Course Name-Biology and Diversity of Algae, Bryophyta and Pteridophyta (Paper Code: BOT 502)

Unit –11 : General Characters, Classification, Distribution and Economic Importance of Bryophytes

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CONTENT

- Introduction
- General Characteristics
- Distribution
- Habitat
- Life Cycle
- Reproduction
- Economic Importance

INTRODUCTION

Bryophytes (nonvascular plants) are the only embryophytes (plants that produce an embryo) whose life history includes a dominant gametophyte (haploid) stage. They are an ancient and diverse group of non-vascular plants. Bryophyta (Gr. Bryon = mass; phyton = plant), a division of kingdom Plantae comprises of Mosses, Hornworts and Liverworts. They are groups of green plants which occupy a position between the thallophytes (Algae) and the vascular cryptogams (Pteridophytes). Bryophytes produce embryos but lack seeds and vascular tissues. They are the most simple and primitive group of Embryophyta. Bryophytes grow in two habitats i.e. water and land so known as amphibians of plant kingdom. They are said to be the first land plants or non-vascular land plants. They cannot reproduce without sufficient moisture because without water sex organs neither matures nor dehisces. Presence of swimming antherozoids is an evidence of their aquatic ancestory. They comprise three main taxonomic groups: mosses (Bryophyta), liverworts (Marchantiophyta or Hepatophyta) and hornworts (Anthocerotophyta) which have evolved quite separately. Most bryophytes have erect or creeping stems and tiny leaves, but hornworts and some liverworts have only a flat thallus and no leaves. There are possibly 25,000 species of mosses and liverworts all over the world.

GENERAL CHARACTERISTICS

1. Small group of primitive land dwellers having small leafy or thalloid green plant body.
2. Like thallophytes plant body is gametophytic, independent, dominant, autotrophic, either thalloid (i.e., thallus like, not differentiated into root, stem and leaves) or foliose, containing a rootless leafy shoot.
3. Plant body is very small and ranges from a few mm to many cm. Zoopsis is the smallest bryophyte (5 mm.) while the tallest bryophyte is Dawsonia (50-70 cms.).
4. Leaves and stems found in vascular plants are absent, these 'leaf' and **'stem'** like structures as **'axis'** and **'phylloid'** respectively.
5. Roots are absent. Functions of the roots are performed by rhizoids. Cells are also capable to absorb moisture directly from the ground or atmosphere. Therefore, Bryophytes can also survive on the moist soils.
6. Rhizoids may be unicellular, un-branched (e.g., *Riccia*, *Marchantia*, *Anthoceros*) or multicellular and branched (e.g., *Sphagnum*, *Funaria*).

7. In members of order Marchantiales (e.g., *Riccia*, *Marchantia*) scales are present. These are violet coloured, multicellular and single cell thick. They protect the growing point and help to retain the moisture.

8. Vascular tissue (xylem and phloem) is completely absent. Water and food material is transferred from cell to cell. However, in some Bryophytes (e.g., mosses) a few cells in groups of 2-3 are present for conduction of water and food (photo assimilate). These cells are known as hydroid (collectively hydrom) and leptoids respectively. Cuticle and stomata are absent.

9. Sexual reproduction is invariably highly oogamous. The sex organs are jacketed and multicellular while in algae they are non-jacketed and unicellular.

10. Female sex organ is archegonium appears for the first time in bryophytes.

11. Sperms are biflagellate and both the flagella are of whiplash type.

12. Fertilization takes place in the presence of water or moisture.

13. Fertilized egg remains in the venter of the archegonia. It neither becomes independent from parent gametophyte nor passes into resting period. In both these respect the bryophyte differs from algae.

14. Zygote undergoes repeated divisions to form an undifferentiated multicellular structure called the embryo.

15. First division of the zygote is transverse and the apex of the embryo develops from the outer cell. Such embryogenesis is called exoscopic.

16. The venter wall enlarges to produce a protective multicellular envelop called calyptra.

17. The embryo by further division and differentiation produce a relatively small spore producing structure which is not independent. It is called sporogonium (sporophyte).

18. Sporophyte is rootless and consists of foot, seta and capsule. In some seta is absent (*Corsinia*) and rarely the both foot and seta (*Riccia*).

19. Sporophyte remains attached with gametophyte throughout its life and also depends on it partially or wholly for nutrition.

20. Sporophyte produces spores which are wind disseminated, non-motile and cutinized, also called meiospores.
21. Morphologically all the meiospores in a given species are alike, thus known as homosporous.
22. Each spore under suitable conditions germinates to give rise gametophyte plant directly or indirectly as lateral bud from protonema.
23. Heterologous type of alternation of generation in the life cycle of bryophytes while in algae it is of homologous type.

