Introduction.

There are millions of organisms – plants, animals, bacteria and viruses. Each one is different from the other in one way or the other. About more than one million of species of animals and more than half a million species of plants have been studied, described and provided names for identification. Thousands are still unknown and are yet to be identified and described. It is practically impossible to study each and every individual. Also, it is difficult to remember their names, characters and uses. However, biologists have devised techniques for identification, naming and grouping of various organisms.

The art of identifying distinctions among organisms and placing them into groups that reflect their most significant features and relationship is called **biological classification**. Scientists who study and contribute to the classification of organisms are known as systematists or taxonomists, and their subject is called systematics (*Gk. Systema* = order of sequence) or **taxonomy** (*Gk. Taxis* = arrangement; *nomos* = law).

History of classification : References of classification of organisms are available in **Upanishads** and **Vedas**. Our Vedic literature recorded about 740 plants and 250 animals. Few other significant contributions in the field of classification are :

(1) **Chandyogya upanishad :** In this, an attempt has been made to classify the animals.

(2) **Susruta samhita :** It classifies all 'substances' into **sthavara** (imbobile) *e.g.* plants and jangama (mobile) *e.g.* animals .

(3) **Parasara :** Here, angiosperms were classified into **dvimatruka** (dicotyledons) and **ekamatruka** (monocotyledons). He was even able to find that dicotyledons bear **jalika parana** (reticulate veined leaves and monocotyledons bear **maun laparna** parallel veined leaves).

(4) **Hippocrates, and Aristotle :** They classified animals into four major groups like insects, birds, fishes and whales.

Types of system of classification.

Different systems of classification proposed from time to time have been divided into three basic categories *viz.*, artificial systems, natural systems and phylogenetic system (However, Redford, (1986), included mechanical systems as a fourth category).

(1) **Artificial system of classifications :** These systems are more or less arbitrary as the plants are classified merely on the basis of gross morophology, habit and their importance to man. The main advocates of artificial system of classifications were :

(i) **Theophrastus :** Father of botany. Theophrastus was a disciple of Plato and later Aristotle. In his book *De Historia plantarum,* he classified about 500 kinds of plants into four major group; trees, shrubs, subshrubs and herbs.

(ii) **Caius Plinius Secundus :** He described the biological, medicinal and agricultural aspects of plants in 37 volumes of *Natural History.* He used the term 'Stamen' for the first time.

(iii) **Pedanios Dioscorides :** He described about 600 plants of medicinal importance in his *Materia Medica*.

(iv) **Charaka :** Indian Scholar. He classified plants of medicinal importance in his *Charaka Samhita*.

(v) **Andrea Caesalpino :** He described 1520 species in 16 volumes of *De Plantis libri* grouped as herbs and trees. He further classified plants based on fruit and seed characters.

(vi) **John Ray :** He was a British botanist who published three volumes of his work *Historia Generalish Plantarum* consisting of improved classification originally proposed by him in *Methodus Plantarum Noven*. He was the first to divided the groups herbs, shrubs and trees into Dicots and Monocots on the basis of the presence of two or one cotyledons respecitvely. He coined the term **species**.

(vii) **Carolus Linnaeus :** Father of taxonomy. A swedish botanist, who published an artificial system of classification based exclusively on floral characters. Linnaeus published several manuscripts including *Hortus cliffortianus* and *Genera plantarum* (1737). In his *Genera plantarum* he listed all the plant genera known to him. He published his best known *Species plantarum* in 1753. In this book he listed and described all species of plants known to him. He established binomial nomenclature.

(2) **Natural System of Classifications :** These systems of classification are based not only on the characters of reproductive organs and structural morphology but used as many taxonomic characters or traits as possible to classify the plants. The advocates of **natural** systems of classification are listed below :

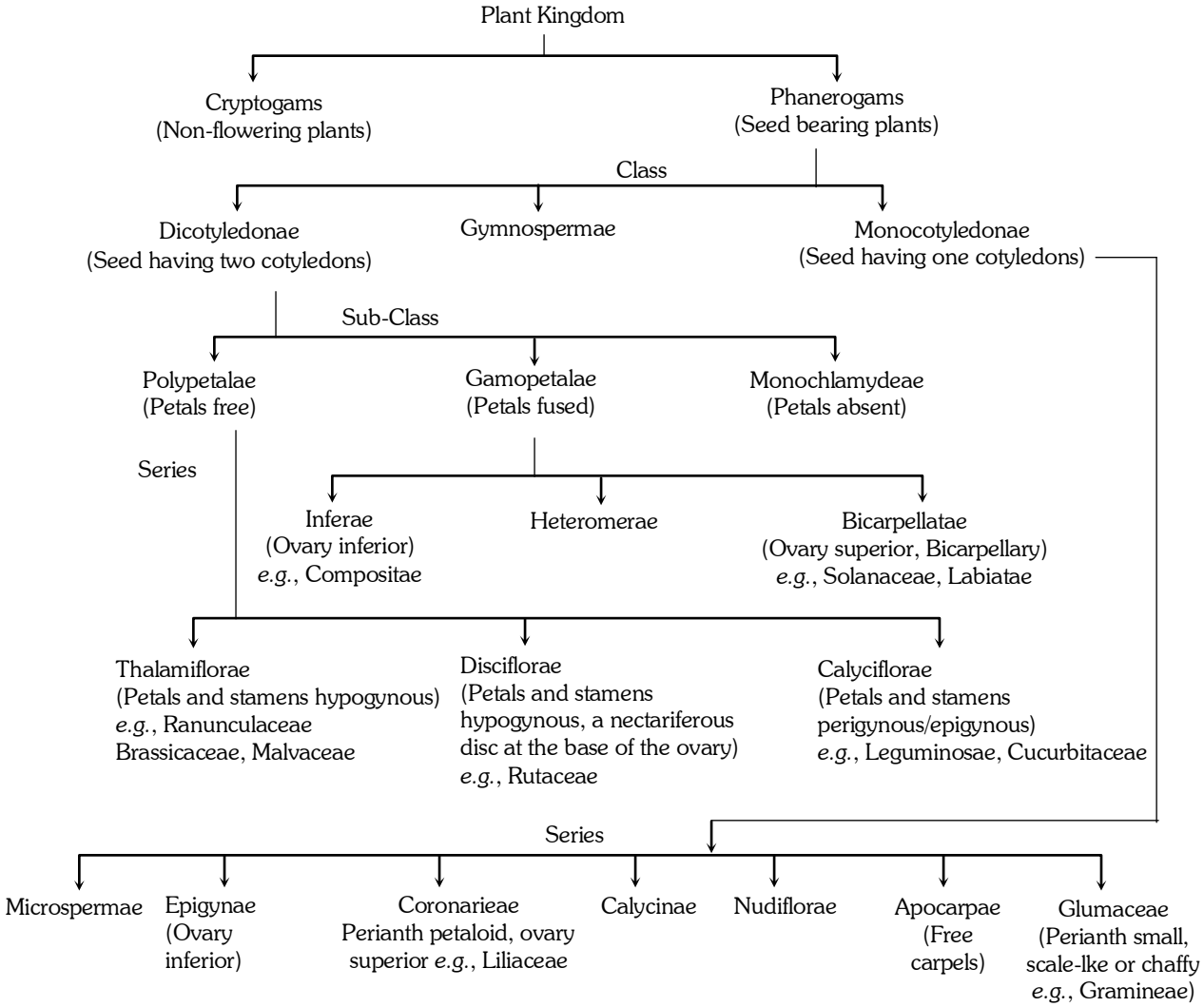
(i) **Michel Adanson :** A French botanist, who classified plants and animals using as many characters as possible and proposed a natural system of classification.

