GENERAL MICROBIOLOGY

UNIT -1
TAXONOMY AND BASIC FEATURES OF MICROORGANISMS

HISTORY

- **Anton van Leeuwenhoek (1632-1723)**: Often regarded as the "father of microbiology," Leeuwenhoek was the first person to observe and document microorganisms using a microscope he created himself. In 1676, he discovered "animalcules" (tiny creatures), which we now know to be bacteria, protozoa, and other microorganisms. His observations sparked interest in the microscopic world, though the significance of microorganisms was not fully understood at the time.
- **The Microscope**: The invention and improvement of the microscope by scientists like Leeuwenhoek and others allowed researchers to explore the microbial world. Early microscopes had limited magnification, but as technology improved, scientists could view even smaller organisms.
- **Antibiotics and Vaccines**: The discovery of penicillin by Alexander Fleming in 1928 revolutionized medicine, making it possible to treat bacterial infections effectively. The development of vaccines also helped control infectious diseases caused by bacteria and viruses.
- **Molecular Biology**: In the mid-20th century, the discovery of the structure of DNA by Watson and Crick in 1953 led to significant advances in molecular biology, genomics, and microbiology. Understanding the genetic makeup of microorganisms has allowed for the development of new diagnostic tools, vaccines, and treatments.
- **Modern Microbiology**: Today, microbiology continues to evolve with new discoveries and technological advancements. Modern techniques, such as PCR (polymerase chain reaction) and genome sequencing, have enabled microbiologists to study microorganisms in unprecedented detail.

•**Metagenomics**: In the late 20th and early 21st centuries, scientists began studying microbial communities in natural environments through **metagenomics**, a technique that analyzes DNA from environmental samples, enabling the study of microorganisms that cannot be cultured in the laboratory. This has led to an explosion of knowledge about the vast diversity of microbes.

•**Human Microbiome**: Research on the **human microbiome** (the collection of microorganisms that live on and inside the human body) has become a significant area of study. These microbes play crucial roles in digestion, immunity, and even mental health. Advances in sequencing technologies have allowed scientists to explore these microbial ecosystems in great detail.

•**Synthetic Biology**: The recent rise of **synthetic biology**, a field that combines biology and engineering, is shaping the future of microbiology. This includes the creation of synthetic life forms, the development of microorganisms to produce biofuels, and advances in microbial-based therapies.

•**Antibiotic Resistance**: In recent years, the growing issue of **antibiotic resistance** has become a major challenge. Microorganisms are evolving resistance to commonly used antibiotics, necessitating the development of new drugs, alternative therapies, and strategies to combat resistance.

- **Invention of the Microscope** (17th century) – Anton van Leeuwenhoek observes microorganisms.
- **Germ Theory of Disease** (19th century) – Louis Pasteur and Robert Koch lay the foundation for understanding microorganisms as causes of disease.
- **Development of Antiseptic Surgery** (Late 19th century) – Joseph Lister introduces antiseptic techniques in surgery.
- **Discovery of Antibiotics** (1928) – Alexander Fleming discovers penicillin.
- **Molecular Biology and Genetic Engineering** (Mid-20th century) – Development of DNA sequencing, PCR, and recombinant DNA technology.
- **Human Microbiome and Metagenomics** (21st century) – Advances in studying microbial communities and their impact on human health.

CONTRIBUTION OF MICROBIOLOGISTS

- **1. Understanding Disease Pathogenesis**
- Microbiologists have played a crucial role in identifying the pathogens responsible for infectious diseases. Their research has led to the discovery of bacteria, viruses, fungi, and parasites that cause conditions such as tuberculosis, pneumonia, HIV/AIDS, malaria, and COVID-19. This has helped in the development of diagnostic tools, vaccines, and treatments.
- **2. Antibiotics and Antimicrobials**
- The discovery of antibiotics, such as penicillin by Alexander Fleming, revolutionized medicine and has saved millions of lives. Microbiologists have further developed new classes of antibiotics, antifungals, antivirals, and antimicrobial agents to combat resistant strains of microorganisms.
- **3. Advancing Vaccines**
- Microbiologists have been instrumental in developing vaccines against various infectious diseases, including polio, smallpox, hepatitis, and influenza. More recently, they contributed to the rapid development of COVID-19 vaccines using novel technologies like mRNA.
- **4. Microbial Ecology and Environmental Impact**
- Microbiologists have deepened our understanding of microbial communities in diverse environments such as soil, water, and the human gut. Their work in environmental microbiology has helped improve waste treatment, bioremediation, and pollution control by harnessing beneficial microorganisms.

5. Food Safety and Biotechnology

- Microbiologists have helped ensure food safety by studying foodborne pathogens and their prevention. Their research also supports biotechnology advancements, including fermentation, genetic engineering, and the production of biofuels, enzymes, and antibiotics.

6. Human Microbiome

- Understanding the human microbiome has been a groundbreaking contribution. Microbiologists have shown how microorganisms living in and on the human body affect health, immunity, digestion, and even mental health, leading to new therapeutic approaches and personalized medicine.