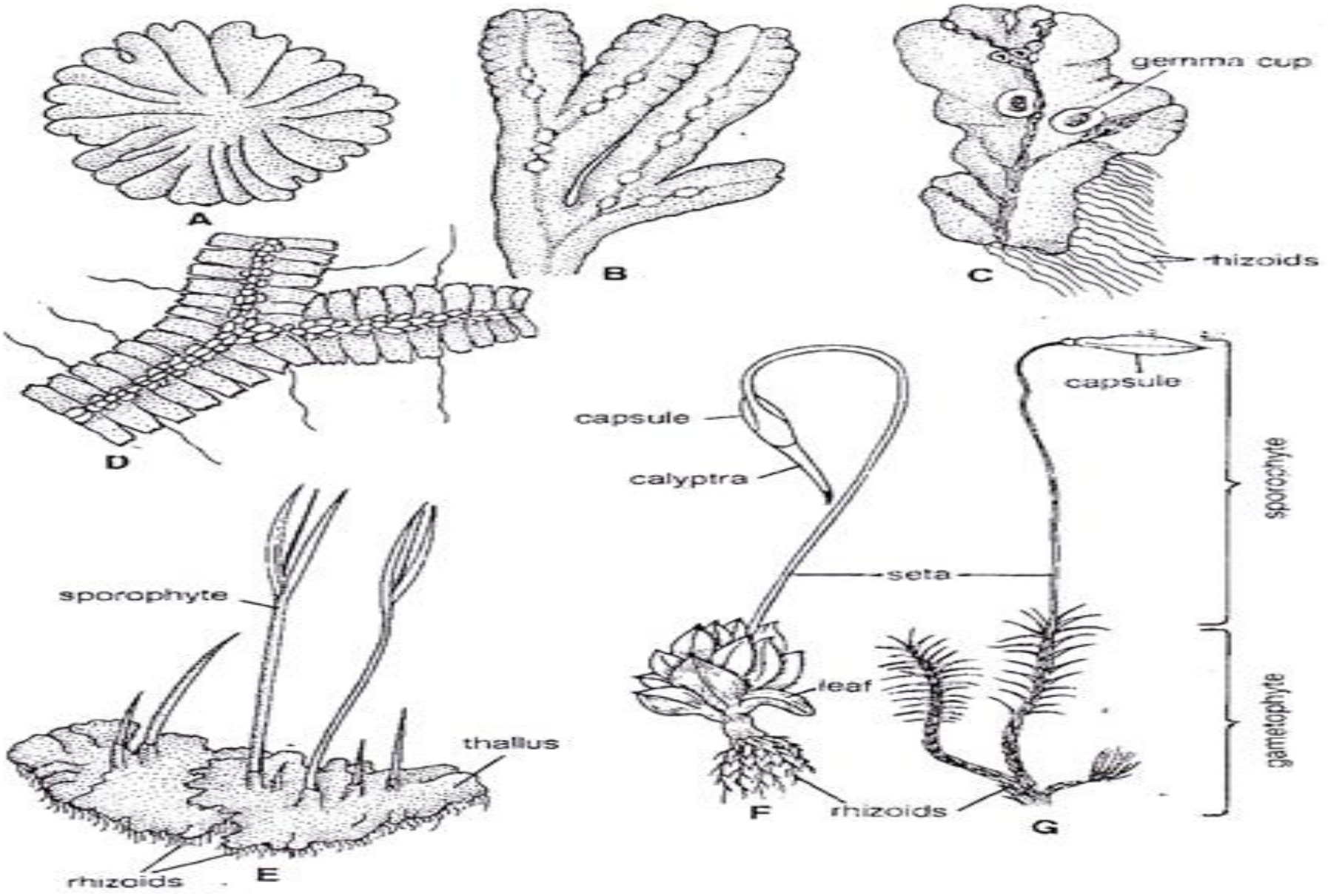

Fig. External Features of Bryophytes (A) *Riccia rosette* (B) *Riccia* Thallus (C) *Marchantia* (D) *Porella* (E) *Anthoceros* (F) *Funaria* (G) *Polytrichum*

DISTRIBUTION

Bryophytes are distributed throughout the world, from polar and alpine regions to the tropics. Water must, at some point, be present in the habitat in order for the sperm to swim to the egg. Bryophytes do not live in extremely arid sites or in seawater, although some are found in perennially damp environments within arid regions and a few are found on seashores above the intertidal zone. A few bryophytes are aquatic. Bryophytes are most abundant in climates that are constantly humid and equable. The greatest diversity is at tropical and subtropical latitudes. Bryophytes (especially the moss *Sphagnum*) dominate the vegetation of peatland in extensive areas of the cooler parts of the Northern Hemisphere.

The geographic distribution patterns of bryophytes are similar to those of the terrestrial vascular plants, except that there are many genera and families and a few species of bryophytes that are almost cosmopolitan. Indeed, a few species show extremely wide distribution.

Some botanists explain these broad distribution patterns on the theory that the bryophytes represent an extremely ancient group of plants, while others suggest that the readily dispersible small gemmae and spores enhance wide distribution. The distribution of some bryophytes, however, is extremely restricted, yet they possess the same apparent dispersibility and ecological plasticity as do widespread bryophytes. Others show broad interrupted patterns that are represented also in vascular plants.

Bryophytes are represented by 960 genera and 25,000 species. They are cosmopolitan in distribution and are found growing both in the temperate and tropical regions of the world at an altitude of 4000-8000 feet. In India, Bryophytes are quite abundant in both Nilgiri hills and Himalayas; Kullu, Manali, Shimla, Darjeeling, Dalhousie and Uttarakhand are some of the hilly regions which also have a luxuriant growth of Bryophytes.

Eastern Himalayas have the richest in bryophytic flora. A few species of *Riccia*, *Marchantia* and *Funaria* occur in the plains of U.P., M.P. Rajasthan, Gujarat and South India.

In hills they grow during the summer or rainy season. Winter is the rest period. In the plains the rest period is summer, whereas active growth takes place during the winter and the rainy season. Some Bryophytes have also been recorded from different geological eras e.g., *Muscites yallourensis* (Coenozoic era), *Intia vermicularies*, *Marchantia* spp. (Palaeozoic era) etc.

HABITAT: Bryophytes grow densely in moist and shady places and form thick carpets or mats on damp soils, rocks, bark of trees especially during rainy season. Small in size, but they can be very conspicuous growing as extensive mats in woodland, as cushions on walls, rocks and tree trunks, and as pioneer colonists of disturbed habitats.

Majority of the species are terrestrial but a few species grow in fresh water (aquatic) e.g., *Riccia fluitans*, *Ricciocarpos natans*, *Riella* etc. Bryophytes are not found in sea but some mosses are found growing in the crevices of rocks and are being regularly bathed by sea water e.g., *Grimmia maritima*. Some Bryophytes also grow in diverse habitats e.g., Sphagnum-grows in bogs, Dendroceros-epiphytic, *Radula protensa* - epiphyllous, *Polytrichum juniperinum*-xerophytic, *Tortula muralis*-on old walls. *Tortula desertorum* in deserts, *Porella platyphylla*-on dry rocks, *Buxbaumia aphylla* (moss), *Cryptothallus mirabilis* (liverwort) are saprophytic.

LIFE CYCLE: The life cycle of bryophytes shows two distinct phases namely a haploid gametophytic phase and a diploid sporophytic phase alternating with each other. The adult plant body represents the gametophyte. A short-lived sporophyte occurs as a parasite on the gametophyte.

Gametophyte: A stage in the life cycle of bryophyte that undergoes alternation of generations. It is a haploid multicellular organism that develops from a haploid spore that has one set of chromosomes. The gametophyte is the sexual phase in the life cycle of bryophytes. It develops sex organs that produce gametes, haploid sex cells that participate in fertilization to form a diploid zygote in which each cell has two sets of chromosomes. Cell division of the zygote results in a new diploid multicellular organism, the second stage in the life cycle known as the sporophyte, the function of which is to produce haploid spores by meiosis.

In bryophytes (mosses, liverworts, and hornworts), the gametophyte is the most visible stage of the life cycle. The bryophyte gametophyte is longer lived, nutritionally independent, and the sporophytes are typically attached to the gametophytes and dependent on them. It is the adult plant body in bryophytes. It is either thalloid or in the form of a leafy shoot with stem-like and leaf-like structures. Roots are absent and instead thread-like rhizoids are present. Vascular tissues xylem and phloem are absent.

Water and food are directly transported from a cell to cell. Vegetative reproduction may sometimes occur by fragmentation. However, sexual reproduction is common and is of oogamous type. The mature gametophyte bears male reproductive organs called antheridia and female reproductive organs called archegonia. The antheridia have a club-shaped body and a stalk. They produce flagellated male gametes called antherozoids or sperms. The archegonia are flask-shaped with a well-defined venter and neck. The venter encloses a venter canal cell and an egg cell while the neck encloses a variable number of neck canal cells.

