Discipline Courses-I
Semester-I
Paper: Phycology and Microbiology
Unit-I
Lesson: Biological Classification
Lesson Developer: Ishwar Singh
College/Department: Hansraj College, University of Delhi

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Chapter: Biological Classification

Introduction

In our daily life we come across several animals, plants and microbes, which have been named in order to understand their importance and to communicate about them. However, this communication about organisms becomes difficult in an area or a region where they do not occur or if they occur but are recognized by some other name. Further, organic evolution has caused great number of biodiversity adding another problem to biologists to remember, and to identify new ones. All these factors contribute to a need of developing a system, called taxonomy.

Taxonomy is the branch of science dealing with naming, grouping of organisms on the basis of the degree of similarity and arranging them in an order on the basis of their evolutionary relationship. Therefore in other words, taxonomy is related to **nomenclature**, **classification** and **phylogeny** of organisms. Taxonomy unlike natural sciences such as Botany, Zoology, Physics, Chemistry, etc. is considered as a synthetic (man made) and multidisciplinary science. It owes its progress on the advancement made in other branches of sciences like morphology, histology, physiology, cell biology, biochemistry, genetics, molecular biology, computational biology etc.

Nomenclature and Taxonomic Hierarchy

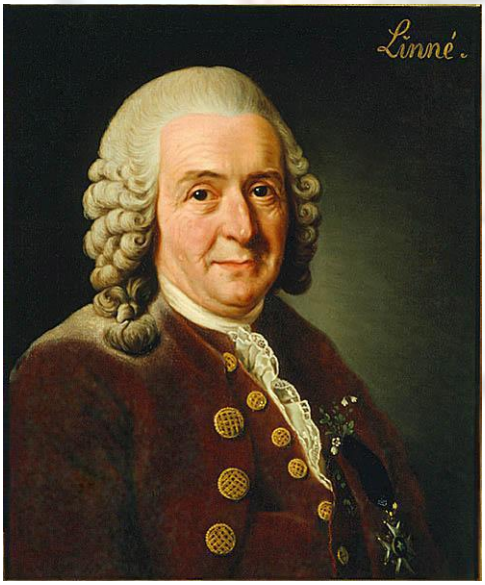

Figure: Carolus Linnaeus (1707-78)

Source:http://commons.wikimedia.org/wiki/File:Carolus_Linnaeus_%28cleaned_up_version%29.jpg

Carolus Linnaeus (1707-78) a Swedish botanist known as father of taxonomy is credited for establishment of taxonomy as a separate science. He was instrumental in framing the rules for naming the organisms, which he applied uniformly while giving his classification. It was he who popularized the **binomial nomenclature** that is the modern scientific way of naming organisms.

- In binomial nomenclature name of every organism is composed of two parts: first is called generic name representing the taxon – **Genus** to which it belongs and second is called specific epithet- **Species**.
- The generic name always starts with capital letter and specific name always with small letter.
- These scientific names are used uniformly regardless of regions/countries or languages, and two different organisms cannot posses same scientific name.
- The names of different organisms used in binomial nomenclature system must be derived from Latin or if names to be used are from different languages they must be treated as Latin.

The nomenclature of organisms is governed by a set of rules framed by International Codes of Nomenclature. There are different codes of nomenclature for different groups of organisms for example, naming of bacteria, animals and plants is governed by International Code for Nomenclature for Bacteria (ICNB), International Code of Zoological Nomenclature (ICZN) and International Code of Botanical Nomenclature (ICBN) respectively. The scientific name of an organism, when cited in any text, is always mentioned as in italics or underlined font style. The name of the author who first gave the correct name as per rules is written in abbreviated form after the specific name and is written in Roman.

Another aspect of taxonomy is classification, which is the grouping of different organisms on the basis of shared features into different categories called taxa. Different taxa are then arranged in a hierarchical manner starting from lower to higher ranks that is:

Species

Genus

Family

Order

Class

Phylum/Division

Kingdom

Domain

This ordered arrangement of various taxa is called taxonomic hierarchy.