(ii) **A.L. de Jussieu :** Classified plants based on natural characters. In his system of classification he grouped the plants resembling each other in a set of characters.

(iii) **A.P. de Candolle :** He grouped all alike plants together and published a new classification of plants in his book *Theorie elementaire de la botanique* (1813).

(iv) **George Bentham and Joseph Dalton Hooker :** These two English botanists classified plants based on original studies of specimens. They published their well known scheme of classification in *Genera plantarum* (1862–83). This system of classification is still regarded as the best classification, especially from the practical point of view.

Bentham and Hooker's classification (Broad outline)



Merits and Demerits of Bentham and Hooker's system of classification

Merits

This system is regarded as most convenient and suitable for practical utility and is followed by most of the herbaria due to following reasons :

(a) Every genus and species was **studied from actual specimens** available in British and continental herbaria.

(b) It is the **first great natural system of classification**. This is very useful for practical purposes.

(c) Gymnosperms have been considered as third taxon and kept between dicots and monocots.

(d) In monocots, stress has been given to relative position of ovary and perianth characteristics.

(e) Great emphasis has been given to free or fused conditions of petals distinguishing dicots into three sub-classes Polypetalae, Gamopetalae and Monochlamydeae.

Demerits : There are some demerits in the classification of Bentham and Hooker. Some of them are :

(a) The greatest demerit of this system is the retention in the group monochlamydeae, a number of orders which represent affinities with those in which biseriate perianth is the rule.

(b) Placing gymnosperms between dicots and monocots.

(c) Here monochlamydeae is considered as most highly evolved and polypetalae as primitive among dicots.

(d) Cucurbitaceae family with fused petals is placed in Polypetalae.

(e) Liliaceae is separated from Iridaceae and Amaryllidaceae merely on the character of ovary, without keeping in mind other similarities.

Differences between Natural and Artificial classification

No.	Characters	Natural classification	Artificial classification
1.	Number of characters	Almost all the characters are considered.	Only few characters are considered.
2.	Hereditary constitution	Members are mostly alike in hereditary pattern of different groups.	Members of different groups are usually not similar in hereditary pattern.
3.	Flexible	May change with advancement in knowledge.	Stable classification.
4.	Phylogeny	Closely related phylogenetically.	Not related phylogenetically.
5.	Information	Provides plenty of useful information.	Provides only limited information.
6.	Recent advances	Recent useful research can be easily incorporated.	Cannot incorporate new work.
7.	Convenience	Identification of plants easy.	Difficult.
8.	Little known plants	Got the place at definite place.	Not certain about position and identification.

(3) **Phylogenetic system of classifications :** These systems of classifications are mainly the rearrangements of natural systems using as many taxonomic characters as possible in addition to the phylogenetic (evolutionary) informations. Some important phylogenetic systems of classifications were proposed by –

(i) **A.W. Eichler :** A German botanist who proposed phylogenetic system of classification and published in the third edition of *Syllabus der vorlesungen* (1883).

(ii) **Adolph Engler and Karl Prantl :** These two german botanists classified plant kingdom on the basis of their evolutionary sequences. They started with simplest flowering plants and ended with plants of complex floral structures.

(iii) **C.E. Bessey :** He classified flowering plants on the basis of their evolutionary relationships.

(iv) **John Hutchinson :** A British botanist published his phylogenetic system of classification in '*The Families of Flowering Plants*'.

(v) **Armen Takhtajan :** A Russian botanist who published his system of classification in *Botanical Review*.

(vi) **Arthur Cronquist :** Published his classification in '*An Integrated System of Classification of Flowering Plants*'.

Differences between Natural and Phylogenetic classification

No.	Characters	Natural classification	Phylogenetic classification
1.	Number of characters	Based on several constant characters.	Along with several constant characters, evolutionary sequences are also considered.
2.	Evolutionary sequences	Not considered. Classification based basically on common characters.	Evolutionary sequence, natural affinities and relationship taken into account.
3.	Practical utility	Used adequately as an aid for easy identification.	Phylogenetic and adopted by many countries.

Plant nomenclature.

Plant nomenclature may be defined as the system of naming plant. Almost all plants (and animals too) are known by different common names in different parts of the world. Even within the same country people of different states and regions use different common names. *Iphomoea batatas*, for example, is called **sweet potato** in English, **Shakarkandi** in Hindi, **Meetha alu** in Assamies and Bengali, **Kundmul** in Telagu, **Ratalu** in Marathi and **Jenasu** in Kannad. The common names are thus quite confusion. This necessiated the need of giving scientific names so that scientists of different parts of the world could understand each other work. The earliest scientific names were **polynomial**, *i.e.*, they were composed of many words (which gave the characteristics of plants), *e.g.*, *Sida acuta* (a member of Malvaceae) was named as *Chrysophylum foliis, ovalis superne glabris parallel striatis subtus, tomentosonitidis*. Such long names were difficult to remember. Hence, to make it easier binomial system of nomenclature was introduced.

(1) **Binomial system of nomenclature :** The credit of giving binomial system of nomenclature goes to Swedish naturalist, Carolus Linnaeus. He employed this system in his book ***Species Plantarum***, published in 1753. According to this system the name of a plant or animal is composed of two Latin (or Latinised) words, *e.g.*, potato is *Solanum tuberosum*. The first word (*i.e., Solanum*) indicates the **name of the genus** (called **generic name**) and the second word (*i.e., tuberosum*) denotes the **name of the species** (called **specific name**). The generic name always begins with a capital letter and the specific name with a small letter and printed in italics.

The generic and specific names always have some meaning. They are based on some special characters of the plant, on the name of any scientist or on some legend.

All plants having general similarity and relations are given a common generic name, *e.g.*, potato, brinjal, black nightshade (makoi) have been placed in the genus *Solanum*. However, their specific names distinguish them from each other – potato is *Solanum tuberosum*, brinjal is *S. melongena* and black nightshade is *S. nigrum*.

Usually the name of the author, who names a plant, is also written in full or in abbreviated form after the specific name. Thus, in case of *Mangifera indica* L., the L. stands for **Linnaeus** and in *Lychnis alba* Mill., the Mill. stands for **Miller**.

Sometimes a single species is described under different names by different authors. These name are called **synonyms**. In such cases, the name under which the species is first described, is considered to be valid.

(2) **Trinomial nomenclature :** Certain species are divisible into smaller units, called varieties, on the basis of finer differences. The name of the variety is written after the specific name. Thus, the name may become trinomial or three word name. *e.g.*, *Homo sapiens europeus* is the name of the man of European race. Trinomial nomenclature is simply an extension of the Linnaean system.