7. Genetics and Molecular Biology

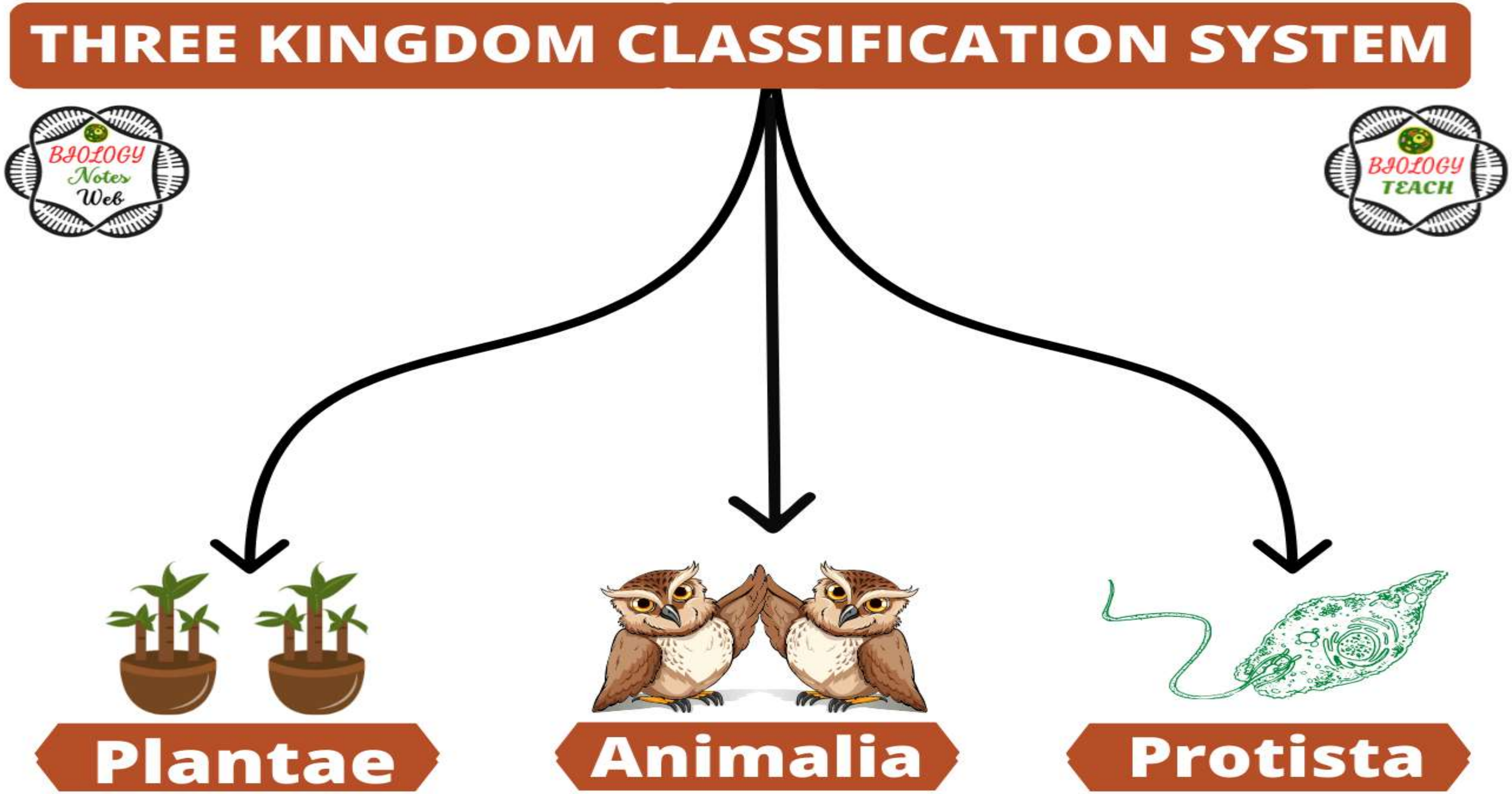
- The study of microbial genetics has expanded our knowledge of genetic engineering, cloning, and gene expression. Microbiologists use model organisms like bacteria to explore fundamental biological processes, which has had implications for medicine, agriculture, and industry.

8. Public Health and Epidemiology

- Microbiologists are at the forefront of tracking and controlling infectious diseases, identifying outbreaks, and providing the scientific basis for public health policies. Their research on pathogen transmission, resistance, and surveillance methods has been vital in preventing the spread of diseases.
-

Haeckel’s Three kingdom System of Classification

- Classification is the arrangement of organisms into taxonomic groups known as taxa on the basis of similarities or relationships. Closely related organisms (i.e., organisms having similar characteristics) are placed into the same taxon. Organisms are categorized into larger groups based on their similarities and differences.
- The classification of living organisms is a complex and controversial subject because of which different taxonomic classification schemes existed at different times. In his classification scheme, Linnaeus recognized only two kingdoms of living things: Animalia and Plantae. At the time, microscopic organisms had not been studied in detail. Either they were placed in a separate category called Chaos or, in some cases, they were classified with plants or animals.
- As the knowledge of the properties of various groups of microbial life exploded, it became apparent that at this level of biological knowledge a division of the living world into two kingdoms cannot really be maintained on a logical and consistent ground. Then in the 1860s, the German investigator Ernst Haeckel proposed a three-kingdom system of classification.
- Three kingdom classification system was put forward by Haeckel in order to overcome the objections and limitations of the Two Kingdom System of Classification. Haeckel suggested that the recognition of a third kingdom could avoid the inconsistencies of the two-kingdom system, and he proposed Protista as a new kingdom to accommodate organisms exhibiting characters either common to both plants and animals, or unique to their own.
- Haeckel’s three kingdoms were Animalia, Plantae, and Protista.