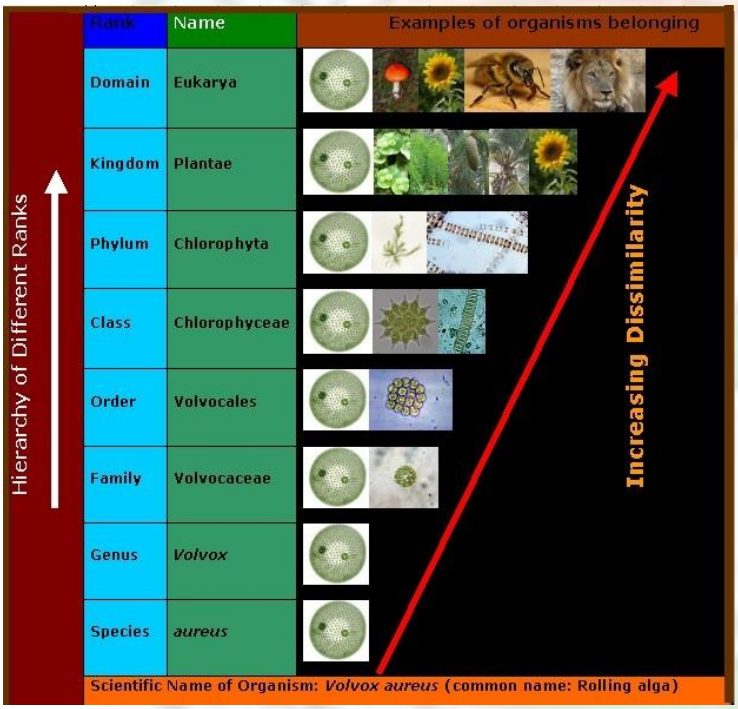

Figure: An organism is placed in different groups (ranks) on basis degree of similarity. All related groups are arranged in a hierarchical fashion starting from lowest, Species to highest. Dissimilarity among different related groups increases of hierarchical order. Example- as shown in the figure classification of rolling alga- *Volvox aureus.*

Source: Author

In this taxonomic hierarchy each organism is assigned a species name and species of very similar organisms are grouped into a genus. The genera having very similar characteristics are grouped together into a family and similarly several families form an order, several orders into a class and ultimately on the top all similar classes are grouped into a kingdom.

In recently proposed classifications, a new higher rank- domain/empire has been added on the top of rank, kingdom.

Classification is done in order to make the process of identification of known organisms simpler. While classifying the organisms it is presumed that all the organisms have been diverged through organic evolution from one common ancestor. This is called concept of unity amongst diversity. Another important point to remember about classification is that members of higher level of ranks share fewer characteristics than those in lower level ranks. One of the objectives of taxonomy is to classify organisms according to their evolutionary (ancestral) relationship (phylogeny), which is not an easy task especially in absence of connecting fossils links. Creating a universally accepted system of classification has always remained a problem in the field of taxonomy. This is because being synthetic branch, taxonomy is very subjective, and there is no consensus among biologists over the uniformity of importance given to different characters in relation to evolution. Moreover, our knowledge about living organisms is still incomplete; therefore any change or addition in this knowledge-database always reflects in the field of taxonomy.

Earlier taxonomists divided the living organisms on the basis of morphological characters, as there was no any sophisticated tool available to study living world. So, whatever information was available it was about visible macro-organisms. Therefore organisms were arranged into two groups- **plants** and **animals** based on easily observable (phenotypic) characteristics.

Table: Different characteristics of two kingdoms, Plantae and Animalia.

Source: Author

Character	Kingdom	
	Plantae	**Animalia**
Body organization	Simple, Organ systems like excretory, sensory, nervous etc. absent	Well developed and organ systems like excretory, sensory, nervous etc. present
Mobility	Absent as organs of locomotion are not present	Present due to occurrence of organs of locomotion
Growth and development	Indefinite	Definite as body grows to certain size and then stop.
Nutrition	Autotrophic through ether photosynthesis or absorption	Heterotrophic through ingestion

This system of classification was called two-kingdom classification and it was followed for a very long period in history of biological sciences. However, invention of microscope in 16th century made it possible to explore the living world, which was not earlier possible to explore through human-naked-eyes. This exploration revealed an altogether new world of microorganisms sharing features of both plants and animals. For example, *Euglena,* a green, **autotrophic**, motile organism having definite shape and size, and obtains food by ingestion process in absence of light. Similarly *Chlamydomonas*, a photoautotrohic organism but also has animal-like feature such as motility and definite shape and growth. Further, fungi although have plant-like features such as immobility, irregular shape and indefinite growth but also posses **heterotrophic** mode of nutrition, a characteristic feature of animals. Therefore such microorganisms could not have appropriate placement in two-kingdom classification. In order to classify these microorganisms, Ernst H. Haeckel in 1866 proposed a three-kingdom classification in which he added a new kingdom – **Protista**.