(3) **Code of biological nomenclature :** Anyone can study, describe, identify and give a name to an organism provided certain universal rules are followed. These rules are framed and standardised by International Code of Botanical Nomenclature (ICBN) and International Code of Zoological Nomenclature (ICZN). The codes help in avoiding errors, duplication, confusion and ambiguity in scientific names. The codes are established and improved upon at International Botanical and Zoological Congress held from time to time. The names of bacteria and viruses are decided by International Code of Bacteriological Nomenclature (ICBN) and International Code of Viral Nomenclature (ICVN). Similarly, there is a separate International Code of Nomenclature for Cultivated Plants (ICNCP).

Explanation of terminology (Units).

(1) **Taxon :** The term taxon is used to represent any unit of classification. The unit (*i.e.*, taxon) many be large (*e.g.*, Plant Kingdom) or small (*e.g.*, Algae, Fungi, or a single species).

(2) **Category :** Various sub-divisions of plants kingdom such as division, class, order, family, etc., are referred to as categories. In the hierarchy of categories kingdom is the highest and species is the lowest category. The following is hierarchial series :

(i) **Kingdom :** It is the highest category in biological classification. All plants are include in plant kingdom.

(ii) **Division :** It is a major group in the Linnean hierarchy used in the classification of plants (equivalent to *phylum* in animal classification). It is a taxonomic category between kingdom and class. The subcategory of division is **subdivision**. The suffix of division is – ophyta.

(iii) **Class :** A division is divided into classes. It is a taxonomic category between the division and order. Its suffix is – ae. The subcategories of class are subclass and series. In the class contain organism least similar to one another.

(iv) **Order :** A class includes one or more orders. It is a taxonomic category between the class and family. Its suffix is – ales. The subcategory of order is **suborder.**

(v) **Family :** An order is divided into one or more families. It is the taxonomic category between the order and the genus. Its suffix is – aceae. The subcategories of family are **subfamily, tribe** and **subtribe**.

(vi) **Genus :** The plural of genus is genera. A family includes one or more genera. The generic name is important and printed in Italics (If hand written, it is underlined). The subcategories of genus are **subgenus, section** and **subsection**.

(vii) **Species :** It is the smallest rank of taxonomic classification. The first letter of the species is denoted with small letter. The species is printed in Italics (It is underlined if hand written). A genus may include one or more species. The subcategories of species are **subspecies, varieties, subvarieties, form** and **subform**.

(3) **New systematics or Biosystematics :** The term new systematics was proposed by Sir Julian Huxley in 1940. In the new systematics, the species are considered related to one another, mutable and the work of gradual modification. This is in confirmity with the facts of evolution.

Forms of new systematics : There are several forms of new systematics –

(i) **Morphotaxonomy :** It is based on the structural features of the organisms.

(ii) **Cytotaxonomy :** It is based on the somatic chromosomes of organisms.

(iii) **Biochemical taxonomy or Chemotaxonomy :** It is based on the protein and serum analyses and on the chemical constituents of the organisms.

(iv) **Numerical taxonomy :** It involves quantitative assessment of similarities and differences in order to make objective assessments. Characters of organisms are given equal weight and the relationships of the organisms are numerically determined, usually with the aid of a computer.

(v) **Experimental taxonomy :** It is based on the genetic relationship determined with the help of experiments.

Important Tips

- *The arrangement of organism in to groups termed as classification.*
- *Forming the rules for classification known as Taxonomy.*
- *De candolle : Coind the term taxomy in 1913.*
- *Floral characters are used as basis of classification and for identifying new species because floral characters are conservative when compared with vegetative characters.*
- *In Bentham and Hooker's classification Dicotyledons have been kept before Monocotyledons. Seeds plants have been divided into Dicots, Gymnospermae and Monocots.*
- *Among the vegetative characters, venation in leaf in one of highly acceptable characters for classification of angiosperms.*
- *In Engler and Prantl's system Monocotyledons have been kept before Dicotyledons.*
- *In Bentham and Hooker's classification 202 families have been identified.*
- *Bentham and Hooker's classification is a natural system of classification and very helpful for practical purposes.*
- *For declaration of new species, floral characters of new species should be used.*
- *In Bentham and Hooker's system of classification, evolutionary criteria have not been followed hence not phylogenetic.*
- *Hooker complied first complete flora of India and wrote the book 'Flora of British India'.*
- ***Bentham and Hooker :** Gave the first natural classification of plants.*
- ***Engler and Prantl :** Gave the first phylogenetic classification of plants.*
- *Engler and Prantl's and Hutchinson's system of classification are phylogenetic.*
- *411 families have been recognised in Hutchinson's system of classification and 280 families have been identify in Engler and Prantl's system of classification.*
- ***Father of Botany :** Theophrastus, a Greek philosopher, produced the first book on botany, **Historia Plantarum**, student of Aristotle.*
- *After the work of Linnaeus, another significant publication was that of **Augustin de Candolle** in theory elementaire de la botanique.*
- *The correct sequence of taxa in Linnaean hierarchy is species → genus → family → order→ class.*
- *A system for naming the organisms called nomenclature.*
- *Bauhin (1623) proposed the binary system of nomenclature which was elaborated by Linnaeus (1753) in to binomial system.*

- *An international code of Botanical nomenclature (IBCN) come into existence in 1930.*
- *International code for nomenclature is divided into three parts i.e. (i) Principles (ii) Rules and recommendations (iii) Provisions.*
- ***Priority :** Nomenclature of taxonomic groups is based upon priority of publication.*
- ***Monotypic Genus :** A genus having only one species, e.g., Home.*
- ***Polytypic Genus :** A genus containing more than one species, e.g., Panthera, Solanum.*
- ***John Ray :** An English naturalist, 1627–1705, introduced the term species. It is a basic unit of classification.*
- *J.K. Maheswari described the plants of India in 'Flora of Delhi'.*
- *Phylogeny was introduced by Homock but concept was introduced by Heackel.*
- *Phylogenetic classification reflect the evolutionary relationships of organisms.*
- ***Type Specimen :** Original specimen is called **holotype**; duplicate of holotype is termed **isotype**; additional one is known as **paratype**; and a new one when the original is lost is referred to as **neotype**.*

Modern system of classification.

(1) **Two kingdom system of classification :** This system of classification is the oldest it was suggested by *Carolus Linnaeus* in 1758. He divided the living word (organism) in to two kingdoms, Plantae (for all plants like tree, shrubs, climbers, creepers, moss and floating green algae) and Animalia (For animals).

(2) **Three kingdom system of classification :** *Ernst Haeckel*, a German biologist and philosopher, suggested a third kingdom protista in 1866 for –

(a) Unicellular organisms such as bacteria, protozoans and acellular algae.

(b) Multicellular organisms without tissue such as algae and fungi.

(3) **Four kingdom system of classification :** It was proposed by *Copeland* in 1956. The two additional kingdoms were Monera for the bacteria and blue green algae and Protista for protozoans, algae and fungi.

(4) **Five kingdom system of classification :** *R.H. Whittaker*, an American ecologist. He proposed five kingdom system of classification in 1969.