THREE KINGDOM CLASSIFICATION SYSTEM
BIOLOGY Notes Web
BIOLOGY TEACH
Plantae
Animalia
Protista

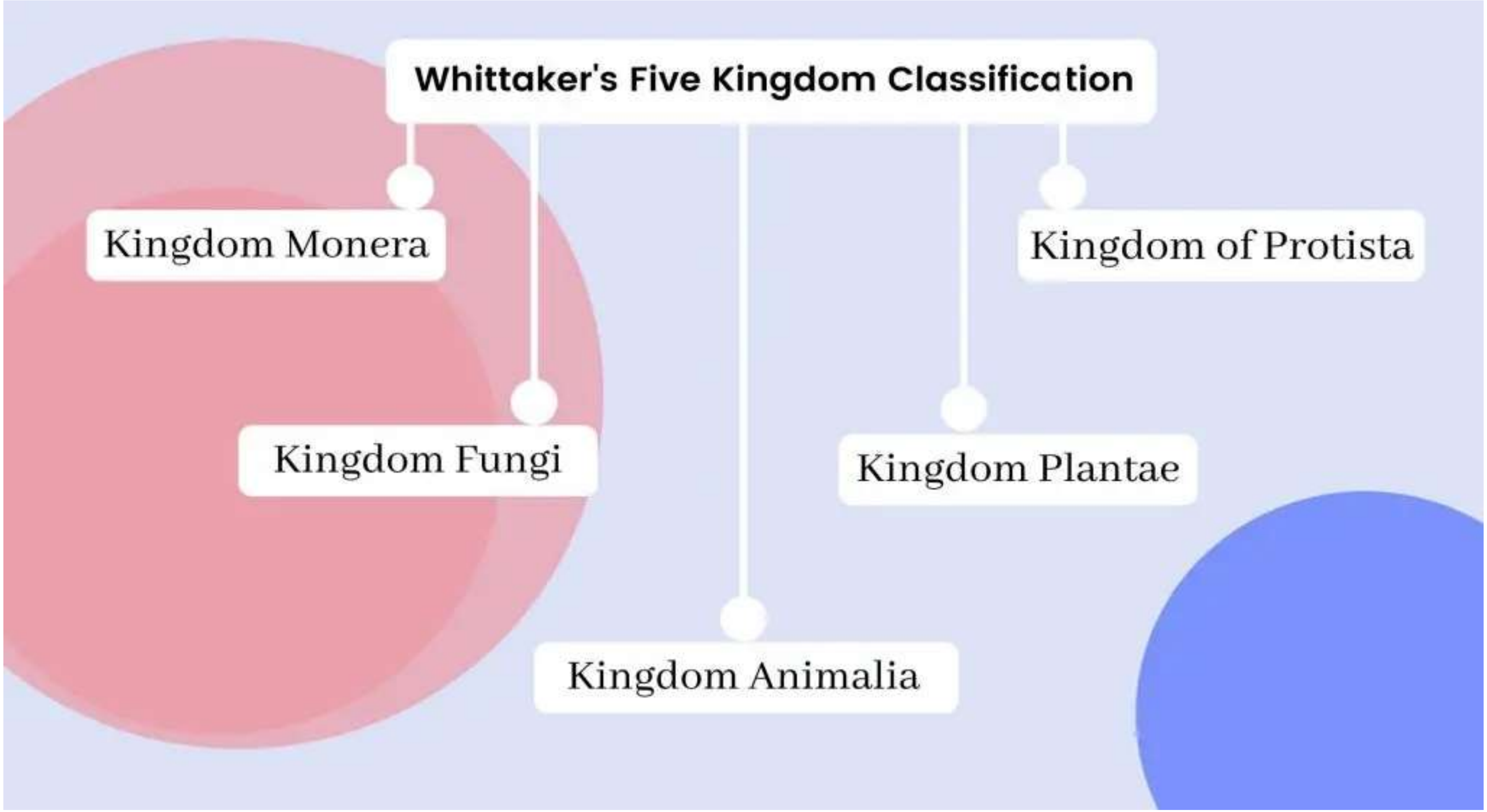
Five kingdom classification

- The Five Kingdom Classification is a system of categorizing living organisms that was proposed by Robert Whittaker in 1969. It divides all life into five major kingdoms based on similarities and differences in their cellular structure, modes of nutrition, and other characteristics. The five kingdoms are:

1. **Monera**: This kingdom includes unicellular organisms that lack a nucleus (prokaryotes). It is further divided into two main groups:
   1. **Bacteria** (e.g., *Escherichia coli*)
   2. **Blue-green algae** (cyanobacteria)
2. **Protista**: This kingdom consists of mostly unicellular organisms with a nucleus (eukaryotes). It includes a diverse range of organisms, such as:
   1. **Protozoa** (e.g., *Amoeba*, *Paramecium*)
   2. **Algae** (e.g., green, brown, and red algae)
3. **Fungi**: Organisms in this kingdom are primarily multicellular (except for yeasts) and are heterotrophic, meaning they obtain food by absorbing nutrients from other organic material. Examples include:
   1. **Mushrooms**
   2. **Molds**
   3. **Yeasts**

1. **Plantae**: This kingdom includes multicellular, autotrophic organisms (capable of photosynthesis) with a cell wall made of cellulose. Plants are typically fixed in one place and provide oxygen and food to other organisms. Examples include:
    1. **Mosses**
    2. **Ferns**
    3. **Flowering plants**
2. **Animalia**: Organisms in this kingdom are multicellular, eukaryotic, and heterotrophic (consume other organisms for food). They lack cell walls and have a nervous system to respond to stimuli. Examples include:
    1. **Invertebrates** (e.g., insects, worms)
    2. **Vertebrates** (e.g., fish, birds, mammals)

- This classification system helps scientists categorize and study the vast diversity of life on Earth.