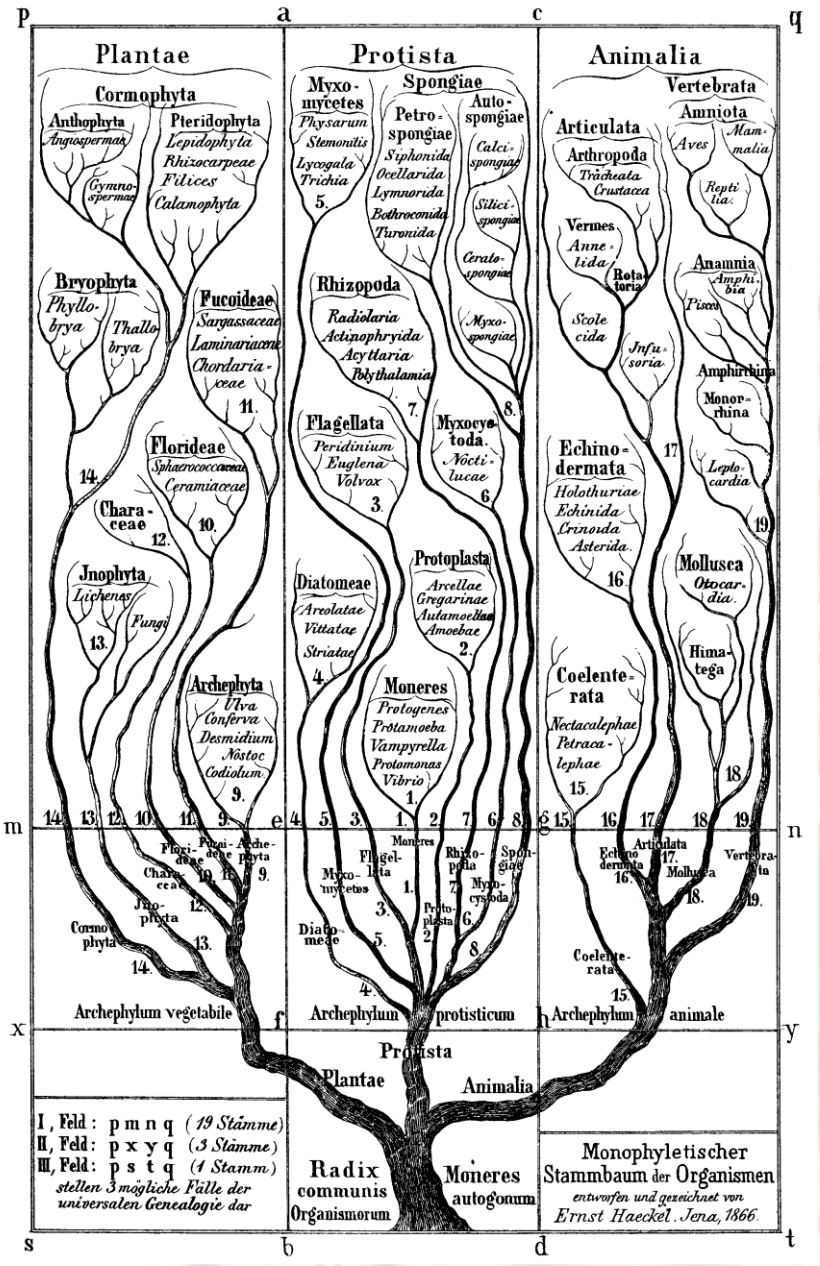

Figure: Tree of life based on three-kingdom classification.

Source: http://commons.wikimedia.org/wiki/File:Haeckel_arbol_bn.png

In this new kingdom he included all simple microscopic living organisms such as bacteria, microalgae, protozoa, fungi and sponges. Further advancement in the techniques of microscopy and their application to biology generated new information that added to the scientific knowledge. Studies of various organisms at cellular and subcellular level in 19th and 20th centuries proved that all organisms are made up of a basic unit called **cell**, which could be structurally simple (**prokaryotic cell**) or complex (**eukaryotic cell**). All the

known organisms posses either prokaryotic or eukaryotic cell organization and therefore they can be accordingly called as ether prokaryotes or eukaryotes, respectively. Several taxonomists insisted on inclusion of this fact (cell type) in classification of organisms. In 1956, Lynn Margulis and H. F. Copeland adapted this criterion in their classification and proposed a four-kingdom classification system in which kingdom- Protista was divided into two new kingdoms, **Monera** containing all prokaryotes and **Protoctista** containing all simple, microscopic eukaryotic organisms like algae, protozoa and fungi.

In 1969, R. H. Whittaker proposed a five-kingdom classification in which kingdom – Protoctista was split into kingdoms- Protista and Fungi. Carl Woese (1990) suggested further rectification in system of classification. Relying on the information gathered with the help of various techniques of molecular biology about different prokaryotes he proposed revision of kingdom- Monera. In this classification kingdom- Monera was abolished and a new category- **domain** on the top of category, Kingdom was introduced. This taxonomic system is known as a three-domain classification that includes domains – Bacteria, Archaea and Eukarya.

Thus, in conclusion, taxonomy is still a growing discipline, and system of classification and status of evolutionary relationship amongst various groups will remain unsettled until we have complete information about all the organisms present on this earth. Till then we have to revisit our taxonomic system again and again in light of new information and knowledge as we have been doing so since past .