This system replaced the old, two-kingdom grouping of living organisms. As already discussed, a division of living world merely into plant and animal kingdoms is too simple. It does not take into account the **gradual** evolution of distinct plant and animal groups and it allows no place for those primitive organisms that even now are neither plants nor animals nor that are both. In this classification eukaryotes were assingned to only four of the five kingdom.

Five-kingdom classification is based on the following four criteria :

(i) Complexity of cell structure.

(ii) Complexity of organism's body.

(iii) Mode of obtaining nutrition.

(iv) Phylogenetic relationship.

The five kingdom are : Monera, Protista, Fungi, Plantae and Animalia.

Kingdom Monera (The prokaryotes).

Monera (*Monos – single*) includes prokaryotes and shows the following characters :

(1) They are typically unicellular organisms (but one group is mycelial).

(2) They lack nuclear membranes.

(3) Ribosomes and simple chromatophores are the only subcellular organelles in the cytoplasm. The ribosomes are 70 S. Mitochondria, plastids, Golgi apparateus, lysosomes, endoplasmic reticulum, centrosome, etc., are lacking.

(4) The predominant mode of nutrition is absorptive but some groups are photosynthetic or chemosynthetic.

(5) Reproduction is primarily asexual by fission or budding.

(6) Protosexual phenomenon also occurs.

(7) The organisms are non-motile or move by beating of simple flagella or by gliding.

(8) Flagella, if present, are composed of many intertwined chains of a protein **flagellin**. They are not enclosed by any membrane and grow at the tip.

(9) Moneran cells are microscopic (1 to few microns in length).

(10) Most organisms bear a rigid cell wall.

(11) The kingdom Monera includes true bacteria, mycoplasmas, rickettsias, actinomycetes (ray fungi) etc. Microbiologists also include blue green algae (*i.e.,* Cyanobacteria) under the group bacteria because of the presence of prokaryotic cell structure. Studies have established that the members of archaebacteria group are most primitive and have separated from eubacteria group very early in the process of evolution. Furthermore, these studies have also concluded that the archaebacteria and eubacteria possibly originated from a more ancient form of life called **Progenote**.

(12) **Nutrition :** They show both autotrophic and heterotrophic modes of nutrition.

(i) **Autotrophs :** These are able to form their own food by one of the following methods.

(a) **Photoautotrophs :** They prepare their own food by reducing CO_2 using light energy.

(b) **Chemoautotrophs :** They form their food by energy derived from chemical reaction.

(ii) **Heterotrophs :** A few live in **symbiosis** while others form association of commensalism. **Saprophytes** also called 'saprobes' cause decay, fermentation or putrefaction of dead organic matter. Some bacteria are facultative sasprophyte (= facultative parasites). In the process of fermentation there is anaerobic break-down of carbohydrates into CO_2, alcohol and some energy. **Putrefaction** or decay is anaerobic break-down of proteins accompanied by foul smell due to evil smelling gases produced in the process.

The saprobes produce enzymes which convert non-diffusible food substrates (carbohydrate fats, proteins, etc.) into simpler diffusible form which diffuses into the cytoplasm and is assimilated, *i.e.*, converted into body cytoplasm or stored as reserve food.

Still others live on other living organisms (animals, plants or man) in the form of parasites directly absorb their food from the body of host. Some of the parasites are **non-pathogenic** *i.e.*, cause no ill-effect or disease in the host, while some are **pathogenic** causing diseases in the host.

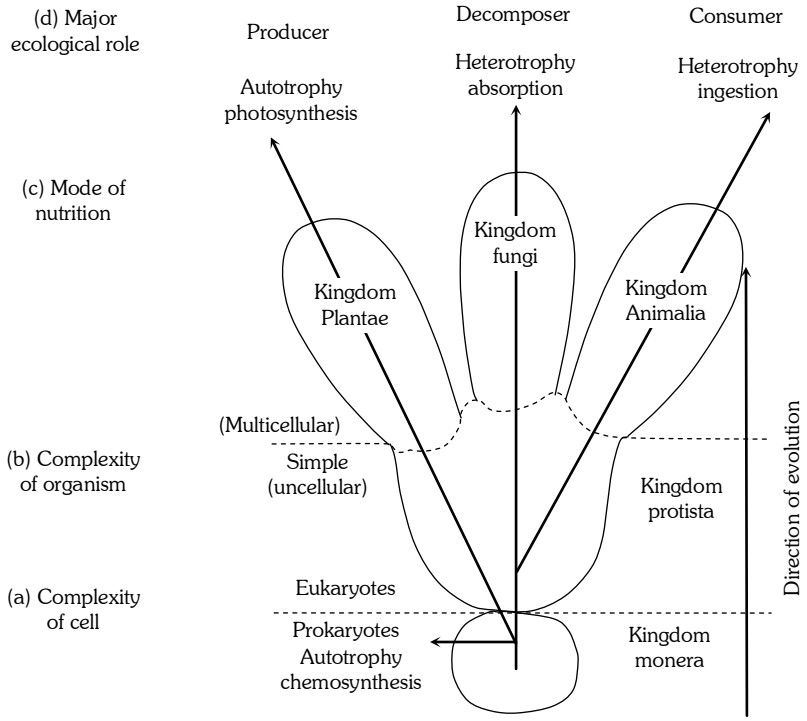


Fig : Probable phylogenetic relationships among the kingdoms

(13) **Reproduction :** It is primarily asexual by binary fission or budding. Mitotic apparatus is not formed during cell division. Distribution of replicated DNA into daughter cells is assisted by cell membrane. Exchange of genetic material between two bacterial cells is known to occur but no gametes are formed. Sterols, the precursor molecules of sex hormones, have been reported from certain prokaryotes. Many bacteria form resistant spores.

Kingdom Protista (Unicellular eukaryotes).

Protista (*Protistos* = Primary) includes unicelluar eukaryotes and show the following characters :

(1) Protists include solitary unicellular or colonial unicellular eukaryotic organisms which not form tissues.

(2) Simple multinucleate organisms or stages of life cycles occur in a number of groups.

(3) The organisms possess nuclear membranes and mitochondria.

(4) In many forms, plastids, (9+2 strand) flagella and other organelles are present.

(5) The nutritive modes of these organisms include photosynthesis, absorption, ingestion and combination of these.

(6) Some protists possess contractile vacuole for regulation of their water content.

(7) Their reproductive cycles typically include both asexual divisions of haploid forms and true sexual processes with karyogamy and meiosis.

(8) The organisms move by flagella or by other means or are non-motile.

(9) **Nutrition :** It is may be photosynthetic, holotrophic, saprotrophic and parasitic. Some have mixotrophic nutrition (holotrophic + saprobic). Chemosynthetic nutrition is lacking. Certain protozoans decompose organic matter, such as cellulose, in the gut of termites and woodroaches. They live as symbionts. The photosynthetic, floating protists are collectively called **phytoplankton**. They usually have a cell wall. The free-floating, holozoic protozoans are collectively termed **zooplankton**. They lack cell wall to allow ingestion of particulate food.

