exact metabolic pathways. Their morphology includes irregular shapes, and they have typical archaeal cell walls and ether-linked lipids in their membranes. Although they are not as well understood, *Korarchaeota* may represent an early branch of the archaeal tree and offer insights into the evolutionary history of *Archaea*.

### 3.4. *Nanoarchaeota*

*Nanoarchaeota* are ultra-small, often less than 1 µm in size. These *Archaea* are **obligate symbionts**, meaning they depend on other organisms, typically *Archaea*, for survival. They have highly reduced genomes, relying on their host for many essential functions. *Nanoarchaeota* are primarily found in hydrothermal vent ecosystems, and their small size and obligate symbiotic lifestyle make them unique among *Archaea*.

### 3.5. *Thaumarchaeota*

*Thaumarchaeota* are known for their ability to **oxidize ammonia**, a critical process in the **nitrogen cycle**. They are generally **aerobic** and are found in marine and soil environments, where they play an essential role in ammonia oxidation, converting ammonia to nitrite. This process is vital for maintaining nitrogen balance in ecosystems. *Thaumarchaeota* also contribute to **carbon fixation** and nitrogen cycling, making them crucial for the stability of marine and terrestrial ecosystems.