Bacterial Systematics

1. Systematics

Systematics is the science that studies the diversity of living organisms and their evolutionary relationships. It aims to organize living beings into hierarchical groups based on their characteristics and evolutionary history.

In bacteriology, systematics relies on several criteria:

- **Phenotypic**: morphology, physiology, metabolism.
- **Genetic**: 16S rRNA analysis, genome sequencing.
- **Ecological**: habitat, role in the environment.

Systematics includes three main areas:

1. **Taxonomy (or classification)**: grouping bacteria into taxa.
2. **Nomenclature**: assigning scientific names.
3. **Identification**: recognizing and characterizing bacteria.

2. Taxonomy (or Classification)

Taxonomy, also called **classification**, is the branch of systematics that groups organisms into categories called **taxa** based on their common characteristics.

2.1 Objectives of Taxonomy

- Describe organisms and their characteristics.
- Group them into hierarchical categories.
- Establish evolutionary relationships among them.

2.2 Taxonomic Levels and Taxon Endings

Bacterial classification follows a precise hierarchy:

Taxonomic Rank	Example	Suffix Used
Domain	*Bacteria*	-
Phylum	*Proteobacteria*	-bacteria / -mycetes
Class	*Gammaproteobacteria*	**-ia**
Order	*Enterobacterales*	**-ales**
Family	*Enterobacteriaceae*	**-aceae**
Genus	*Escherichia*	**-us, -a, -er**
Species	*Escherichia coli*	No specific suffix

In practice, the **genus and species** are often sufficient to name a bacterium.

2.3 Concept of Bacterial Species and Strain

Bacterial Species

The **species** is the fundamental unit of classification. It groups bacteria that share common characteristics and may inhabit the same environment.

In bacteriology, a species is defined by several criteria:

- **Genotypic**: ≥ (greater than or equal) 97% similarity in the 16S rRNA gene.
- **Phenotypic**: morphological and biochemical characteristics.
- **Ecological**: common habitat.

Subdivisions of a Species

- **Variant (biovar, serovar, morphovar)**: biochemical or antigenic differences.
- **Bacterial Type**: groups defined by specific antigens.

Bacterial Strain

A **strain** is a pure culture of bacteria derived from a single isolate. Each strain may present variations within a species.

The strain is generally designated by the name of the author responsible for its isolation (e.g., *Corynebacterium diphtheriae* strain Park-William), by the laboratory where it was isolated, or by a numerical designation (e.g., *Lactobacillus casei* 8000 ATCC/American Type Culture Collection).

Other examples:

- *Escherichia coli* O157:H7 (a pathogenic strain).
- *Bacillus subtilis* 168 (a model strain used in research).

3. Nomenclature

Nomenclature is the set of rules that define bacterial names. It is governed by the **International Code of Nomenclature of Bacteria (ICNB)**.

3.1 Bacterial Nomenclature Rules

- **Bacterial names are in Latin**.
- **The genus is italicized with a capital letter** (e.g., *Escherichia*).
- **The species is italicized and written in lowercase** (e.g., *Escherichia coli*).
- **The strain can be specified** (e.g., *E. coli* O157:H7).
- **Names must be validated** by the International Committee on Systematics of Prokaryotes (ICSP).

3.2 Examples of Bacterial Nomenclature

- *Staphylococcus aureus* (a human pathogenic bacterium).
- *Lactobacillus bulgaricus* (a bacterium used in dairy products).
- *Clostridium botulinum* (producer of botulinum toxin).

4. Identification

Identification involves assigning an unknown bacterial strain to a described taxon. It is essential in clinical, food, and environmental microbiology.

4.1 Identification Methods

- **Morphology and staining** (microscopy, Gram staining).
- **Biochemical tests** (fermentation, catalase, oxidase, API tests).
- **Immunological methods** (ELISA, serotyping).
- **Molecular methods** (PCR, 16S rRNA sequencing, MALDI-TOF mass spectrometry).

4.2 Examples of Identification

- **Selective media isolation**: MacConkey agar for *E. coli*, Chapman agar for *Staphylococcus aureus*.
- **Catalase test**: positive for *Staphylococcus*, negative for *Streptococcus*.
- **16S rRNA PCR**: precise bacterial strain identification.

Bacterial Classification

Why classify bacteria?

- To organize and name bacteria for easier identification.
- To understand their evolutionary relationships and diversity.
- To aid research in medicine, biotechnology, and microbial ecology.

Criteria for Bacterial Classification

1. Morphological Characteristics

- Microscopic observation of bacterial shape and structure.
- Genetically determined and stable over time.

2. Metabolic Characteristics

- Study of enzymes and metabolic pathways:
    - Energy sources (phototrophs, chemotrophs, etc.).
    - Relationship with oxygen (aerobic, anaerobic).
    - Specific nutritional requirements.

3. Genomic Characteristics

- Analysis of **DNA and RNA sequences**.
- **DNA/DNA hybridization tests** and study of associated proteins.
- Identification based on **molecular evolutionary relationships**.