(10) **Reproduction :** It is occurs by both asexual and sexual methods :

(i) **Asexual reproduction :** It is the most common method of reproduction in protists in which the genetic constitutions of young ones remains the same as that of the parent. Under favourable environmental conditions, they reproduce asexually several times a day resulting in population explosions. The major types of asexual reproductions are as follows :

(a) **Binary fission :** The parent cell divides into two approximately equal daughter cells either transversely (*e.g.*, *Paramecium*), longitudinally (*e.g., Euglena*) or axially (*e.g., Amoeba*) by mitosis.

(b) **Multiple fission :** Division of parent cell into a number of daughter cells is called multiple fission. It occurs in *Amoeba*.

(c) **Plasmotomy :** Fission of multinucleate protist into two or more multinucleate offsprings by the division of cytoplasm without nuclear division is called plasmotomy. It occurs in *Opalina*.

(d) **Budding :** In this type of asexual reproduction, a small bud is formed from the parent body which separates and develops into new individual. *e.g., Paracineta, Arcella, etc.*

(e) **Spore formation :** Sessile or stalked sporangia containing spores are formed in slime moulds. They liberate the spores which can withstand a prolonged period of desiccation. On germination, each spore gives rise to new individual. *e.g.*, Slime moulds.

(ii) **Sexual reproduction :** Sexual reproduction is believed to have originated in primitive protists. It involve meiosis (reduction division) and syngamy. It occurs following types.

(a) **Isogamy :** The two fusing gametes are structurally and functionally similar, *e.g.*, *Monocystis*.

(b) **Anisogamy :** The two fusing gametes are similar but differ only in their size and/or motility, *e.g., Ceratium*.

(c) **Oogamy :** Large non-motile gametes are fertilized by smaller motile gametes, *e.g., Plasmodium*.

(11) **Major group of protists :** Unicellular protists have been broadly divided is to three major grous

(i) **Photosynthetic protists :** Protistan algae *e.g.* **Dinoflagellates** (*i.e. Ceratium, Glenodinium, Gymnodinium, Gonyaulax, Noctiluca* and *Peridinium*), **Diatoms** (*Navicula, Nitzchia, Melosira, Cymbella, Amphipleura, Pinnularia*) and **Euglenoids** or Euglena like flagellates (*Euglena, Eutreptia, Phacus, Peranema*).

(ii) **Consumer protists :** Slime moulds or Myxomycetes, *e.g., Physarum, Physarella*.

(iii) **Protozoan protists :** It is include four phyla – **Zooflagellata** (*e.g., Trypanosoma, Giardia, Trichonympha, Trichomonas, Leishmania* etc.), **Sarcodina** (*e.g., Amoeba, Entamoeba, Pelomyxa, Mestigamoeba* etc.), **Sporozoa** (*e.g., Plasmodium, Monocystis, Eimeria* etc. all are endoparasites) and **Ciliata** (*e.g., Paramecium, Vorticella, Opalina, Podophyra* etc.).

Dinoflagellates (Division-Pyrrophyta)

(1) **Habit and Habitat :** This is well defined group of unicellular, golden-brown photosynthetic organisms. Majority of them are motile and flagellated but a few are non-motile and non-flagellated. Flagellated forms exhibit peculiar spinning movement. Hence, they are called **whorling whips.** The group includes about 1000 species. Most of them are marine but some occur in fresh water. Majority of the forms are **planktonic** and cover the surface of water body imparting them the characteristic colours.

(2) **Structure**

(i) **Cell wall :** The cell wall of dinoflagellates, if present, is composed of a number of plates made up of cellulose. It is called **theca** or **lorica**. The theca contains two grooves-longitudinal **sulcus** and transverse **girdle** or **annulus**. The cell surface usually bears sculpturing and hexagonal platelets.

(ii) **Flagella :** Usually the cells possess two **flagella** which are of different types (heterokont). One flagellum is transverse which arises from an anterior point in the transverse girdle. It is helical in form and ribbon-furrow and trails behind the cell. It is narrow, smooth and acronematic type. Both the flagella arise through pores in lorica.

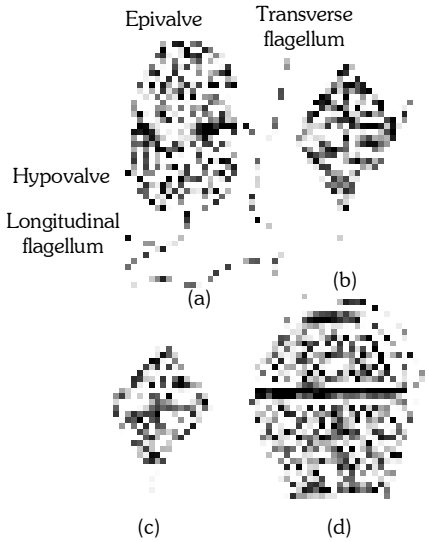


Fig : Some dinoflagellates (a) Glenodinium (b) Peridinium (c) Gynnodium (d) Gonyaulax

(iii) **Nucleus :** Cells possess a relatively large and prominent nucleus known as **mesokaryon.** The interphase nucleus has condensed chromosomes which lack histones.

(iv) **Plastids :** There are numerous discoid chloroplasts without pyrenoids. They are yellow-brown to dark-brown in colour due to presence of characteristic **pigments** – Chlorophyll a, c, α - carotene and xanthophylls (including dinoxanthin and peridinin).

(v) **Reserve food :** The reserve food material is starch or oil.

(vi) **Pusule :** The cells possess an osmoregulatory organelle called **pusule** which superficially looks like contractile vacuole.

The cells posses mitochondria, ribosomes and Golgi bodies. They also possess mucilage bodies or vesicles below the cell membrane.

(3) **Nutrition :** In dinoflagellates it is mainly holophytic or photosynthetic. However, some forms are saprobic, parasitic, symbiotic or holozoic. For example, an colourless *Blastodinium* is parasite on animals.

(4) **Reproduction**

(i) **Asexual reproduction :** Dinoflagellates reproduce asexually through cell division or by the formation of zoospores and cysts.

The cell division starts from posterior end. During cell division, centromeres and spindle are not seen. The spindle is replaced by cytoplasmic microtubules. During mitosis, the chromosomes break up into pairs of romatids. The nuclear envelops and nucleolus persists during divison.

(ii) **Sexual reproduction :** If it is occurs, is isogamous or anisogamous. Two cells conjugate by a conjugation canal where the two amoeboid gametes fuse to form a diploid zygote. Life cycle involves zygotic meiosis (*e.g., Ceratium, Gymnodinium* etc.) or gametic meiosis (*e.g. Noctiluca*).

Diatoms (Division-Bacillariophyta)

(1) **Habit and Habitat :** Most of the diatoms occur as **phytoplanktons** both in fresh and marine waters. A few forms occur as benthos the bottom of water reservoirs. Some are terrestrial and grow on moist soil. Diatoms constitute a major part of phytoplankton of the oceans. It is estimated that a 60 ton blue whale may have approximately 2 tons of plankton (mostly diatoms) in its gut.

(2) **Structure**

(i) **Shape :** The cells of diamots are called frustules or shell. They are microscopic, unicellular, photosynthetic organisms of various colours and diverse forms. They may be circular, rectangular, triangular, elongated, spindle-shaped, half-moon shaped, boat-shaped or filamentous.