The antherozoids liberated from antheridia, swim in a film of water and reach the archegonia. They are attracted into the archegonia to bring about fertilization. The zygote develops into the sporophyte.

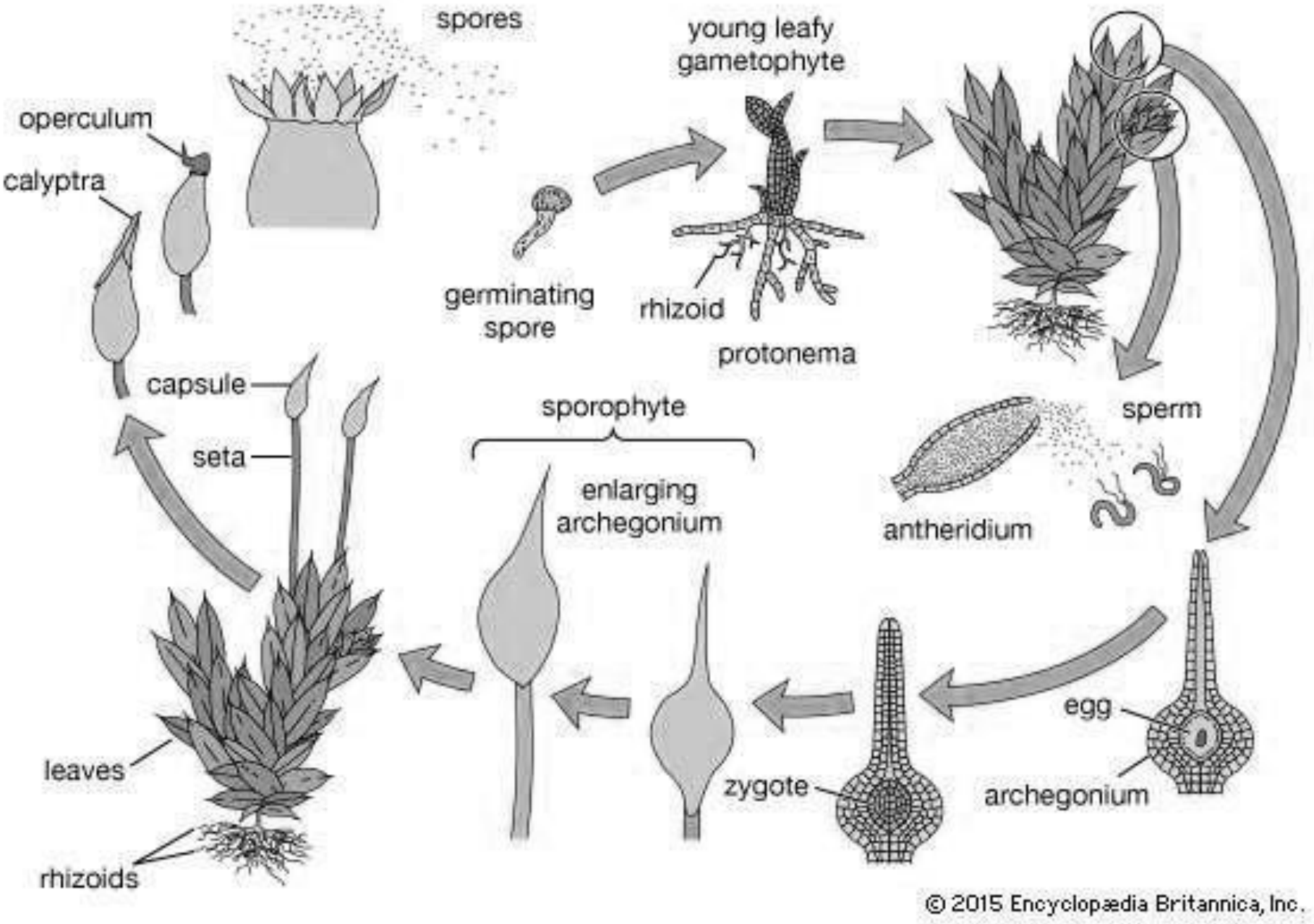

Fig. Moss Life Cycle

Sporophyte: Zygote represents the first cell of the sporophytic phase. It divides and develops into a sporophytic plant body called sporogonium. It is neither independent of the parent gametophyte nor passes into the resting phase. In both respects differs from the zygote of green algae. Further development of zygote into embryo occurs within venter of the archegonium. Zygote undergoes segmentation without a resting period into multicellular, undifferentiated structure called embryo. Embryo by further segmentation and differentiation finally develops into full-fledged sporophyte called sporogonium. The wall of venter forms a protective covering to the sporogonium, called calyptra. Sporogonium in bryophytes is leafless and rootless. Most often, the sporogonium is differentiated into a foot, a seta and a capsule. It remains attached throughout its life to the gametophytic host with the help of foot. It absorbs nutrients directly from the gametophyte. In some bryophytes the foot is much reduced and its function is performed by haustorial collar which develops from the junction of reduced foot and seta.

Seta conducts the absorbed food to the capsule. The terminal capsule is considered equivalent to fern sporangium is mainly concerned in the production of spores which are nonmotile and wind disseminated.

The sporogonium produces haploid spores (meiospores) which get released from the capsule. Spores are highly specialized cells differentiated from the diploid spore mother cell by meiosis. They are thus haploid cells. The spores represent the first cells of gametophytic generation. They germinate under suitable condition to produce new gametophytes either directly or through a juvenile stage called protonema.

Another remarkable feature in the lifecycle of bryophyte in which they differ from thallophytes is the complete absence of asexual spores called the mitospores in the life cycle. Asexual reproduction takes place only by the vegetative method of fragmentation and gemmae.

REPRODUCTION IN BRYOPHYTES

Bryophytes reproduce only by vegetative and sexual means. Asexual reproduction is absent in these.

A. Vegetative Reproduction in Bryophytes:

Bryophytes possess a characteristic feature and that is their tendency towards extensive vegetative reproduction. The vegetative reproduction takes place in favourable season for vegetative growth. Majority of the Bryophytes propagate vegetatively and it is brought about in many ways.

1. **By Death and Decay of the Older Portion of Thallus or by Fragmentation:**

In Bryophytes the growing point is situated at the tip of the thallus. The basal, posterior or older portion of the thallus starts rotting or disintegrating due to ageing or drought. When this process of disintegration or decay reaches up to the place of dichotomy, the lobes of the thallus get separated. These detached lobes or fragments develop into independent plants by apical growth. This is the most common method of vegetative reproduction in *Riccia*, *Marchantia*, *Anthoceros* and some mosses like Sphagnum

2. **By Persistent Apices:**

Due to prolonged dry or summer or towards the end of growing season the whole thallus in some Bryophytes (e.g., *Riccia*, *Anthoceros*, *Cyathodium*) dries and get destroyed except the growing point. Later, it grows deep into the soil and becomes thick. Under favourable conditions it develops into a new thallus.