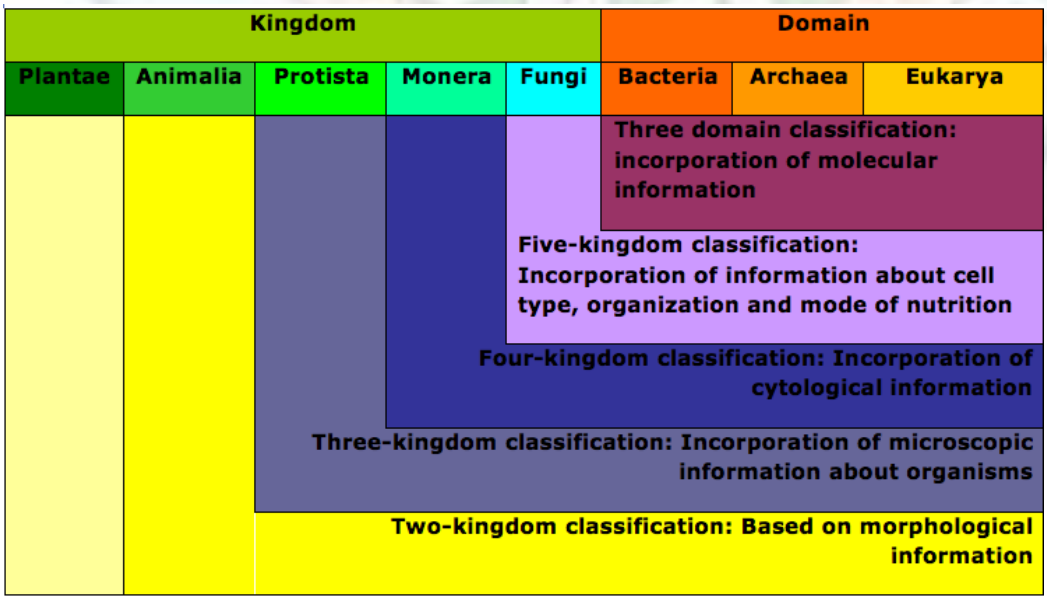

Figure: Progress taken place in classification system as a result of incorporation of new information.

Source:Author

Five Kingdom Classification

This is one of the most widely accepted systems of classification proposed by an American taxonomist, R. H. Whittaker in 1969. After Whittaker, this system is also called Whittaker's system of classification. In this classification, cellular organisms have been divided into five kingdoms namely, Monera, Protista, Fungi, Plantae and Animalia. This classification is an improvement of earlier proposed four-kingdom classification as in this system a new kingdom- Fungi has been erected.

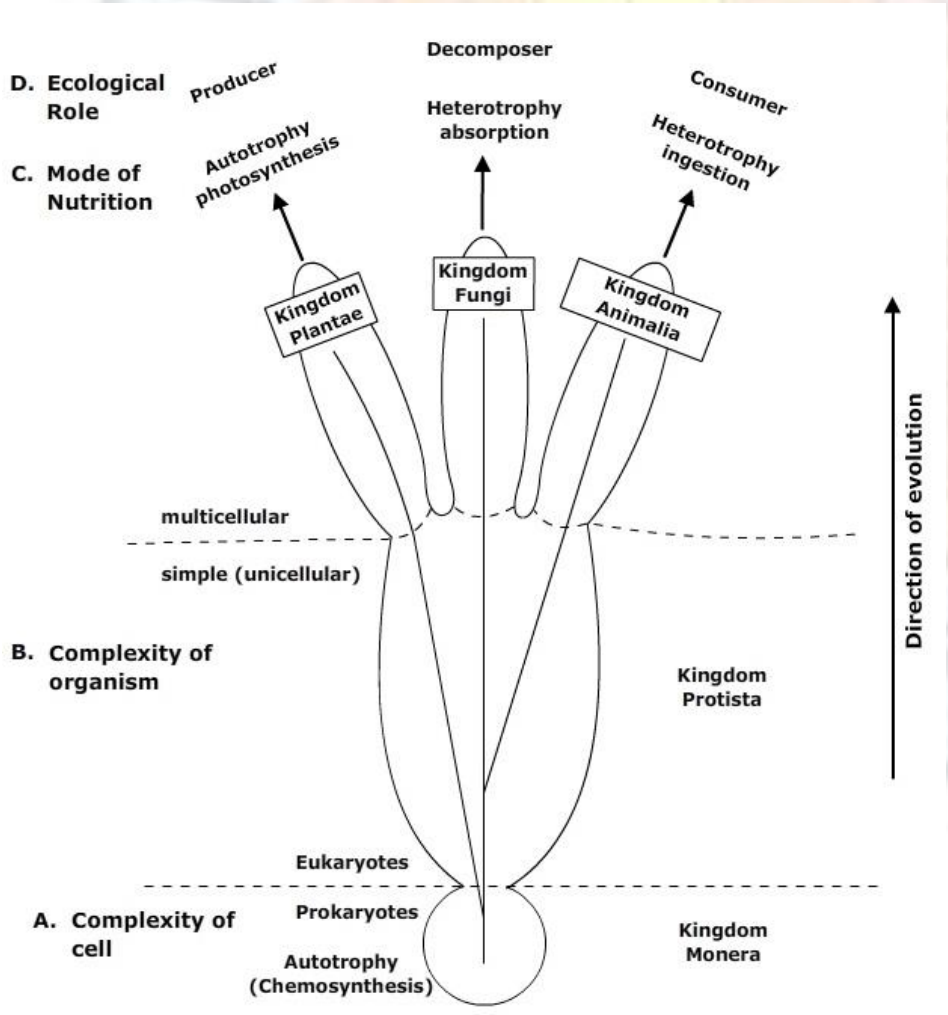

Figure: Whittaker's five-kingdom classification based on complexity of cell, cellular organization, mode of nutrition and ecological role played

Source: adapted from Dr S.K. Aggarwal,2010. Foundation course in Biology.