(ii) **Symmetry :** They exhibit mainly two types of symmetry-radial symmetry as in **centrales** (*e.g. Cyclotella*) and isobilateral symmetry as in **Pennales** (*e.g. Pinnularia*).

(iii) **Cell wall :** The cells of diatoms are called **frustules.** The cell wall is chiefly composed of cellulose impregnated with glass-like silica. It shows sculpturings and ornamentations. It is composed of two overlapping halves (or theca) that fit togather like two parts of a soap box. The upper half (lid) is called **epitheca** and the lower half (case) is called **hypotheca.**

(iv) **Flagella :** Diatoms do not possess flagella except in the reproductive stage. They show **gliding** type of movement with the help of mucilage secretion. They float freely on the water surface due to presence of light weight lipids.

(v) **Nucleus :** Each cell has a large central vacuole in which a prominent nucleus is suspended by means of cytoplasimc strands. The cells are **diploid** (2 N). In case of centrales, the nucleus lies in the peripheral region.

(vi) **Plastids :** The cells possess plate-like or discoid chromatophores (or chloroplasts). They contain Chlorophyll *a,* Chlorophyll *c,* carotenes, diatoxanthin, diadinoxanthin and fucoxanthin (chlorophyll *b* is absent).

(vii) **Reserve food :** The reserve food material is **oil** and a polysaccharide – **chrysolamisarin** (or **leucosin**).

(3) **Reproduction**

(i) **Asexual reproduction :** The most common method of multiplication is **binary fission** (cell division) that occurs at night. In this process, each daughter individual retains one half of the parent cell and the other half is synthesized *i.e.* epitheca is retained and the hypotheca is synthesized. As a result, one of the two daughter individual is slightly smaller than the parent cell and there is gradual reduction in the frustule over the generations. However, the normal size is maintained by – formation of rejuvenescent cells (auxospores), growth of protoplast secreted from the frustule and secretion of new frustule of larger size.

(ii) **Sexual reproduction :** Reproduction takes place by the fusion of gametes. Meiosis is gametic *i.e.* takes place during the formation of gametes. The diploid nucleus of parent cell divides by meiosis into 2 or 4 daughter cells. Out of 4 haploid daughter nuclei only one or two survive and rest degenerate. Thus they produce only one or two gametes. The gametes may come out by an amoeboid movement and fuse externally in pairs within a mucilaginous sheath to produce zygote. The diploid zygote then a transformed into **auxospore.**

Important Tips

- *The term prokaryotes and eukaryotes were coined by Fott.*
- *In five kingdom system of classification, the main basis of classification is structure of nucleus.*
- *Gold Fuss give the term 'Protozoa'.*
- *Ernst Haeckel proposed the term 'Protista'.*
- *Photosynthetic protists fix about 80% of CO_2 in the biosphere.*
- ***Protistology :** Study of protists.*
- ***Monerology :** Study of monerans.*
- *Slime moulds possess animal like as well as fungi like character.*
- *Euglenoids possess plant like as well as animal like characters.*
- *De Bary (1887) classified slime moulds as a animal and called them 'Mycetozoa'.*
- *Macbrid coind the term 'Myxomycetes' (Slime moulds).*
- *Dinoflagellates, due to **spinning** caused by activity of transverse flagellum (in cingulum/annulus) and longitudinal flagellum (in sulcus), represent whorling whips.*
- *Dinoflagellates with bioluminescence/phosphorescence due to light producing protein luciferin are called **fire algae**. e.g. Noctiluca, Pyrocystis, Pyrodinium etc.*
- ***Leeuwenhock** (1674, 1675, 1681) was first to observe and sketch protozoan protists including Vorticella and Giardia.*
- *Acellular organisms do not contain cellular structure e.g., viruses or not considered as cells but as complete organisms e.g., protists.*
- *Wall-less multicellular protoplasm of acellular slime moulds having branched veins and with process of cyclosis are called **phaneroplasmodium.***
- *Dinoflagellates symbionts in other protists and invertebrates are called zooxanthellae.*
- *Some dinoflagellates produce blooms or red tides. e.g. Gonyaulax, Gymnodinium etc.*
- *Silicon is present in the frustule of diatoms.*
- *Auxospones are formed by diatoms.*
- *Noctiluca dinoflagellate is called 'night light'.*
- *Diatoms are emploid as a source of water glass or sodium silicate.*
- *Ganobacteria term was coined by **IBCN** (1978).*

Kingdom fungi.

(1) **Introduction :** The science dealing with the study of fungi is called as **mycology**. The knowledge of fungi to mankind dates back to prehistoric times. *Clausius*, 1601 may be regarded as one of the earliest writers to describe fungi. *Bauhin* (1623) also included the account of known fungal forms in his book **Pinax Theatric Botanica**. The fast systematic account of fungi came from Pier Antonio Micheli (1729) who wrote '**Nova Plantarum Genera**'. He is described by some workers as founder or mycology. *Linnaeus* (1753) also included fungi included fungi in his '**Species Plantarum**'. Elias Fries (1821-31) gave a more detailed account of fungi in his '**Silloge Fungorum**' in 25 volumes describing some 80,000 species of fungi. This work remains unparalleld even today.

(2) **Thallus organization :** The plant body of true fungi (Eumycota), the plant body is a **thallus**. It may be **non-mycelial** or **mycelial**. The non-mycelial forms are **unicellular**, however, they may form a **pseudomycelium** by budding. In mycelial forms, the plant body is made up of thread like structures called hyphae (sing. hypha). The mycelium may be **aseptate** (non-septate) or **septate**. When non-septate and multinucleate, the mycelium is described as **coenocytic**. In lower fungi the mycelium is non-septate *e.g.,* Phycomycetae. In higher

forms it is septate *e.g.*, Ascomycotina, Basidiomycotina and Deuteromycotina. In some forms the plant body is unicelled at one stage and mycelial at the other. Their organization is sometimes described as **dimorphic**.

Holocarpic and Eucarpic : When the entire mycelium is converted into reproductive structure, the thallus is described as holocarpic. However, if only a part of it becomes reproductive, the thallus is called as **eucarpic**. The eucarpic forms may be **monocentric** (having a single sporangium) or **polycentric** (having many sporangia).

(3) **Specialised formation :** In higher forms the mycelium gets organised into loosely or compactly woven structure which looks like a tissue called **plectenchyma**. It is of two types :

(i) **Prosenchyma :** It comprises loosely woven hyphae lying almost parallel to each other.

(ii) **Pseudoparenchyma :** If the hyphae are closely interwoven, looking like parenchyma in a cross-section, it is called as pseudoparenchyma.

In addition to above, the fungal mycelium may form some specialized structures as under :

(a) **Rhizomorphs :** Its a 'root-like' or 'string-like' elongated structure of closely packed and interwoven hyphae. The rhizomorphs may have a compact growing point.

(b) **Sclerotia :** Here the hyphae gets interwoven forming pseudoparenchyma with external hyphae becoming thickened to save the inner ones from desiccation. They persist for several years.

(c) **Stroma :** It is thick mattress of compact hyphae associated with the fruiting bodies.