Whittaker's Five Kingdom Classification
Kingdom Monera
Kingdom of Protista
Kingdom Fungi
Kingdom Plantae
Kingdom Animalia

Three-domain system (Carl Woese's Classification)

- The three-domain system was first introduced by **Carl Woese in 1990** that is why its called Carl Woese's Classification**.** This classification system also is known as the **Six Kingdoms and Three Domains Classification** because it divides the life forms into **three domains** and **six kingdoms**.
- The three-domains of **Carl Woese's Classification system** include archaea, bacteria, eukaryote, and six kingdoms are Archaebacteria (ancient bacteria), Eubacteria (true bacteria), Protista, Fungi, Plantae, Animalia.
- This classification system divides the life based on the differences in the **16S ribosomal RNA (rRNA) structure** and as well as the cell's membrane lipid structure and its sensitivity to antibiotics. The main difference from earlier classification systems is the splitting of archaea from bacteria.

- The evaluating rRNA structure is very helpful. As a result of rRNA molecules, throughout nature perform the identical function, their structure modifications very little over time. Subsequently, similarities and dissimilarities in rRNA nucleotide sequences are a very good indication of how associated or unrelated completely different cells and organisms are.
- It is universally distributed means its presence in all species.
- It is functionally similar in all organisms.
- It can change its sequence slowly.
- Its sequences can be aligned, or matched up, between 2 organisms.