3. **By Tubers:**

Tubers are formed in those species which are exposed to desiccations (drying effect of the air). Towards the end of the growing season, the subterranean branches get swollen at their tips to from the underground tubers. On the periphery of a tuber are two to three layers of water proof corky, hyaline cells develop.

These layers surround the inner cells which contain starch, oil globules and albuminous layers. During the unfavorable conditions the thallus dies out but the dormant tubers remain unaffected. On the return of the favourable conditions each tuber germinates to form a new plant e.g., *Riccia*, *Anthoceros*, *Fossombronia* etc. Thus, tubers also serve as organ of perennation.

4. **By Gemmae:**

Gemmae are green, multicellular reproductive bodies of various shapes. These are produced in gemma cups, on the surface of the leaves, on stem apex or even inside the cells. They get detached from the parent plant and after falling on a suitable substratum gemmae give rise to a new individual directly (e.g., *Marchantia*) or indirectly (e.g., Mosses).

5. **By Adventitious Branches:**

The adventitious branches develop from the ventral surface the thallus e.g., *Riccia fluitans, Anthoceros*. On being detached from the parent plant these branches develop into new thalli. In Marchantia, Dumortiera these branches develop from archegoniophore while in *Pellia* these branches arise from the dorsal surface or margins of the thallus.

6. **By Regeneration:**

The liverworts possess an amazing power of regeneration. Part of the plant or any living cell of the thallus (e.g., rhizoid, scales).are capable of regenerating the entire plant e.g., *Riccia*, *Marchantia* etc.

7. **By Innovation:**

In Sphagnum one of the branches in the apical cluster instead of forming drooping branches or divergent branches, develop more vigorously than the others and continues the growth upwards. This long upright branch has all the characteristics of main axis. It is called innovation. Due to progressive death and decay of the parent plant these innovation become separated from the parent plant and establish themselves as parent plants.

8. **By Primary Protonema:**

Primary protonema is the filament like stage produced by the developing spores of the mosses. It produces the leafy gametophores. It breaks into short filament of cells by the death of cells at intervals. Each detached fragment grows into a new protonema which bears a crown of leafy gametophores e.g., *Funaria*.

9. **By Secondary Protonema:**

The protonema formed by other methods than from the germination of spores is called secondary protonema. It may develop from any living cells of the leafy gametophore i.e., from leaf, stem, rhizome, injured portion of the leafy gametophore, antheridium, paraphysis or archegonium. From this arise the leafy gametophores or lateral buds in the same manner as in primary protonema e.g., *Funaria*, *Sphagnum.*

10. **By Bulbils:**

These are small resting buds develop on rhizoids. Bulbils are devoid of chlorophyll but full of starch. On germination bulbils produce a protonema which bears leafy gametophores

11. **By Apospory:**

The production of diploid gametophyte from the unspecialized sporophyte without meiosis is known as apospory e.g., *Anthoceros*. In *Funaria* green protonemal filaments may arise from the unspecialized cells of the various parts of sporogonium. These protonemal filaments bear lateral buds which develop into leafy gametophores.

12. **By Rhizoidal Tips:**

The apical part of the young rhizoids divide and re-divide to form a gemma like mass of cells e.g., *Riccia glauca*. These cells contain chloroplast and are capable to develop into new thallus.

B. Sexual Reproduction in Bryophytes:

1. Sexual reproduction is highly oogamous.
2. Male and female sex organs are known as antheridia (Sing, antheridium) and archegonia (Sing, archegonium), respectively.
3. Sex organs are jacketed and multilayered.
4. Antheridium is stalked, pear shaped or oblong and has an outer one cell thick jacket which encloses a mass of fertile cells called androcytes. Each androcyte metamorphoses into biflagellate antherozoid.

5. Archegonium is stalked, flask shaped structure. It has a basal swollen portion called venter and an elongated neck. The neck is filled with many neck canal cells whereas venter has a large egg cell and a small venter canal cell,

6. Antherozoids are attracted towards the neck of the archegonium chemotactically by certain substances (like sugars, malic acid, proteins, inorganic salts of potassium etc.) present in the mucilaginous substance formed by the degeneration of neck canal cells and venter canal cell.

7. Water is essential for fertilization.

8. The fertilized egg or zygote is the beginning of the sporophytic phase. It is retained within the venter of the archegonium.

Sporophyte:

1. Without resting period, the zygote undergoes repeated divisions to form a multicellular structure called the embryo.

2. The first division of the zygote is always transverse and the outer cell develops into embryo. Such an embryogeny is called exoscopic.

3. Embryo develops into a sporophyte or sporogonium.

4. The sporophyte is usually differentiated into foot, seta and capsule. In certain cases it is represented only by capsule (e.g., *Riccia*) or by foot and capsule (e.g., *Corsinia*).

5. Sporophyte is attached to parent gametophytic plant body throughout its life. It partially or completely depends on it for nutrition.

6. Foot is basal, bulbous structure. It is embedded in the tissue of parent gametophyte. Its main function is to absorb the food material from the parent gametophyte.

7. Seta is present between the foot and capsule. It elongates and pushes the capsule through protective layers. It also conducts the food to the capsule absorbed by foot.
8. Capsule is the terminal part of the sporogonium and its function is to produce spores
9. All Bryophytes are homosporous i.e., all spores are similar in shape, size and structure
10. Capsule produces sporogenous tissue which develops entirely into spore mother cells it e.g., *Riccia*) or differentiated into spore mother cells and elater mother cells (e.g., *Marchantia*, *Anthoceros*).
11. Spore mother cells divide diagonally to produce asexually four haploid spores which are arranged in tetrahedral tetrads.
12. Elater mother cells develop into elaters (e.g., *Marchantia*) or pseudo elaters (e.g., *Anthoceros* which are hygroscopic in nature. Elaters are present in liverworts and absent in mosses.
13. Venter wall enlarges with the developing sporogonium and forms a protective multicellular layer called calyptra (gametophytic tissue enclosing the sporophyte).

Young Gametophyte:

1. The meiospore (spore formed after meiosis) is the first cell of the gametophytic phase.
2. Each spore is unicellular, haploid and germinates into young gametophytic plant (e.g., *Riccia* or *Marchantia)* or first germinates into a filamentous protonema on which buds are produced to give rise to a young gametophytic plant, (e.g., *Funaria*).

ALTERNATION OF GENERATION: The life-cycle of a bryophyte shows regular alternation of gametophytic and sporophytic generations. This process of alternation of generations was demonstrated for the first time in 1851 by Hofmeister. Thereafter in 1894 Strassburger could actually show the periodic doubling and halving of the number of chromosomes during the life-cycle.