(4) **Cell organization :** The cell wall of fungi is mainly made up of chitin and cellulose. While chitin is a polymer of N-acetyl glucosamine, the celulose is polymer of d-glucose. Precisely, the cell wall may be made up of cellulose-glucan (Oomycetes), chitin chitosan (Zygomycetes) mannan-glucan (Ascomycotina), chitin-mannan (Basidiomycotina) or chitin-glucan (some Ascomycotina, Basidiomycotina and Deuteromycotina). Besides, the cell wall may be made up of **cellulose-glycogen, cellulose-chitin** or **polygalactosamine-galactan.**

In higher fungi, where the mycelium is septate, the septa are of several types :

(i) **Solid septum :** It has no perforations.

(ii) **Perforated septum :** It has several perforations.

(iii) **Acomycetean septum :** It has a single large pore in the centre of the septum.

(iv) **Bordered pit type septum :** It has a perforation in the septum resembling the bordered pit of tracheary elements.

(v) **Dolipore septum :** It has a single barrel shaped pore in the septum due to thickened rim. The pore has a cap of ER called **parenthosome**.

The cell wall is closely associated with the inner layer, the **plasma membrane**. In fungi, specialized structure called **lomasomes** are also found associated to the plasma membrane. They appear to be as infoldings or invagination of the membrane. Almost similar structures called **plasmalemmasomes** are also found associated to the membrane. The cell contains one or more well defined

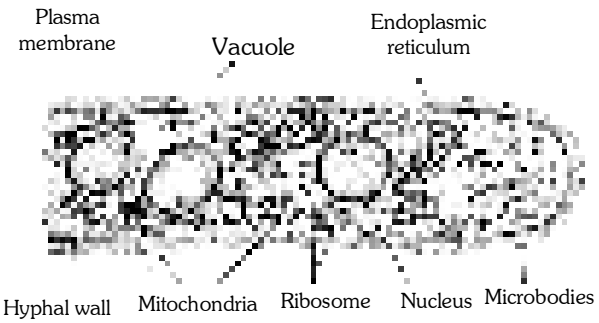


Fig : Diagrammatic electronmicrograph of a fungal cell

eukaryotic nuclei. In fungi the nuclei show intranuclear mitosis which is sometimes referred to as **karyochorisis**. They also contains mitochondria, E.R., ribosomes, microbodies, lysosomes, vacuoles and crystals of reserve food particles (glycogen, lipid etc.). The cells lack golgi and chloroplast and therefore, chlorophyll and starch grains are also absent. However, a reddish pigment, **neocercosporin** has been isolated from the fungus *Cercospora kikuchii*. The vacuoles are bound by tonoplast. The genetic material is DNA.

(5) **Nutrition :** The fungi are achlorophyllous organisms and hence they can not prepare their food. They live as heterotrophs *i.e.*, as **parasites and saprophytes**. Some forms live **symbiotically** with other green forms.

(i) **Parasites :** They obtain their food from a living host. A parasite may be **obligate** or **facultative**. The obligate parasites thrive on a living host throughout their life. The facultative parasites are infact saprophytes which have secondarily become parasitic. While the above classification is based on the mode of nutrition, however, on the basis of their place of occurrence on the host, the parasites can be classified as **ectoparasite, endoparasite** and **hemiendoparasite** (or **hemiectoparasite**). The ectoparasites occur on the surface of the host tissue whereas the endoparasites are found within the host tissue. The forms belonging to the third category are partly ecto- and partly endoparasites. In parasitic forms. The mycelium may occur within the host cells (**intracellular**) or in between the host cells (**intercellular**).

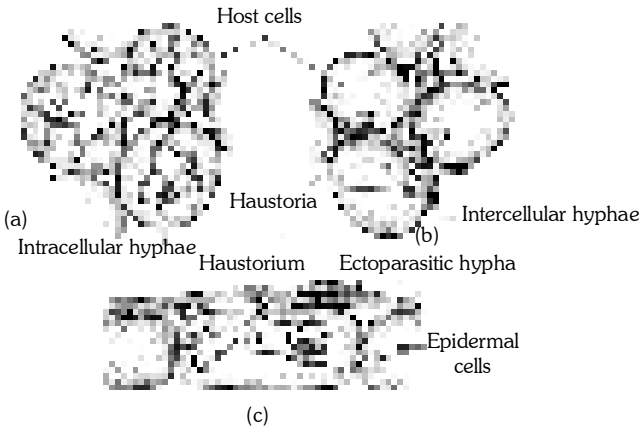


Fig : Parasitic hyphae and haustorial appendages : (a) Interacellular hyphae (b) and(c) Intercellular hyphae with haustoria

Some forms produce **rhizoids** for absorbing food. The parasitic fungi produce **appressoria** for adhering to the host. For absorbing food, the obligate parasites produce **haustoria**. As a result, the plasma membrane of the host cell becomes convoluted but it does'nt break. The fungal cell wall also remains intact. The haustoria may be finger-like, knob-like or branched. Each haustorium is distinguishable into a **base, stem** and **body**.

(ii) **Saprophytes :** They derive their food from dead and decaying organic matter. The saprophytes may be **obligate** or **facultative**. An obligate saprophyte remains saprophytic throughout it's life. On the other hand, a facultative saprophyte is infact a parasite which has secondarily become saprophytic.

(iii) **Symbionts :** Some fungal forms grow in symbiotic association with the green or blue-green algae and constitute the **lichen**. Here the algal component is photosynthetic and the fungal is reproductive. A few fungal forms grow in association with the roots of higher plants. This association is called as **mycorrhiza**. They are two types – Ectotrophic mycorrhiza and Endotrophic mycorrhiza *e.g.,* (VAM).

(6) **Reproduction :** The fungi may reproduce vegetatively, asexually as well as sexually :

(i) **Vegetative reproduction**

(a) **Fragmentation :** Some forms belonging to Ascomycotina and Basidiomycotina multiply by breakage of the mycelium.

(b) **Budding :** Some unicelled forms multiply by budding. A bud arises as a papilla on the parent cell and then after its enlargement separates into a completely independent entity.

(c) **Fission :** A few unicelled forms like yeasts and slime molds multiply by this process.

(d) **Oidia :** In some mycelial forms the **thallus** breaks into its component cells. Each cell then rounds up into a structure called oidium (pl. oidia). They may germinate immediately to form the new mycelium.

(e) **Chlamydospores :** Some fungi produce chlamydospores which are thick walled cells. They are intercalary in position. They are capable of forming a new plant on approach of favourable conditions.

(ii) **Asexual reproduction**

(a) **Sporangiospores :** These are thin-walled, non-motile spores formed in a sporangium. They may be uni- or multinucleate. On account of their structure, they are also called as aplanospores.

(b) **Zoospores :** They are thin-walled, motile spores formed in a zoosporangium. The zoospores are of several types :

- Uniflagellate with whiplash type flagellum *e.g., Allomyces.*
- Uniflagellate with tinsel type flagellum *e.g.*, *Rhizidiomyces.*
- Biflagellate with a tinsel type and a whiplash type flagella *e.g., Saprolegnia.*
- Biflagellate with two whiplash type flagella *e.g., Plasmodiophora.*

(c) **Conidia :** In some fungi the spores are not formed inside a sporangium. They are born freely on the tips of special branches called **conidiophores**. The spores thus formed are called as conidia. On the basis of development, two types of conidia are recognised namely thallospores and blastospores or true conidia.