The Three-Domain System

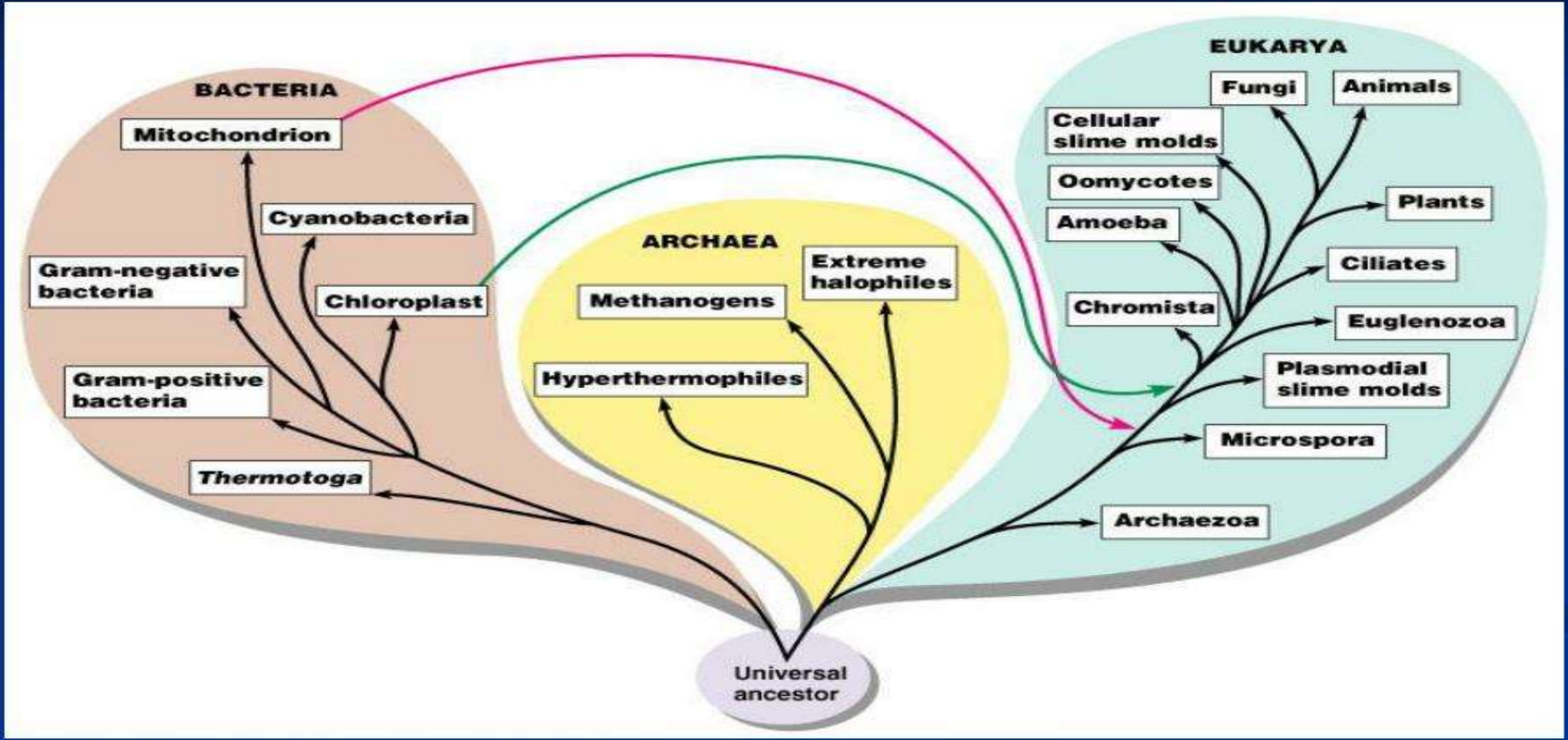


Figure 10.1

Modern Trends in Classification of Microorganisms

- **1. Molecular Phylogeny and Genetic Sequencing**
- **16S rRNA Gene Sequencing**: One of the most significant advancements in microbial taxonomy is the use of 16S ribosomal RNA (rRNA) gene sequencing for bacteria and archaea. The 16S rRNA gene is highly conserved across species, making it an ideal marker for identifying and classifying microbes at various taxonomic levels.
- **Whole Genome Sequencing (WGS)**: Genomic sequencing allows for a comprehensive analysis of an organism's entire genetic makeup. This has revolutionized taxonomy by enabling the classification of microbes based on their full genetic content rather than just specific markers.
- **Single-Cell Genomics**: The ability to sequence the DNA of single cells is particularly valuable for identifying unculturable or rare microorganisms that cannot be studied using traditional culturing techniques.

2. Metagenomics and Microbial Communities

- **Metagenomic Sequencing**: Metagenomics involves sequencing DNA directly from environmental samples (e.g., soil, water, human microbiome) without isolating individual microorganisms. This approach allows for the discovery of novel species and offers insights into microbial communities as a whole, providing a more holistic view of microbial diversity.
- **Microbiome Analysis**: The human microbiome, environmental microbiomes, and other complex microbial communities are being increasingly studied using high-throughput sequencing techniques. Understanding the interplay between different species and their functions within these communities is a major trend in modern microbial classification.
- **3. Bioinformatics and Computational Tools**
- The integration of **bioinformatics** has dramatically changed how microorganisms are classified. With the advent of sequencing technologies, vast amounts of genomic data are produced, and computational tools are required to process and analyze this data. Software and databases like BLAST, SILVA, and GenBank enable researchers to compare genetic sequences and construct phylogenetic trees, leading to more precise taxonomic classification.
- **Machine Learning and AI**: Artificial intelligence and machine learning algorithms are increasingly being used to analyze large microbial datasets, predict microbial functions, and classify organisms based on genomic data.

4. Emphasis on Phylogenetic Trees and Evolutionary Relationships

- Traditional taxonomic methods based on morphological traits are being supplemented by more robust and accurate **phylogenetic trees**, which are constructed using molecular data to reflect the evolutionary relationships among microorganisms. The phylogenetic approach is increasingly being applied to classify microbes at a deeper evolutionary level.
- **Lateral Gene Transfer (LGT)**: One modern consideration in classification is lateral (or horizontal) gene transfer, where genes are passed between different organisms, complicating the traditional tree-like structure of evolutionary relationships. Researchers are now incorporating these dynamics into their models of microbial evolution and taxonomy.
- **5. New Taxonomic Domains and the Phylogeny of Life**
- The discovery of novel microorganisms and the use of molecular techniques have led to the proposal of new domains of life, including the recognition of **Archaea** as a distinct domain, separate from Bacteria. This has led to a rethinking of the **Tree of Life**, with three primary domains: Bacteria, Archaea, and Eukarya.
- Additionally, efforts are underway to explore and classify microbes that belong to new, uncharacterized branches of the microbial world, especially in extreme environments (e.g., deep-sea hydrothermal vents, acid mine drainage).

6. Microbial Species Concept

- The traditional concept of a **microbial species** has been increasingly questioned due to the genetic diversity observed within microbial populations. Modern trends often focus on species being defined by genetic relatedness, with the **Average Nucleotide Identity (ANI)** and **Digital DNA-DNA Hybridization (dDDH)** methods being used to compare genomes more precisely.
- The definition of species is more fluid in microorganisms than in multicellular organisms, and researchers often use a combination of genomic and ecological data to define microbial species.

7. Use of Multilocus Sequence Typing (MLST)

- **MLST** involves sequencing several housekeeping genes and comparing their sequences across different strains of microorganisms. This technique is widely used to track the genetic diversity of microbial populations and to classify strains in epidemiological studies.
- **8 Integration of Multi-Omics Approaches**
- The integration of data from different "omics" technologies (e.g., genomics, transcriptomics, proteomics, and metabolomics) is a modern trend in microbial classification. By studying not just the genes but also the functional proteins and metabolites produced by microbes, researchers gain a more comprehensive understanding of microbial diversity and ecological roles.