The haploid phase (n) is the gametophyte or sexual generation. It bears the sexual reproductive organs which produce gametes, i.e., antherozoids and eggs. With the result of gametic union a zygote is formed which develops into a sporophyte. This is the diploid phase (2n). The sporophyte produces spores which always germinate to form gametophytes.

During the formation of spores, the spore mother cells divide meiotically and haploid spores are produced. The production of the spores is the beginning of the gametophytic or haploid phase. The spores germinate and produce gametophytic or haploid phase. The spores germinate and produce gametophytes which bear sex organs.

Ultimately the gametic union takes place and zygote is resulted. It is diploid (2n). This is the beginning of the sporophytic or diploid phase. This way, the sporophyte generation intervenes between fertilization (syngamy) and meiosis (reduction division); and gametophyte generation intervenes between meiosis and fertilization.

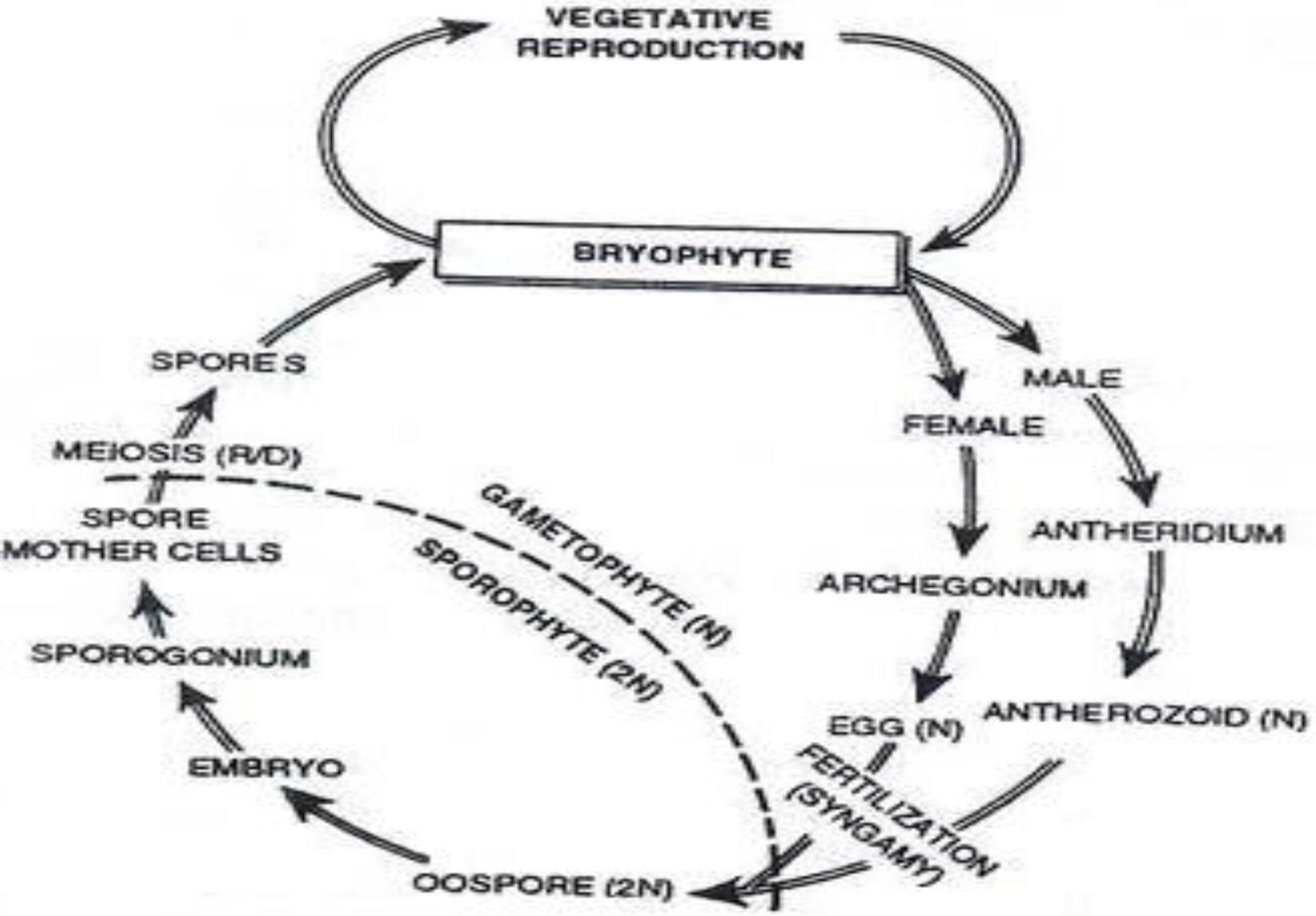

Fig. Bryophytes life cycle (Graphic Representation)

ECOLOGICAL AND ECONOMIC IMPORTANCE

Bryophytes are of great ecological importance due to following reasons:

(a) Pioneer of the land plants. Bryophytes are pioneer of the land plants because they are the first plants to grow and colonize the barren rocks and lands.

(b) Bryophytes prevent soil erosion. They usually grow densely and hence act as soil binders. Mosses grow in dense strands forming mat or carpet like structure.

They prevent soil erosion by:

(i) Bearing the impact of falling rain drops

(ii) Holding much of the falling water and reducing the amount of run-off water.

(c) Formation of soil- Mosses and lichens are slow but efficient soil formers. The acid secreted by the lichens and progressive death and decay of mosses help in the formation of soil.

(d) Bog succession- Peat mosses change the banks of lakes or shallow bodies of water into solid soil which supports vegetation e.g., Sphagnum

(e) Rock builders- Some mosses in association with some green algae (e.g., *Chara*) grow in water of streams and lakes which contain large amount of calcium bicarbonate. These mosses bring about decomposition of bi-carbonic ions by abstracting free carbon dioxide. The insoluble calcium carbonate precipitates and on exposure hardens, forming calcareous (lime) rock like deposits.

Economic importance

1-Formation of Peat:

Peat is a brown or dark colour substance formed by the gradual compression and carbonization of the partially decomposed pieces of dead vegetative matter in the bogs. Sphagnum is an aquatic moss. While growing in water it secretes certain acids in the water body.

This acid makes conditions unfavorable for the growth of decomposing organisms like bacteria and fungi. Absence of oxygen and decomposing microorganisms slows down the decaying process of dead material and a large amount of dead material is added year by year. It is called peat (that is why Sphagnum is called peat moss).

2-As Packing Material:

Dried mosses and Bryophytes have great ability to hold water. Due to this ability the Bryophytes are used as packing material for shipment of cut flowers, vegetables, perishable fruits, bulbs, tubers etc.

3- As Bedding Stock:

Because of great ability of holding and absorbing water, in nurseries beds are covered with thalli of Bryophytes.