Whittaker delimited the five kingdoms on the basis of three main criteria viz. cell structure type, degree of cellular organization and mode of **nutrition**. Besides these major characteristics he has also given importance to characters of ecological role-played and mode of reproduction.

Table: Major criteria on which five-kingdom classification is based

Criterion	**Kingdom**				
	Monera	**Protista**	**Plantae**	**Fungi**	**Animalia**
Cell type	Prokaryotic	Eukaryotic	Eukaryotic	Eukaryotic	Eukaryotic
Cellular organization	Unicellular	Unicellular	Multicellular	Multicelluar	Multicellular
Nutrition mode	Variable- Phtotrophic/ heterotrophic/ chaemoautotrophic	Phototrophic/ heterotrophic	Autotrophic (photosynthesis)	Heterotrophic (absorption)	Heterotrophic (ingestion)
Reproduction	Asexual	Asexual or sexual without embryo stage	Asexual or sexual with embryo stage	Asexual or sexual with spore	Sexual with embryo stage
Ecological role	Variable	Variable	Producer	Decomposer	Consumer

He also attempted to establish phylogentic relationship amongst various groups of different kingdoms.

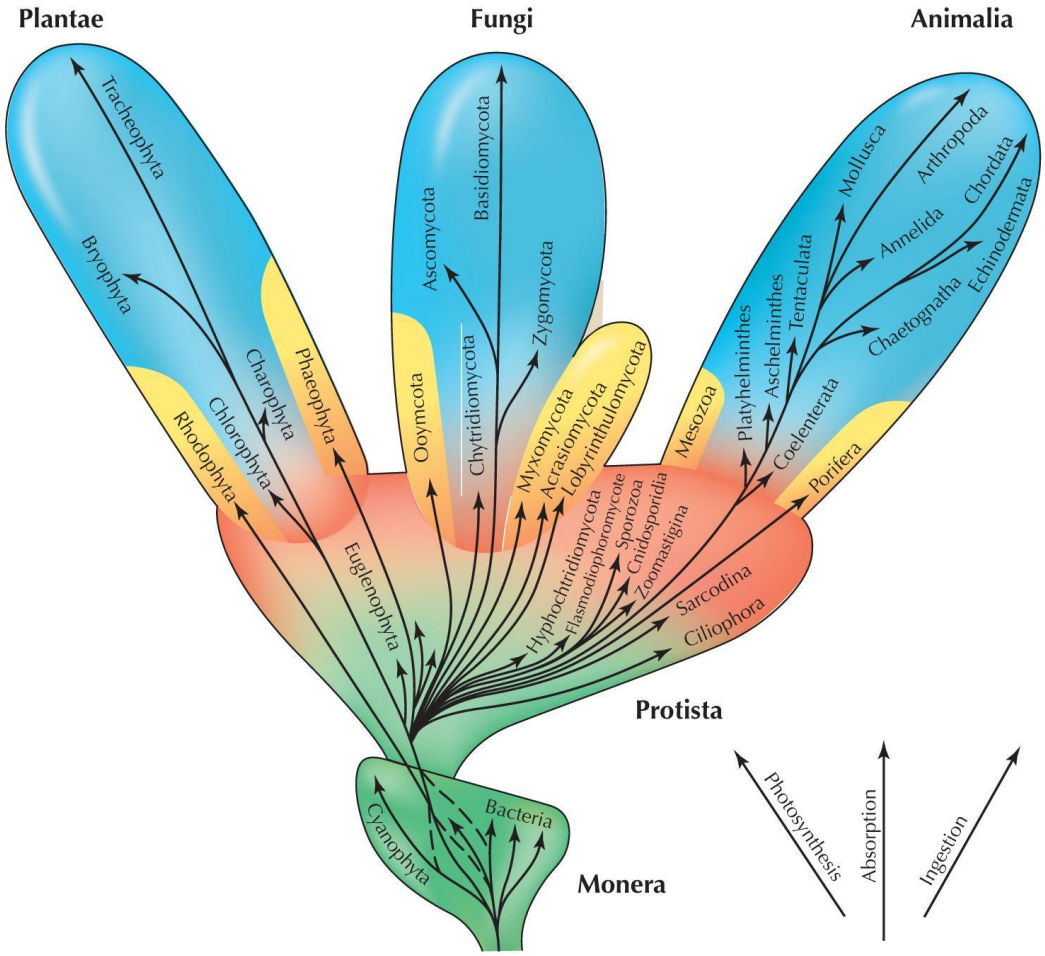

FIGURE 5.15. Whittaker's five-kingdom tree. This system contains five kingdoms based on three levels of organization: prokaryotic (kingdom Monera), eukaryotic unicellular (kingdom Protista), and eukaryotic multicellular and multinucleate (kingdoms Fungi, Animalia, and Plantae). The three kingdoms at the top of the figure are distinguished mainly by differences in nutrition (see the *inset*).