Classification and salient features of bacteria according to the Bergey's manual of bacteriology 1994

- Bergey’s Manual of Systematic Bacteriology is a manual referring to the taxonomy of prokaryotic bacteria.
- First published in 1923 by David Hendricks Bergey it is used to classify bacteria based on their structural and functional attributes by arranging them into specific familial orders.
- The first eight editions were published under the name ‘Bergey’s Manual of Determinative Bacteriology’. In the 9th edition, it was renamed as ‘Bergey’s Manual of Systematic Bacteriology’ and was published in four volumes in 1984, 1986, 1989 and 1991.
- The five-volume BMSB is officially replaced by ***Bergey's Manual of Systematics of Archaea and Bacteria*** (BMSAB), a continuously-updated online book, since 2015
- The **Bergey’s Manual of Systematic Bacteriology** is a comprehensive reference that classifies bacteria based on a variety of criteria, including their morphology, biochemistry, and genetic characteristics.

1. Classification of Bacteria :

Bacteria are classified into **phyla**, which are further subdivided into **classes**, **orders**, **families**, **genera**, and **species**. The classification uses a hierarchical system to group bacteria based on shared characteristics. The primary factors influencing bacterial classification include:

Morphology: Shape, size, and structural features of cells.

Staining properties: Whether they are Gram-positive or Gram-negative, or their behavior in other types of staining techniques.

Physiological characteristics: Metabolic properties, such as the ability to ferment sugars or utilize specific compounds.

Genetic characteristics: DNA sequences, ribosomal RNA (rRNA) analysis, and other molecular markers.

•The **Bergey's Manual** contains detailed information on many classes of bacteria, categorized into 4 major groups:

Gracilicutes (Gram-negative bacteria): This group is characterized by a thin peptidoglycan layer and an outer membrane. Bacteria in this class include a wide variety of pathogens, environmental bacteria, and symbionts.

Firmicutes (Gram-positive bacteria): Firmicutes have a thick peptidoglycan layer. This group contains bacteria that are important in fermentation, some pathogens, and others that form endospores, such as *Bacillus* and *Clostridium*.

Tenericutes (Mycoplasmas): These bacteria lack a cell wall, which makes them different from most other bacteria. They have a unique biology and are often associated with diseases in humans and animals.

Mendosicutes (Archaea): These bacteria have distinctive genetic, biochemical, and structural characteristics. Archaea are genetically different from other bacteria and live in extreme environments.

2.Salient Features of Bacteria :

Some of the key characteristics used to describe bacteria in **Bergey’s Manual** include:

Cell Shape:

Cocci (spherical)
Bacilli (rod-shaped)
Spirilla (spiral-shaped)
Vibrios (comma-shaped)
Filamentous (long and thread-like)

Cell Wall Composition:

Gram-positive bacteria have a thick peptidoglycan layer and no outer membrane.
Gram-negative bacteria have a thin peptidoglycan layer and an outer membrane.
Some bacteria, like *Mycoplasma*, lack a cell wall altogether.

Metabolic Activity:

Aerobic bacteria require oxygen.
Anaerobic bacteria can survive in the absence of oxygen.
Facultative anaerobes can use oxygen when available but can also survive in anaerobic conditions.
Fermentative bacteria rely on fermentation pathways to produce energy.

<u>Presence of Flagella</u>:

- **Monotrichous**: One flagellum at one end.
- **Lophotrichous**: Multiple flagella at one or both ends.
- **Peritrichous**: Flagella distributed over the entire surface.
- **Atrichous**: No flagella.

<u>Spore Formation</u>:

- Some bacteria, like *Bacillus* and *Clostridium*, can form endospores, which are highly resistant to environmental stress, including heat, desiccation, and chemicals.

<u>Gram Staining</u>:

- **Gram-positive** bacteria retain the violet dye during the Gram stain process.
- **Gram-negative** bacteria do not retain the violet dye and instead take up the counterstain (usually red or pink).

<u>Pathogenicity</u>:

- **Pathogenic bacteria** cause diseases in humans, animals, or plants.
- **Non-pathogenic bacteria** may be part of the normal flora in humans or exist as environmental organisms.

<u>DNA/RNA Homology</u>:

- Genetic studies, especially 16S rRNA sequencing, are frequently used in modern bacteriology to identify and classify bacteria. This molecular approach has become increasingly important in resolving relationships among bacteria.

Examples of Major Groups in Bergey's Manual (1994 Edition)

The manual organizes bacteria into groups such as:

•**Proteobacteria**: Gram-negative bacteria with diverse metabolic pathways, including *Escherichia*, *Salmonella*, *Pseudomonas*, and others.