4. In Medicines:

Some Bryophytes are used medicinally in various diseases for e.g.,

(a) Pulmonary tuberculosis and affliction of liver—*Marchantia* spp.

(c) Acute hemorrhage and diseases of eye—Decoction of *Sphagnum*.

(d) Stone of kidney and gall bladder—*Polytrichum commune*.

(e) Antiseptic properties and healing of wounds—Sphagnum leaves and extracts of some Bryophytes for e.g., *Conocephalum conicum*, *Dumortiera*, *Sphagnum protoricense*, *S. strictum* show antiseptic properties.

5. In Experimental Botany:

The liverworts and mosses play an important role as research tools in various fields of Botany such as genetics. For the first time in a liverwort, Sphaerocarpos, the mechanism of sex determination in plants was discovered.

6. As Food:

Some Bryophytes e.g., mosses are used as food by chicks, birds and Alaskan reindeer etc.

CLASSIFICATION OF BRYOPHYTES

The term Bryophyta was first introduced by Braun (1864); however, he included algae, fungi, lichens and mosses in this group. Later, algae, fungi and lichens were placed in a separate division Thallophyta and liverworts, mosses in division Bryophyta.

Eichler (1883) was the first to divide Bryophyta into two groups:

Group I. Hepaticae

Group II. Musci.

Engler (1892) recognised Hepaticae and Musci as two classes and divided each class into the following three orders:

Division- Bryophyta:

Class I. Hepaticae: Divided into three orders:

Order 1. Marchantiales

Order 2. Jungermanniales

Order 3. Anthocerotales

Class II. Musci: Divided into three orders:

Order 1. Sphagnales

Order 2. Andreaeales

Order 3. Bryales

International code of Botanical Nomenclature (ICBN) suggested in 1956-that the suffix-opsida should be used for the classes and such usage had already been proposed by **Rothmaler (1951)** for the classes of Bryophytes. He changed the class names as:

Class I. Hapaticae as Hepaticopsida.

Class II. Anthocerotae as Anthoceropsida

Class III. Musci as Bryopsida.

Proskauer (1957) suggested that the class name Antheoceropsida should be Anthocerotopsida. Parihar (1965) and Holmes (1986) followed Proskauer's classification and divided Bryophyta into three classes:

Clase I. Hepaticopsida

Class II. Anthocerotopsida

Class III. Bryopsida.

Class I. Hepaticopsida (Liverworts):

General Characters:

1. This class includes about 280 genera and 9500 species.
2. The name of this class is derived from a Latin word Hepatica which means liver. Hence members of this class are commonly known as liverworts.
3. Plant body is gametophytic and the gametophyte is either thalloid or foliose.
4. Thalloid forms are prostrate, lobed, dorsiventral and dichotomously branched.
5. In foliose forms, **'leaves'** are entire, lobed or divided and without **'midrib'**. 'Leaves arranged in two to three rows on the axis.
6. Rhizoids are unicellular and branched.
7. Photosynthetic cells contain many chloroplasts.
8. Pyrenoids are absent.
9. Sex organs are borne dorsally or apically, superficial or embedded in gametophytic tissue
10. Members may be monoecious or dioecious.
11. Sporophyte is either simple or represented by capsule only (e.g., *Riccia*) or may differentiated into foot, seta and capsule (e.g., *Marchantia*).
12. Archesporium is endothecial in origin.
13. Sporogenous tissue either forms only spores (e.g., *Riccia*) or is differentiated into sterile elater mother cells and fertile spore mother cells.
14. Columella is absent in the capsule.

15. Elaters are unicellular, hygroscopic with spiral thickenings.
16. Capsule wall is one to several layers thick and without stomata.
17. Dehiscence of the capsule is irregular or in definite number of valves.
18. Spores on germination form the gametophytic plant body.
19. Plants show heteromorphic alternation of generation. Schuster (1957) divided the class Hepaticae into two sub-classes:

Sub-class 1. Jungerinanniae. It includes four orders:

Order 1. Calobryales (e.g., *Calobryum*)
Order 2. Takakiales (e.g., *Takakia)*
Order 3. Jungermanniales (e.g., *Pellia*)
Order 4. Metzgeriales (e.g., *Metzgeria*)

Sub-class 2. Marchantiae: It includes three orders:

Order 5. Sphaerocarpales (e.g., *Sphaerocarpos*)
Order 6. Marchantiales (e.g., *Marchantia*).

All these 6 orders have their characteristic features and all these are described here. The important features of these orders are:

1. Order- Calobryales (2 genera- Calobryum (8 spp.) and Haplomitrium (1 spp.):

The characteristic features are as follows:
1. They possess erect leafy gametophytes with leaves in three vertical rows.
2. The leaves are dorsiventrally flattened.

3. They have a pale, subterranean, sparingly branched rhizome from which arise erect leafy branches.
4. Erect branches bearing sex organs have the uppermost leaves close together and in more than three rows.
5. They are devoid of rhizoids.
6. The antheridia are ovoid, stalked, and borne at the apex of the stem.
7. The jacket of the neck of archegonium has only four vertical rows of cells.
8. The sporophyte bears an elongate capsule whose jacket layer is only one cell in thickness except at the apex.
9. The number of chromosomes is-n=9.
Since there is single family Calobryaceae the characters are similar to that of the order.
Two genera - Calobryum and Haplomitrium.

Order-Takakiales (1 genus; 2 species):
The characteristic features are as follows:
1. They possess cylindrical, rhizomatic and erect gametophores.
2. They are devoid of rhizoids.
3. They possess copious beaked or non-beaked mucilage hairs on them.
4. They possess bifid-trifid-quadrifid leaves or phyllids.
5. The gametophores are about 1 to 1.5 cm. in height.
6. The leafless branches facing downward known as 'flagella' or 'stolons' may be present.

7. Asexual reproduction is not known.
8. Only female (archegonial) shoots are known. They bear conspicuous pedestalled archegonia.
9. The male (antheridial) shoots and the sporophytes are not known.
10. They have lowest chromosome number (i.e., n=4).
11. They are supposed to be most primitive and sometimes known as living fossil. There is one family Takakiaceae, and one genus Takakia.

3. Order- Jungermanniales (220 genera; 8, 500 species):
The characteristic features of this order are as follows:
1. The gametophyte is differentiated into stem and leaves; the leaves are borne in a regular spiral succession along the stem.
2. The apical cell is pyramid-like with three cutting faces.
3. The stem generally bears three rows of leaves; two rows are lateral and consist of leaves of normal size; the third row consists of the under leaves which are generally smaller than the lateral leaves.
4. The archegonia are always restricted to the apices of the axis and its branches.
5. The sporophytes are always terminal in position.
6. The antheridia are borne singly or in groups in the axis of leaves.