Thallospores : In some forms the thallus itself forms spore like bodies called **thallospores**. The thallospore are of two types namely **arthrospores** and **chlamydospores**.

- **Arthrospores :** They are thinwalled spores formed in basipetal order *e.g., Endomyces.*
- **Chlamydospores :** Some of the hyphal cells are converted into thick walled chlamydospores. They may be terminal or intercalary *e.g.*, *Ustilago, Saprolegnia*.

Blastospores : They develop on conidiophores in acropetal or basipetal succession. They are of two types –

- **Porospores :** When the blastospores develop by the balooning of the inner wall of conidiophore, it is called as porospore *e.g., Alternaria.*
- **Phialospore :** On the other hand, when the first conidium carries the broken parent wall of conidiophore and subsequent conidia possess a new wall, such basipetally formed conidia are called as phialospore *e.g., Aspergillus*.

Bi-celled conidia are formed in *Trichothecium*. In *Fusarium* it is possible to differentiate smaller **microconidia** from larger **macroconidia**. Sometimes the conidiophores form specialised structures as under :

Synnema or Coremium : Here the conidiophores get arranged in closely placed parallel plates.

Acervulus : It is a cushion-shaped mass of hyphae having closely packed conidiophores.

Sporodochium : It is also a cushion-shaped acervulus like structure having loosely arranged conidiophores.

Pycnidium : It is pitcher-shaped, embedded body which opens to exterior by a pore called **ostiole**. It is lined by conidiogenous hyphae. The conidia developing in pycnidia are often described as **pycniospores.**

(iii) **Sexual reproduction :** With the exception of Deuteromycotina (Fungi imperfecti), the sexual reproduction is found in all groups of fungi. During sexual reproduction the compatible nuclei show a specific behaviour which is responsible for the onset of three distinct mycelial phases. The three phases of nuclear behaviour are as under :

Plasmogamy : Fusion of two protoplasts.

Karyogamy : Fusion of two nuclei.

Meiosis : The reduction division.

These three events are responsible for the arrival of the following three mycelial phases :

Haplophase : As a result of meiosis the haploid (*n*) or haplophase mycelium is formed.

Dikaryotic phase : The plasmogamy results in the formation of dikaryotic mycelium (*n* + *n*).

Diplophase : As a result of karyogamy the diplophase mycelium (2*n*) is formed.

In some fungi plasmogamy, karyogamy and meiosis do occur in a regular sequence but not at specified time or points in life cycle. Such a cycle is described as parasexual cycle and phenomena celled parasexuality recorded by Pontecorvo and Roper.

The fungi reproduce sexually by the following methods :

- **Isogamy :** It involves fusion of two morphologically similar flagellate gametes.
- **Anisogamy :** Here the two gametes are motile but morphologically dissimilar. The larger gamete may be called as female and the smaller one as male.
- **Heterogamy :** It involves fusion of a non-motile female gamete (egg) with the motile male gamete (antherozoid). While the male gamete is formed inside the **antheridium**, the female is produced inside the **oogonium**. Both the sex organs are unicelled structure.
- **Gametangial contact :** It involves fusion of two gametangia. In lower forms the female gametangium is called as **oogonium.** The male gametangium is termed as **antheridium**. A contact develops in between the two gametangia and then the male nucleus is transferred into the female directly or through a tube.
- **Gametangial copulation :** In this case the fusion occurs in between the two gametangia. When it occurs in some holocarpic forms where the entire thallus acts as gametangium, the phenomenon is called as **hologamy**. In others, dissolution of cell wall in between the two gametagial brings about gametangial copulation.
- **Spermatization :** Here the uninucleate male gametes called **spermatia** are formed in special structures called **spermogonia** or **pycnidia**. The female gametangium is called as **ascogonium** which has a long neck called **trichogyne**. The spermatium attaches itself with the trichogyne and transfers the male nucleus, thus bringing about **dikaryotisation**.
- **Somatogamy :** In higher fungi there is reduction of sexuality to the maximum level. Here two hyphae of opposite strains are involved in fusion thus bringing about dikaryotization.

(7) **Clamp connection :** In Basidiomycotina, the dikaryotic cells divide by **clamp connections**. They were first observed by Hoffman, (1856) who

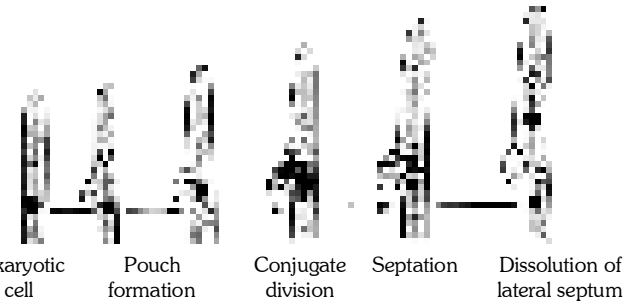


Fig : Various stages in the formation of clamp connections

named it as '**Schnallenzellen**' (buckle-joints). A lateral pouch like outgrowth arises which projects downward like a hook. This pouch or **clamp** becomes almost parallel to the parent cell. The two nuclei now undergo conjugate division in such a way that one spindle lies parallel to the long axis of the cell and the other somewhat obliquely. As a result, one daughter nucleus enters into the clamp. Now, septae appear separating the clamp and the lower hyphal cell. The upper cell has both the nuclei. The clamp with a nucleus now fuses with the lower cell. The septum between the pouch and the lower cell is dissolved and thus the lower cell now contains both the nuclei of opposite strains. The entire process takes some 23-45 minutes.

(8) **Heterothallism :** Blakeslee, (1904) while working with *Mucor* sp. observed that in some species sexual union was possible between two hyphae of the same mycelium, in others it occured between two hyphae derived from 'different' spores. He called the former phenomenon as **homothallism** and the latter as **heterothallism**. Thus, the homothallic species are self-fertile whereas the heterothallic are self sterile. In heterothallic species the two 'thalli' are sexually incompatible. They are said to belong to opposite strains. Blakeslee designated them as + and– *i.e.*, belonging to opposite strains or mating types. Whitehouse, (1949) differentiated the phenomenon into two categories as under :

(i) **Morphological heterothallism :** When male and female sex organs are located on different 'thalli' the heterothallism is said to be **morphological**. Such species are generally described as dioecious.

(ii) **Physiological heterothallism :** In bisexual forms the two sex organs may be located on the same 'thallus' or on different 'thalli'. In some forms the two sexes even when present on the same 'thallus' are unable to mate, the heterothallism is said to be **physiological**. Such forms are self-sterile as they need genetically different nuclei. Such nuclei are absent when the same 'thallus' forms the two sex organs. Heterothallic fungi may be bipolar or tetrapolar.

(9) **Classification of fungi :** It is based largely on the characteristics of the life cycle involved like.

Nature of somatic phase, kinds of asexual spores, kinds of sporangia, nature of the life cycle and presence or absence of perfect or sexual stage.