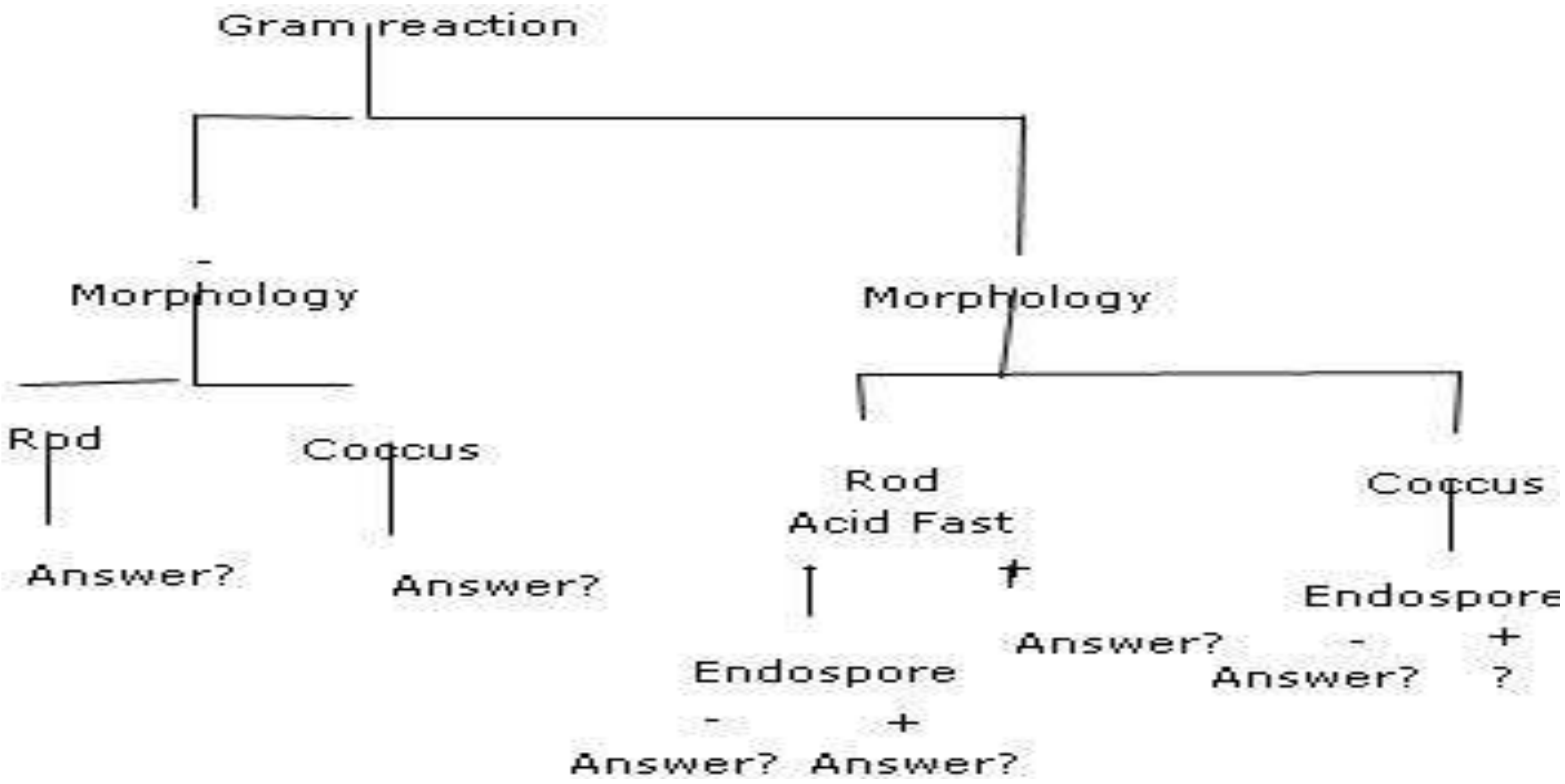
•**Firmicutes**: Include well-known genera such as *Staphylococcus*, *Streptococcus*, *Bacillus*, and *Clostridium*.

•**Actinobacteria**: Gram-positive, often high G+C content bacteria, including *Mycobacterium* (the cause of tuberculosis) and *Corynebacterium*.

•**Spirochaetes**: Long, spiral-shaped bacteria like *Treponema* (syphilis-causing) and *Borrelia* (Lyme disease).

•**Cyanobacteria**: Photosynthetic bacteria also known as blue-green algae, important in oxygen production and nitrogen fixation.

MANUAL FLOWCHART- BERGEY'S



OUTLINE CLASSIFICATION & GENERAL FEATURES OF VIRUS,ALGAE,FUNGI & PROTOZOANS :

1.Viruses

•**Classification:**

•**Based on structure:**

- DNA viruses (e.g., Herpesviruses, Poxviruses)
- RNA viruses (e.g., Influenza, Coronavirus)

•**Based on shape:**

- Icosahedral (e.g., Adenovirus)
- Helical (e.g., Tobacco mosaic virus)
- Complex (e.g., Bacteriophages)

•**Based on the host they infect:**

- Animal viruses
- Plant viruses
- Bacterial viruses (bacteriophages)

•**Baltimore Classification System:** Categorizes viruses based on their genome type (DNA or RNA), strandedness (single or double), and replication strategy.
•**International Committee on Taxonomy of Viruses (ICTV):** Provides a comprehensive classification system based on viral morphology, genome characteristics, and evolutionary relationships.

•**General Features:**

•Non-living outside a host cell (cannot reproduce or carry out metabolic processes on their own)

•Composed of nucleic acid (DNA or RNA) surrounded by a protein coat (capsid)

•Obligate intracellular parasites

•Infect specific types of cells based on surface receptors

2.Algae

•**Classification:**

•**By pigmentation:**

- Green algae (Chlorophyta)
- Brown algae (Phaeophyta)
- Red algae (Rhodophyta)
- Golden algae (Chrysophyta)

By habitat:
•Marine algae
•Freshwater algae
By cell structure:
•Unicellular (e.g., Chlorella)
•Multicellular (e.g., Kelp)
•Colonial (e.g., Volvox)

General Features:

•Eukaryotic, simple photosynthetic organisms

•Contain chlorophyll (and other pigments) for photosynthesis

•Can be unicellular, colonial, or multicellular

•Found in aquatic environments (freshwater, marine)