Family- Porellaceae (single genus- Porella):

1. The leaves are arranged in three rows on the stem; ventral leaves are well developed and usually decurrent at the base.
2. The rhizoids are scarce and arise from the lower side of the stem in tufts generally near the base of under leaves (ventral leaves).
3. The archegonia are borne in terminal cluster on small lateral branches; the archegonia remain surrounded by a large inflated perianth.
4. The spherical capsule dehisces by four valves which split only to half way down.

Family- Frullaniaceae (three genera; important genus Frullania):

1. The thallus is pinnately branched and differentiated into stem and leaves.
2. The leaves are arranged in three rows two laterals unequally lobed and a ventral lobule.
3. The ventral leaves are bifid and trumpet-shaped.
4. The archegonia develop in a group.

4. Order- Metzgeriales (23 genera; 550 species):

The characteristic features of this order are as follows:

1. The gametophyte may be thalloid or differentiated into stem and lateral leaves.
2. In most cases the gametophytes are without internal differentiation of tissues but certain genera have a central strand of thick-walled cells.
3. The ventral surface of a gametophyte bears smooth-walled rhizoids.

4. The sex-organs are found to be scattered on dorsal surface of thallus.
5. The archegonia arise from the young segments cut off by the apical cell.
6. The mature sporophytes lie some distance back from the growing apex of a gametophyte.
7. The sex organs (antheridia and archegonia) are produced on any branch of the gametophyte or only on special branches.

Family-Pelliaceae (Three genera- Pellia, Noteroclada and Calycularia):
1. The thallus is prostrate, dorsiventral and very often lobed by irregular incisions.
2. The rhizoids are simple, non-septate, smooth and thin-walled. The scales are absent.
3. The sex organs (antheridia and archegonia) remain scattered on the dorsal surface of the thallus.
4. The archegonial cluster always remains surrounded by an involucre which is an outgrowth of the thallus.
5. The capsule (sporogonium) is globose or oval in shape. It possesses a basal elaterophore.

Family- Riccardiaceae (two genera):
1. The gametophytes are wholly thallose or have thallose terminal branches.
2. The cells of thallus possess finely segmented oil bodies.
3. The sex organs (antheridia and archegonia) are borne on short lateral branches.
4. A well-developed calyptra is present but there is no involucre.

5. A distal elaterophore is present to which some elaters are attached.
6. The capsule is ovoid to cylindrical and dehisces longitudinally into four parts extending to the base.

Family- Fossombroniaceae (4 genera; Fossombronia, Simodon, Petalophyllum and Sewardiella):

1. Thallus is distinctly foliose.
2. The thallus is dorsiventral and prostrate.
3. The stem is branched. Growth of the main axis and of its branches is by means of an apical cell with two cutting faces.
4. The leaf is thin, one cell-thick except the basal portion which is 2 or 3 cells in thickness.
5. Antheridia develop in acropetal succession singly or in small groups.
6. Archegonia occur in small groups.
7. Young sporophyte remains surrounded by a calyptra and which is ensheathed by a cuplike involucre.
8. The mature sporophyte is surrounded and protected by a bell-shaped sheathing perianth.
9. Important genus-Fossombronia.

5. Order- Sphaerocarpales (3 genera)-two families:

1. Family- Sphaerocarpaceae - Sphaerocarpos (seven species) and Geothallus (single species).
2. Family- Riellaceae- *Riella* (17 species).

The characteristic features of the order are as follows:

1. Vegetative structure of gametophyte is similar to that of order-Metzgeriales, but in which development and structure of sex organs, as well as the structure of sporophyte are similar to those of order-Marchantiales, and because of this the genera are placed in separate order Sphaerocarpales.
2. The main diagnostic feature by which the order is recognized is the presence of globose or a flask-like envelope or involucre around each of the sex organs (i.e., antheridia and archegonia).

6. Order-Marchantiales (32 genera; 400 species):

The characteristic features are as follows:

1. The ribbon-like, dichotomously branched and dorsiventral thalli grow prostrate upon suitable substrata.
2. Excluding Dumortiera, Monoselenium and Monoclea, the rest of the genera possess internally differentiated air chambers on the dorsal side of the thallus; such chamber opens outside by an air pore of a particular design.
3. The ventral portion of the thallus consists of parenchyma which acts as storage tissue; oil and mucilage cells may be present in this region.

4. The scales and rhizoids are present on the ventral side of the thallus; the rhizoids are of two types (smooth-walled and tuberculate).
5. The antheridia and archegonia may be found directly on the dorsal surface of the thallus or they may be present on the special branches known as antheridiophores and archegoniophores respectively.
6. In most of cases the capsules of the sporophytes possess single layered jacket.
7. The capsule may be simple as in *Riccia* or it may be differentiated into foot, seta and capsule as in *Marchantia.*
8. The elaters may or may not be present. According to Campbell (1940), there are five families in this order. The characteristic features of two families are given here:

I. Family- Ricciaceae (3 genera; 140 species):
1. The gametophyte consists of a rosette-like dichotomously branched thallus.
2. In the thallus, the dorsal portion consists of chlorophyllous strips which may or may not have air canals among them; the ventral portion of the thallus is parenchymatous and acts as storage tissue.
3. The sex organs (antheridia and archegonia) are found in the longitudinal groove on the dorsal side from the growing apex to backward in basipetal succession.
4. The sporogonium consists of a simple capsule which is not differentiated into foot, seta and capsule.
5. Elaters not present.

6. The archesporium produces only the spores.
The important genera are- *Ricciocarpus* and *Riccia.*

II. Family- Marchantiaceae (23 genera; 250 species):
1. The thallus is dorsiventral; it has distinct assimilatory and storage regions.
2. The assimilatory region remains divided into several chambers and each chamber contains branched assimilatory filaments.
3. The pores of the thallus may be simple or barrel-shaped.
4. The archegonia are borne upon special erect, stalked, vertical branches, the archegoniophores.
5. The antheridiophores may or may not present; however, in *Marchantia*, the antheridia are borne upon these erect, stalked antheridiophores.
6. The typical sterile elaters are found in the sporogonium mixed with the spores. The important genera are - *Conocephalum*, *Cryptometrium*, *Lunularia*, *Marchantia*, etc.

Class II. Anthocerotopsida (Hornworts):
General Characters:
1. This class is represented by about 6 genera and 300 species.
2. Plant body is flat, dorsiventral, thalloid, gametophytic and variously lobed.
3. Smooth walled rhizoids are present.
4. Tuberculated rhizoids and scales are absent.
5. Internally the thallus is not differentiated into zones.