5.15, redrawn from Whitaker R.H., *Science* **163:** 150–160, © 1969 American Association for the Advancement of Science

Evolution © 2007 Cold Spring Harbor Laboratory Press

Figure: Phylogenetic relationship among different groups in five-kingdom classification

Source: http://evolution-textbook.org/content/free/figures/05_EVOW_Art/15_EVOW_CH05.jpg

According to him the earliest living forms (progenote) produced prokaryotic organisms or monerans. Monera gave rise to protists probably through association of several types of primitive and advanced monerans. Protists in tern gave rise to fungi, plants and animals. The characteristic features and members of each of five kingdoms are briefly discussed:

Kingdom – Monera

1. It is the kingdom of all the prokaryotes and includes eubacteria, cyanobacteria (blue-green algae) and archebacteria.
2. The organisms are unicellular, colonial, mycelial and filamentous in form.
3. They lack true nuclei and other membrane bound organelles such as mitochondrion, chloroplast, Golgi bodies, lysosomes etc. and DNA, which is the genetic material and is called nucleoid, is not found associated with histone proteins; cell wall is often present but chemically made up material other than cellulose.
4. Mode of nutrition varies from autotrophy to heterotrophy.
5. Sexual reproduction is absent and asexual reproduction may take place through fission, fragmentation, budding and sporulation.

Kingdom – Protista

1. It is a group of organisms differing widely with one another except that they all are simple and minute eukaryotes. It includes microalgae, protozoa and slime moulds.
2. Majority of them are unicellular but some may be colonial in form.
3. They contain true nuclei and membrane bound organelles; cell wall may or may not be present.
4. Nutrition is very diversified and may be autotrophic (via photosynthesis) or heterotrophic (ingestion/absorption).
5. Asexual means of reproduction is common but when organisms reproduce sexually, embryo is not formed.

Kingdom – Fungi

1. It is the group of mostly multicellular or multinucleate achlorophyllous and spore-producing eukaryotic organisms and includes mildews, moulds, yeasts, morals, truffles, mushrooms, rusts etc.
2. The body of organisms is mycelial in form; cell wall is present and made up of chitin or cellulose.
3. Nutrition is absorptive heterotrophy where organism secretes digestive enzymes into the substrate and then absorbs the digested food.

4. Asexual reproduction is primary mode of reduction and sexual reproduction causes formation of specialized spores.

5. They play the ecological role of decomposer.

Kingdom – Plantae

1. It includes all coloured multicellular photosynthetic eukaryotic organisms commonly called as plants. The important constituents are macroalgae, bryophytes, pteridophytes, gymnosperms and angiosperms.

2. Plant body is either thalloid (algae and some of bryophytes) or differentiated into root, stem and leaves; nonmotile; Cell wall is present and it is chemically made up of cellulose.

3. Nutrition by: autotrophy (photosynthetic)

4. Both asexual and sexual reproductions occur. An embryo stage is present except in algal group.

5. They play the ecological role of producers.

Kingdom – Animalia

1. It is a group of all macroscopic animals derived from zygote and includes sponges, coelentrates, worms, annelids, arthopodes, mollusces, star fishes, fishes, amphibians, reptiles, birds and mammals.

2. Organisms are multicellular with higher degree of body organization where tissue differentiation usually leads to specialized organ formation. Eukaryotic cell is without cell wall and chlorophyll pigments.

3. They exhibit mobility, sensitivity to different stimuli and definite growth.

4. They reproduce primarily by sexual reproduction and embryo stage is usually present.

5. They play ecological role of consumer.

Demerits of five- kingdom Classification: Although this system is considered to be an advanced system but still objections have been raised against this, which are following.

1. It fails to distinguish between archaebacteria and eubacteria.
2. The kingdom- Protista is highly heterogeneous group of organisms, which seems to be having polyphylatic evolution.
3. Placement of algae on the basis of degree of cellular organization into different kingdoms appears to be unrealistic.
4. Red and brown algae placed in kingdom – Plantae are not related to other members.
5. Viruses an important form of life has not been considered in this system of classification.

Three Domain Classification

Progress done in molecular biology especially in biochemistry and molecular genetics in later decades of 20th century provided new techniques to study and compare organisms. The study of chemical structure and sequence of macromolecules such as proteins and nucleic acid can give insights in understanding the functions and evolutionary relationship of different organisms. For example, cytochrome c protein, a component of electron transport chain occurring in mitochondria; *rbcl* gene, encoding rubisco enzyme present in chloroplast and small subunit ribosomal RNAs (SSUrRNAs) are very useful in such studies.