•Serve as primary producers in ecosystems

3.Fungi

•**Classification:**

•**By structure and reproduction:**

- Zygomycota (e.g., bread molds)
- Ascomycota (e.g., yeasts, molds like Aspergillus)
- Basidiomycota (e.g., mushrooms, puffballs)
- Chytridiomycota (e.g., Chytrids)

•**By lifestyle:**

- Saprophytic (decomposers)
- Parasitic (e.g., rusts, smuts)
- Mutualistic (e.g., lichens, mycorrhizal fungi

•**General Features:**

•Eukaryotic organisms, primarily multicellular (except yeasts which are unicellular)

•Have a cell wall made of chitin

•Non-photosynthetic, absorb nutrients through external digestion

•Reproduce both sexually and asexually (via spores)

•Found in a wide range of habitats, often decomposers or symbiotic

4.Protozoans

- **Classification:**
- **By movement structure:**
  - Flagellates (e.g., Trypanosoma, Giardia)
  - Amoeboids (e.g., Amoeba, Entamoeba histolytica)
  - Ciliates (e.g., Paramecium)
  - Apicomplexans (e.g., Plasmodium, Toxoplasma)
- **By habitat and lifestyle:**
  - Free-living (e.g., Paramecium)
  - Parasitic (e.g., Plasmodium causing malaria)
- **General Features:**
- Eukaryotic, single-celled organisms
- May be free-living or parasitic
- Often motile (using flagella, cilia, or pseudopodia)
- Can reproduce asexually (binary fission) or sexually (conjugation)

BINOMIAL NOMENCLATURE :

- Binomial nomenclature is the biological system of naming the organisms in which the name is composed of two terms, where, the first term indicates the genus and the second term indicates the species of the organism.”
- The system of binomial nomenclature was introduced by Carl Linnaeus. Multiple local names make it extremely difficult to identify an organism globally and keep a track of the number of species.
- Each organism would have one scientific name which would be used by everyone to identify an organism. This process of standardized naming is called as Binomial Nomenclature.

•**Genus Name**:

•Represents a group of species that are closely related.

•Always **capitalized**.

•Written in **italic** or **underlined** when handwritten.

•**Species Epithet** (or specific name):

•Describes a particular species within the genus.

•Written in **lowercase**.

•Also written in **italic** or **underlined** when handwritten.

•**Example:**

•**Homo sapiens**

- **Homo**: genus (capitalized)
- **sapiens**: species (lowercase)

Additional Rules:

- The binomial name is always **Latin** or **Latinized**.
- If referring to the name in a sentence, the genus may be abbreviated to the first letter after it has been mentioned once (e.g., **H. sapiens**).
- **Subspecies**, **varieties**, or **cultivars** may also be identified in addition to the binomial name but are written with an additional descriptor after the species epithet (e.g., *Panthera leo persica* for the Asiatic lion).

CYANOBACTERIA :

- **Classification**: Cyanobacteria are a group of photosynthetic bacteria, also known as "blue-green algae" (though they are not true algae). They belong to the domain **Bacteria**.
- **Characteristics**:
  - Unicellular or colonial organisms.
  - Have chlorophyll a and other pigments like phycocyanin, which gives them a blue-green color.
  - Perform photosynthesis, producing oxygen (oxygenic photosynthesis), similar to plants.
  - Can live in various environments (freshwater, marine, terrestrial).
  - Some species can fix nitrogen, which is essential for the nitrogen cycle.

- **Ecological Role**: They are primary producers in many ecosystems, forming the basis of food chains in aquatic habitats. Some species are involved in nitrogen fixation, enriching soil and water.

Mycorrhizae

•**Classification**: Mycorrhizae are symbiotic associations between fungi and plant roots. Fungi can belong to various groups, such as **Ascomycota** or **Basidiomycota**.

•**Characteristics**:

•The fungal hyphae penetrate plant roots and form a mutualistic relationship, where the fungus benefits from carbohydrates produced by the plant, and the plant benefits from increased nutrient (especially phosphorus) and water absorption facilitated by the fungus.

•There are two main types:

- •**Ectomycorrhizae**: Fungi grow on the exterior of root cells.
- •**Endomycorrhizae** (Arbuscular mycorrhizae): Fungi penetrate the root cells and form structures like arbuscules.

•**Ecological Role**: Mycorrhizae enhance plant growth by improving nutrient uptake, especially in nutrient-poor soils. They also play a role in soil structure and protect plants from pathogens.

Lichens

- **Classification**: Lichens are a mutualistic association between a fungus and a photosynthetic partner (either algae or cyanobacteria).
- **Characteristics**:
  - The fungal component is usually from the Ascomycota or Basidiomycota.
  - The photosynthetic partner provides sugars through photosynthesis, while the fungus provides protection and access to moisture and minerals.
  - Lichens can be found in a wide range of habitats, including extreme environments like rocky surfaces, tree bark, and deserts.
  - They are classified into three major growth forms: **crustose** (crust-like), **foliose** (leaf-like), and **fruticose** (branched, bushy).
- **Ecological Role**: Lichens are important as bioindicators of air quality (especially for pollutants like sulfur dioxide). They are also primary colonizers in harsh environments, helping to break down rocks and create soil.