6. All cells are alike.
7. Air chambers or air pores are absent.
8. Each cell has a single chloroplast and each chloroplast contains a single pyrenoid.
9. Mucilage cavities open on the ventral surface by slime pores.
10. Sex organs are embedded in the thallus.
11. Antheridia develop either singly or in groups in closed cavities called antheridial chambers.
12. The sporophyte is differentiated into foot, an intermediate zone or meristematic zone and capsule.
13. Due to the presence of the meristematic zone, the sporophyte shows indeterminate growth i.e., it continues to grow indefinitely.
14. Archesporium is amphithecial in origin.
15. Sporogenous tissue forms the fertile spores and sterile elaters. Elaters do not have spiral thickenings and are known as pseudo elaters.
16. Capsule wall is four to six layered thick and epidermis has the stomata.
17. Capsule matures from apex to base and usually dehisce by two valves. The class Anthocerotopsida has only a single order Anthocerotales.

Muller (1940), Proskauer and Reimers (1954) divided the order Anthocerotales in two families:
Family 1. Anthocerotaceae (e.g., *Anthoceros*)
Family 2. Notothylaceae (e.g., *Notothylas*).

Family-Anthocerotaceae (4 or 5 genera; important genus Anthoceros):

1. The capsule is linear and vertical.
2. The stomata are present on the wall of capsule.
3. The archesporium develops from amphithecium.
4. The elaters are four-celled, smooth or thick-walled; thickening band may or may not be present.

Family-Notothylaceae (single genus- Notothylas):

1. The capsule is cylindrical and horizontal.
2. The stomata are not found on the wall of capsule.
3. Archesporium arises from endothecium and amphithecium.
4. Elaters are short and stumpy; they have irregular thickening bands.

Class III. Bryopsida (Mosses):

General Characters:

1. It is the largest class in Bryophyta and includes about 700 genera and 14,000 species.
2. The main plant body is gametophytic and can be differentiated into two stages- juvenile stage and leafy stage or gametophore.
3. Juvenile stage is represented by green, filamentous branched structures called protonema. It develops from the germination of the spore.
4. Gametophores are erect leafy branches which develop on the protonema.

5. Gametophores can be branched or un-branched and can be differentiated into three parts-rhizoids, **'stem'** and **'leaves'**.
6. Branches arise below the **'leaves'**.
7. **'Leaves'** are with midrib, un-lobed and arranged spirally in three to eight rows on the axis or
8. Rhizoids are multicellular, filamentous, branched with oblique septa.
9. The axis is differentiated into central conducting strand enclosed by cortex.
10. The sex organs (antheridia and archegonia) develop from the superficial cells of the gametophore.
11. The sporophyte is green in early stages and can be differentiated into foot, seta and capsule.
12. The seta is usually elongated and rigid.
13. The capsular wall remains interrupted by stomata at several places.
14. Columella is usually present and endothecial in origin.
15. Archesporium (spore forming tissue) is differentiated only in spores.
16. Elaters are absent.
17. Dehiscence of capsule takes place by separation of lid or operculum.
18. Peristome helps in the dispersal of spores.
19. Spores on germination produce the protonema.

The class Bryopsida (Musci) has been divided into three sub-classes (1) Sphagnobrya (Sphagnidae); (2) Andreaeobrya (Andreaeidae) and (3) Eubrya (Bryidae).

I. Sub-class: Sphagnobrya:

The sub-class has a single order, the Sphagnales and a single family, the Sphagnaceae. (Single genus Sphagnum with 326 species). The characteristic features are as follows:

1. They are called 'bog mosses' or 'peat mosses'.
2. The protonema is broad and thallose; it produces one gametophore; the leaves or gametophores lack mid-rib and usually composed of two types of cells-(i) the narrow living green cells and (ii) large hyaline dead cells.
3. The branches arise in lateral clusters in the axis of the leaves borne on the stem.
4. The antheridia are borne in the axis of leaves on the antheridial branch.
5. The archegonia are terminal and formed acrogenously.
6. The sporogenous tissue of a sporophyte develops from the amphithecium.
7. The sporogonium remains elevated above the gametophyte due to elongation of a stalk of gametophytic tissue, the pseudopodium.

II. Sub-class. Andreaeobrya:

This sub-class has a single order, the Andreaeales, and a singly family, the Andreaceceae. The important genus is Andreaea. The characteristic features are as follows:

2. There is practically no tissue differentiation in plant body.
3. The leaves are generally large, erect and convolute.
4. The archesporium and colonmella develop from the endothecium.

III. Sub-class Eubrya (650 genera; 14,000 species):

This sub-class has been further divided into three cohorts and fifteen orders. The true mosses are included in this sub-class. The characteristic features are as follows:

1. The leaves of the gametophores are more than one cell in thickness and possess midrib on them.
2. The protonema is filamentous.
3. The sporophyte bears a well differentiated, elongated seta which pushes out the capsule from the gametophore.
4. The sporogenous tissue is derived from the endothecium.
5. The archesporium does not overarch the columella; the columella continues upto the apex of the capsule; both columella and archesporium have been derived from the endothecium.
6. In between spore sac and columella, the partitioned air spaces are present.
7. The mature capsule possesses the complex structure made of many tissues.
8. The capsule opens at its apex by an operculum; the spore dispersal is regulated by teeth like apparatus, the peristome.

Order-Funariales (26 genera; 356 species):
Characteristic features:
1. The plants are terrestrial; they are small in size and may be annual or biennial.
2. The leaves possess distinct mid-ribs and arranged in rosettes at the apex of the gametophyte.
3. The capsule is wide and provided with an unbeaked operculum.
4. The peristome of the capsule is double and consists of inner and outer peristome called endostome and exostome respectively.
5. There are five families in this order, of which Funariaceae is most important.

Family-Funariaceae (9 genera; 200 species):
1. The leaves are one cell in thickness except at the mid-rib region.
2. The small mosses form the velvety appearance on the surface of the sustratum.
3. The calyptra is soon detached from the opercula of the capsules; the calyptra is provided with long beaks.
4. The capsules are pyriform and situated on the long, elongated setae.

Order-Polytrichales:
Characteristic features:
1. The gametophyte is perennial and tall.
2. The leaves are narrow and possess longitudinal lamellae on the upper surface of the midrib.

3. The capsule is terminal.
4. The single annular series of cells gives rise to a peristome in the inner zone of the amphithecium.
5. There are 32 to 64 pyramidal teeth in peristome; the tips of the peristome teeth remain joined above to a thin membrance, the epiphragm covers the mouth of the capsule.
6. There is a single family, the Polytrichaceae in this order; the important genera of this family are — *Polytrichum and Pogonatum.*

Apogamy and Apospory in Bryophytes

Bryophytes are endowed with a remarkable regeneration capacity. Parts of the plant or any living cell of the thallus are capable of regenerating the entire plant. The sporophytic cells regenerate to form a protonema on which appear gametophytes. This regeneration of diploid gametophyte from a sporophyte without the formation of spores is called aposporY.
Conversely a gametophyte may form a mass of cells which may regenerate a sporophyte. This regeneration of a diploid sporophyte from a gametophyte, without the formation of gametes is called apogamy. Aposory and apogamy are rarely found in life cycle of Bryophytes.