Types of classification

Two main types of classification:

1. **Artificial classification**: Based on observable characteristics (morphology, metabolism, etc.).
2. **Natural (phylogenetic) classification**: Based on evolution and genetic relationships.

1. Artificial (Phenotypic) Classification

Principles

- Based on the observation of **phenotypic characteristics** that are easily identifiable.
- Groups bacteria according to their **common properties**, such as:
  - Cell shape (cocci, bacilli, spirilla, etc.).
  - Respiratory type (aerobic, anaerobic, facultative).
  - Optimal growth temperature/pH.
  - Presence of specific pigments or enzymes.

Advantages and Limitations

 Simple and quick for identification.
 Does not always reflect true evolutionary relationships.

2. Natural (Phylogenetic) Classification

Foundations of Natural Classification

- Introduced after **Charles Darwin's** publication of *On the Origin of Species*.
- Based on **evolutionary relationships** between bacterial species.
- Uses **genetic and molecular characteristics** to establish phylogenetic links.

Why is it more reliable?

- It does not depend only on appearances but also on DNA analysis.
- It allows identification of closely related species even if their phenotypes differ.

Importance of Molecular Genetics

Why analyze the genome?

- **An essential tool** for classifying microorganisms.
- Comparative DNA analysis allows for more precise classification.
- Examples:
  - The **whale** was classified with **Artiodactyls** due to genetic studies.
  - In bacteria, phylogenetics helps clarify evolutionary relationships.

Units of Bacterial Classification

The Prokaryotic Kingdom

- Includes **Eubacteria and Archaebacteria**.
- Classification based on **molecular characteristics**.

Taxonomic Ranks

Like all living organisms, bacteria are classified into hierarchical levels:

Species - Genus –Family- Order- Class- Phylum- Domain

Classification According to BERGEY'S Manual

What is BERGEY'S Manual?

- The primary reference for bacterial classification since **1923**.
- Initially based on **phenotypic characteristics**, including:
  - **Gram staining**.
  - Respiratory type.
  - Motility, sporulation, energy sources…

Evolution Towards Molecular Classification

- Regular revisions to integrate new discoveries.
- In 1994, the *Bergey's Manual of Determinative Bacteriology* was published.
- Gradual integration of **DNA sequence analysis**.

According to the *Bergey's Manual of Systematic Bacteriology*, 2nd edition, prokaryotes are classified into two domains:

- **Domain: ARCHAEA**
  These are the Archaebacteria, often considered a third superkingdom alongside Eukaryotes and Bacterial Prokaryotes. They can also be regarded as a major subdivision of prokaryotes, which appears to be the classification choice in *Bergey's Manual*.
- **Domain: BACTERIA**
  These include "traditional" bacteria, which are divided into **23 phylum** (in 1994) :

Phylum I: Aquificae : …….

Phylum II: Thermotogae : …….

Phylum III: Thermodesulfobacteria : …….

Phylum IV: Deinococcus-Thermus : …….

Phylum V: Chrysiogenetes : …….

Phylum VI: Chloroflexi : …….

Phylum VII: Thermomicrobia : …….

Phylum VIII: Nitrospirae : …….

Phylum IX: Deferribacteres : …….

Phylum X: Cyanobacteria : …….

Phylum XI: Chlorobi : …….

Phylum XII: Proteobacteria : …….

Class I: Alphaproteobacteria : …….

- **Order II: Rickettsiales**
  - **Family I: Rickettsiaceae** (Genus *Rickettsia*)
- **Order IV: Sphingomonadales**
  - **Family: Sphingomonadaceae** (Genus *Sphingomonas*)
- **Order V: Caulobacteriales**
- **Order VI: Rhizobiales**
  - **Family I: Rhizobiaceae** (Genus *Rhizobium*):
    Large Gram-negative rod-shaped bacteria, symbiotic nitrogen fixers.
  - **Family II: Brucellaceae** (Genus *Brucella*)

Class II: Betaproteobacteria

- **Order IV: Neisseriales**
  - **Family: Neisseriaceae** (Genera *Neisseria*, etc.)

Class III: Gammaproteobacteria

- **Order III: Xanthomonadales**
  - **Family: Xanthomonadaceae** (Genus *Xanthomonas*, etc.)
- **Order V: Thiotrichales**
  - **Family III: Francisellaceae**
- **Order VI: Legionellales**
  - **Families: Legionellaceae, Coxiellaceae**
- **Order IX: Pseudomonadales**
  - **Family: Pseudomonadaceae** (Genera *Pseudomonas*, *Morococcus*, etc.)
  - **Family: Moraxellaceae** (Genera *Moraxella*, *Acinetobacter*)
- **Order X: Alteromonadales**

- **Family: Alteromonadaceae** (Genera *Alteromonas*, *Shewanella*)
- **Order XI: Vibrionales**
  - **Family: Vibrionaceae** (Genus *Vibrio*)
    - *Vibrio* are Gram-negative bacilli, typically isolated, straight or curved, relatively short, and motile with a single polar flagellum.
    - The human pathogenic species: *Vibrio cholerae*.
- **Order XII: Aeromonadales**
  - **Family: Aeromonadaceae** (Genus *Aeromonas*)
- **Order XIII: Enterobacteriales**
  - **Family: Enterobacteriaceae**
    Gram-negative bacilli, mostly short, straight, either immobile or motile with peritrichous flagella (with some exceptions).
    - **Genus I:** *Escherichia*
    - **Genus XVI:** *Klebsiella*
    - **Genus XXVIII:** *Proteus*
    - **Genus XXXII:** *Salmonella*
    - **Genus XXXIV:** *Shigella*
    - **Genus XL:** *Yersinia*
- **Order XIII: Pasteurellales**
  - **Family: Pasteurellaceae** (Genera *Pasteurella*, *Haemophilus*, *Actinobacillus*, etc.)