Among various probable contender macromolecules that can help in determining the relationship amongst entire living world, rRNA fits the requirement the most as this form of ribonucleic acid is (a) found uniformly distributed in all the self-replicating cells as one of the basic components of ribosomes; (b) easy to isolate; (c) structurally stable due to its very low mutation rate therefore making it an ideal molecule for detecting the relatedness amongst distant species. Carl Woese and George Fox (1977) compared 16s/18s rRNA present in different species and concluded that rather than two different basic cell types (prokaryotic and eukaryotic cells) as suggested by cytological data, molecularly, there are, in actual, three basic types of cells –

- one, present in eubacteria
- second, present in archaebacteria and
- third, present in eukaryotes.

If organisms are grouped on the basis of three basic cells, the molecular dissimilarity among different cell type based groups appears so prominent that these groups cannot be

considered equivalent to the taxon, kingdom. Therefore, Carl Woese et al. introduced a new taxon – domain above the level of kingdom in their new system of classification, which they proposed in 1990. Under this system, life has been divided into three domains, the Bacteria, the Archaea and the Eukarya.

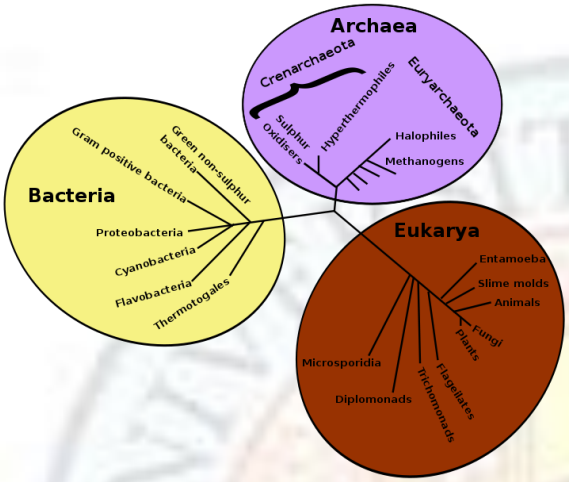

Figure: Three domains of life showing phylogenetic relationship among groups on the basis of rRNA data.

Source: http://commons.wikimedia.org/wiki/File:Tree_of_life.svg

Just beneath domain is the rank of kingdom. The question of exact number of kingdoms in each domain has been left unaddressed for future settlement, as new emerging molecular data will soon throw more light on such natural groupings. However, in domain- Bacteria the elevation of different phyla, proposed in earlier contemporary systems, to the ranks of kingdoms has been suggested. Similarly, in domain- Eukarya three kingdoms: Plantae, Animalia and Fungi; and division of protists (kingdom-Protista) into various kingdoms on the basis of molecular characterization have been suggested. Domain, Archaea contains two kingdoms- Euryarchaeota (group of methanogens) and Crenarchaeota (group of extreme thermophiles).

Table : Characteristic features of three domains.

Character	**Bacteria**	**Archaea**	**Eukarya**
Cell type	Prokaryotic	Prokaryotic	Eukaryotic
Cell wall	Present; contain peptidoglycan	Present; peptidoglycan absent	Present/absent; peptidoglycan absent

Membrane lipids	Diacyl glycerol diesters	isoprenoid glycerol diethers or diglycerol tetraethers	Glycerol fattyacyl diesters
Genetic material	Small circular DNA not associated with histones	Small circular DNA associated with histones like proteins	Large linear DNA associated with histones
Translation (first amino acid)	Formylmethionine	Methionine	Methionine
RNA polymerase	One; simple	One; complex	Three; complex
tRNA (TψC arm)	Thymine present	Thymine absent	Thymine present
Intron	Absent	Present rarely	Present
Antibiotic sensitivity	Yes	No	No
Diphtheria toxin sensitivity	No	Yes	Yes
Reproduction	Spore formation present	Spore formation absent	Spore formation present or absent
Habit	Variable	Extremophile	Variable

The distinguishing features of these domains :

Domain – Bacteria

1. It is a group of organisms having prokaryotic cell organization.
2. Lipids present in plasma membrane are predominantly diacyl glycerol diesters; cell wall contains peptidoglycan.
3. Ribosomes present in these organisms contain bacterial type of rRNA where between position 500 and 545 occurs a hairpin loop possessing a side bulge made up of six nucleotides.

Domain – Archaea

1. Cellular organization is prokaryotic.

2. Membrane lipids present are predominantly isoprenoid glycerol diethers or diglycerol tetraethers; cell wall lacks peptidoglycan.

3. Ribosomes contain an archaeal type of rRNA where corresponding side bulge is made up of seven nucleotides and exhibit unique structure between positions 180-197 or 405 and 498.