Class IV: Deltaproteobacteria

Class V: Epsilonproteobacteria

- **Order I: Campylobacterales**
  - **Families: Campylobacteraceae, Helicobacteraceae**

Phylum XIII: Firmicutes (firmis = strong; cutis = skin)

Class I: Clostridia

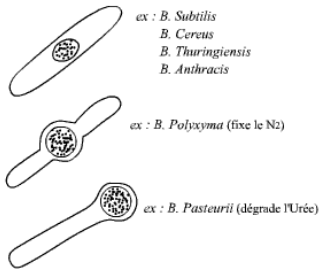
- **Order I: Clostridiales**
  - **Family I: Clostridiaceae** (Genus *Clostridium*)
    Gram-positive rod-shaped bacteria forming endospores.
    Two types of interest:
    - **Pathogenic Clostridium:** *C. tetani*, *C. botulinum*
    - **Industrial Clostridium:** *C. acetobutylicum*, *C. butyricum*

Class II: Mollicutes

- **Order I: Mycoplasmatales**
  - **Family: Mycoplasmataceae**
    Prokaryotes without a cell wall, incapable of synthesizing peptidoglycan precursors, surrounded by a cytoplasmic membrane.

Class III: Bacilli

- **Order I: Bacillales**
  - **Family I: Bacillaceae** (Genera *Bacillus*, *Amphibacillus*, etc.)
    - *Bacillus* species: Gram-positive rods forming endospores, classified into three subgroups based on spore type.



    - **Family V: Staphylococcaceae** (Genus *Staphylococcus*)
        - Gram-positive cocci, typically found on the skin or mucous membranes in clusters, chains, or pairs.
        - Example: *Staphylococcus aureus* (golden staph), which can cause folliculitis and food poisoning.
- **Order II: Lactobacillales**
    - **Family I: Lactobacillaceae** (Genus *Lactobacillus*)
        - Gram-positive rods, either isolated or in chains, non-sporulating.
        - Some *Lactobacillus* species play a fundamental role in food production, such as yogurt and cheese (*Lactobacillus bulgaricus*).
    - **Family IV: Enterococcaceae** (*Enterococcus*)
    - **Family V: Leuconostocaceae**
    - **Family VI: Streptococcaceae** (*Streptococcus*, *Lactococcus*)
        - *Streptococcus* species: Rounded, immobile, non-sporulating Gram-positive cocci, often forming chains.
        - Major pathogenic and industrial species:
            - *Streptococcus pneumoniae* (pneumococcus): Causes pneumonia and various infections.
            - *Streptococcus lactis* (*Lactococcus*): Used in the dairy industry for lactic fermentation in cheese production.

Phylum XIV: Actinobacteria

Class III: Actinobacteria

- **Subclass V: Actinobacteridae**
    - **Order I: Actinomycetales**
        - **Suborder VI: Micrococcineae**
            - **Family I: Micrococcaceae** (Genera *Micrococcus*, *Staphylococcus*, etc.)
        - **Suborder VI: Corynebacterineae**
            - **Family I: Corynebacteriaceae** (Genus *Corynebacterium*)
            - **Family IV: Mycobacteriaceae** (Genus *Mycobacterium*)
                - Two major human pathogens:
                    - *Mycobacterium tuberculosis*: Causes tuberculosis.
                    - *Mycobacterium leprae*: Causes leprosy, a chronic skin and nerve infection.
        - **Suborder XI: Streptomycineae** (Family *Streptomycetaceae*, Genus *Streptomyces*)
    - **Order II: Bifidobacteriales**
        - **Family I: Bifidobacteriaceae** (Genera *Bifidobacterium*, *Gardnerella*)

Phylum XV: Planctomycetes

Phylum XVI: Chlamydiae

- **Class I: Planctomycetacia**
    - **Order I: Chlamydiales**
        - **Family I: Chlamydiaceae**

Phylum XVII: Spirochaetes

Représention schématique d'un spirochète

- **Class I: Spirochaetes**
    - **Order I: Spirochaetales**
        - **Family I: Spirochaetaceae** (Genera *Spirochaeta*, *Borrelia*, *Treponema*)

- **Family III: Leptospiraceae** (Genera *Leptonema*, *Leptospira*)

Phylum XVIII - XXIII:

- **Fibrobacteres, Acidobacteria, Bacteroidetes, Fusobacteria, Verrucomicrobia, Dictyoglomi**