Domain – Eukarya

1. Organisms posses eukaryotic cell organization.

2. Membrane lipids are predominantly glycerol fattyacyl diesters; cell wall when present contains chemicals other than peptidoglycan.

3. Ribosomes contain eukaryotic type of rRNA.

Merits of Carl Woese's system: Since this is most advance system of classification, it has attempted to address various demerits of five-kingdom classification. This system recognizes the independent lineages of archaebacteria and bacteria and provides their natural classification. By introduction of the rank of domain, this system has become natural up to highest level.

Summary

Taxonomy is a synthetic and multidisciplinary branch of science dealing with nomenclature, classification and phylogeny of organisms. The progress of this science is directly related to the advancement made in other sciences from which it owes its principles. Carolus Linnaeus established taxonomy as a separate science. Binomial nomenclature is used for assigning scientific names to different organisms in which each name is composed of two names, first, generic name and second, specific name. Each organism has a unique scientific name in Latin language. Classification is the grouping of different organisms in different taxa and then their arrangement in hierarchical manner starting from species to kingdom. Initially organisms were classified on the basis of phenotypic characters into plants and animals. This system is called two-kingdom classification. Revelation of microbial word created problem of distribution of these microorganisms into existing two kingdoms. So a new kingdom, Protista was erected to adjust these and this system is known as three-kingdom classification. Further cytological studies showed that all organisms are basically made up of either prokaryotic cell or eukaryotic cell. Therefore, system of classification was modified to

four-kingdom classification in which fourth kingdom, Monera was added. The most widely accepted system of classification, known as five-kingdom classification, was proposed by R. H. Whittaker in 1969. In this classification living organisms have been divded into kingdoms, Monera, Protista, Fungi, Plantae and Animalia on the basis of certain criteria. However, this also needs revision as some valid objections have been raised against this. The most advance classification is three-domain classification that based on molecular characterization of different organisms. In this system life has been divided into domains, Bacteria, Archaea and Eukarya.

Glossary

Autotrophic: Ability to prepare own food using ether solar light (phtoautotrophy) or chemical energy (chemoautotrophy).

Binomial nomenclature: Giving two names to an organism.

Cell: The basic structural and functional unit of life.

Classification: Formation and arrangement of groups in an order.

Heterotrophic: Dependence for food on others.

Nomenclature: System of assigning names to organisms as per set rules.

Nutrition: Process of acquiring nutrients.

Phylogeny: Evolutionary history of any group.

Species: The basic unit of taxonomy; according to typological –morphological concept it is a group of individuals, which are morphologically distinct from other such groups.

Taxon: Any taxonomic group.

Exercise/ Practice

Q1. Define the following.

(i) Taxonomy

(ii) Binomial nomenclature

(iii) Classification

(iv) Taxon

(v) Domain

(vi) Phylogeny

Q2. Fill in the blanks.

(i) The basic unit of biological classification is ……..

(ii) …… is a group of related genera.

(iii) …….. is the top most rank in most advance system of classification.

(iv) Carolus Linnaeus is called as …….. of taxonomy.

(v) Specific epithet is ……. .name in binomial nomenclature and this always starts with a ……. .letter.

(vi) Major criteria used in two-kingdom classification are ……. characters in number.

(vii) Whittaker proposed a new kingdom,…….. in his classification in 1969.

(viii) Three domain classification was given by ……

(ix) Three domain classification is mainly based on criterion of …….

Q3. Taxonomy is a multidisciplinary science. How does development taken place in other branches change the course of taxonomy? Elaborate with examples.

Q4. What is a hierarchical order? What is the importance of this in classification?

Q5. Why is it considered difficult to propose a phylogenetic classification?

Q6. What are the major criteria of Whittaker's classification?

Q7. Name all the kingdoms along with characteristic features in Whittaker's classification.

Q8. Distribute given organisms - *E. coli* (bacterium), *Chlamydomonas* sp. (microalga), *Amoeba* sp. (protozoan), brown alga, bread mould, pea plant and horse at the level of kingdom as per following systems of classification.

(i) Two-kingdom classification

(ii) Three-kingdom classification

(iii) Four-kingdom classification

(iv) Five-kingdom classification

Q9. Why is the study of rRNA considered useful in determining the evolutionary relationship among organisms?

Q10. What are the distinguishing features of three domains?

Q11. Write the major differences among eubacteria, archaebacteria and eukaryotes.

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Links

1. http://www.youtube.com/watch?v=g9AQbkQgVeU

2.http://books.google.co.in/books?id=Vs5V3cAzOMsC&pg=PR3&lpg=PR3&dq=S+K+aggarwal+deshbandhu+college&source=bl&ots=BLmLNS6M67&sig=4TTSNnwJeZK3O2TumifEyAvnme0&hl=en&sa=X&ei=2xAfUtDvKoHjrAfFxoDYAQ&ved=0CGAQ6AEwCQ#v=onepage&q=S%20K%20aggarwal%20deshbandhu%20college&f=false