



Indira Gandhi National
Open University
School of Sciences

BBYCT-131 BIODIVERSITY (MICROBES, ALGAE, FUNGI AND ARCHEGONIATES)

Block

5

PTERIDOPHYTES

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Course Design Committee

Dr. A.K. Kavathekar (Retd.)
Sr. Consultant
Department of Botany
Sri Venkateswara College,
University of Delhi,
New Delhi-110001

Prof. M.S. Nathawat
Director,
School of Sciences

Prof. Vijayshri
Director (Ex.)
School of Sciences

Dr. Sneha Chopra (Retd.)
Department of Botany
Kalindi College, University of Delhi,
New Delhi-110017

Prof. Jaswant Sokhi
School of Sciences
IGNOU, Maidan Garhi
New Delhi-110068

Prof. Amrita Nigam
School of Sciences
IGNOU, Maidan Garhi
New Delhi-110068

Block Preparation Team

Prof. Amrita Nigam
School of Sciences
IGNOU

Dr. A.K. Kavathekar (Retd.)
Sr. Consultant
Department of Botany
Sri Venkateswara College
University of Delhi
New Delhi-110001

Course Coordinators: Prof. Jaswant Sokhi and Prof. Amrita Nigam

Print Production

Sh. Sunil Kumar
Assistant Registrar (P)

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BLOCK 5 : PTERIDOPHYTES

You have studied that bryophytes are regarded as the pioneers of land habitat. Bryophytes, though pioneers are non-vascular plants. If you were to look around, you will observe that almost all the land plants possess vasculature and are termed tracheophytes. When and in which group of plants had vasculature first evolved. As per the fossil record, there is a consensus amongst the scientists, that the plant group, the pteridophytes are the first vascular plants and are regarded as the most primitive tracheophytes.

What makes the pteridophytes even more interesting and important is the fact that along with vasculature there are many features in morphology, anatomy and reproductive cycle that appeared initially in pteridophytes. Some of these features are: independent – dominant, long-lived, sporophyte; branched sporophyte; lignified secondary cell wall; sclerenchyma for mechanical support; tracheary elements for conduction of water and nutrients; sieve elements to transport photosynthetic metabolites, endodermis involved in selective transfer across it; shoot system for harnessing maximum sunlight; well-developed stomata for gaseous exchange; true roots for anchorage and uptake of water and nutrients from soil etc.

Interestingly, despite possessing these advanced features which help survival on land habitat, the once dominant flora on land, the pteridophytes are now geographically restricted to certain areas only. One principal reason for this, is the fact that pteridophytes are dependent on water for transfer of its male gametes during sexual reproduction, a feature that is characteristic of bryophytes. Hence, they are also referred to as 'vascular cryptogams'. Short-lived, independent gametophytes are characteristic of majority of pteridophytes.

In this block you shall study the biology, ecology, classification, aesthetic and economic importance of this interesting group of plants, the pteridophytes in three units: 16, 17 and 18.

The unit 16, deals with the study of general characteristics, generalized life cycle, classification of pteridophyta in addition to a brief introduction to different modes of fossilisation. The life cycles of three representative genera are described in Unit 17. The economic importance, telome theory, stellar evolution and heterospory and seed habit are the principal subjects discussed in the Unit 18.

Objectives

After studying this block, you will be able to:

- familiarise with the general characteristics of pteridophytes and distinguish pteridophytes from other plant groups, especially the bryophytes and gymnosperms;
- describe the life cycle of a homosporous pteridophyte;
- distinguish various types of steles and their evolution and understand the principal modes of fossilization;
- correlate the heterospory to seed habit; and explain the telome theory;
- describe the structure of two fossil genera : *Rhynia* and *Cooksonia* ;
- compare the life cycles in homosporous *Pteris*, incipient heterosporous *Equisetum* and heterosporous *Selaginella*; and
- appreciate the ecology and economic importance of pteridophytes.

UNIT 16

PTERIDOPHYTES: AN INTRODUCTION

Structure

16.1 Introduction	16.4 Classification
Objectives	16.5 Early Land Plants
16.2 General Characteristics	<i>Rhynia</i>
Life Cycle of a Pteridophyte	<i>Cooksonia</i>
General Characteristics	16.6 Summary
Comparison between Bryophyta and Pteridophyta	16.7 Terminal Questions
Pteridophytic Features that Resemble Seed Plants	16.8 Answers
16.3 Formation of Fossils and their Types	Glossary

16.1 INTRODUCTION

Pteridophytes occupy a position in between bryophytes and gymnosperms and therefore, they are similar to bryophytes in some characters while similar to gymnosperms in some other characters. The most familiar plants of this group are ferns which we commonly see as houseplants, in parks and also in landscapes along with other ornamental plants. Ferns are rather small plants with stylish, often delicate compound leaves. Because of their beauty and difficulty in propagation, they are considered very valued plants. They generally live as an understory plant in shades and moist areas.

Pteridophyta name was first used by Haeckel (1866) and they are the most primitive living and fossil vascular plants. This name was given due to presence of pinnate or feather like leaves and phyton meaning plant.

Pteridophytes are vascular plants and they possess root, stem and leaves. They were the first vascular plants to grow on land and began their life cycle from leafless and rootless individuals in the Silurian and Devonian periods about 350-315 million years ago. They were the first group of cryptogams which showed the presence of well developed conducting system with xylem and phloem, hence they are called vascular cryptogams. Among the vascular plants, there is great variation in the relative position and arrangement of xylem and phloem, other associated tissues and in the presence or absence of pith.

In pteridophytes a natural gradation in vascular tissues from simple to complex forms is observed.

In this unit you will study the general characteristics of the life cycle of pteridophytes and the extinct members *Rhynia* and *Cooksonia*. Scientists got to know about the early vascular land plants from fossils of the extinct members *Rhynia* and *Cooksonia* which were simple and regarded as most primitive pteridophytes. One of the simplest living members of this group is *Psilotum*.

Objectives

After studying this unit, you should be able to:

- ❖ list characteristics of pteridophytes;
- ❖ describe the life cycle of a typical homosporous pteridophyte;
- ❖ compare the general features and life cycle of pteridophytes with bryophytes;
- ❖ differentiate between different types of fossils, give examples of fossil pteridophytes and describe them; and
- ❖ describe the morphology and anatomy of *Rhynia* and *Cooksonia*.

16.2 GENERAL CHARACTERISTICS

16.2.1 Life Cycle of a Pteridophyte

Pteridophytes also have two distinct phases in the life cycle: gametophytic and sporophytic similar to bryophytes (Fig. 16.1), that alternate with each other in regular succession. Since the two generations are dissimilar morphologically, they are termed **heteromorphic**. Their gametophytes are very small in size, and are short-lived and live independent of sporophyte. The sporophyte is diploid and represents dominant phase of life cycle. Let us first study the generalized life cycle of pteridophytes because it would be easier for us to list their characteristics. Under normal circumstances, gametophyte produces motile male gametes (sperms) and non-motile female gametes (eggs). Fusion between an egg cell and a male gamete results in the formation of a diploid zygote. The zygote is divided by mitotic division and subsequent mitotic cell divisions form an embryo. The embryo develops into a sporophyte. The haploid spores produced on sporophytes could be homospores and heterospores. The life cycle is completed when a spore germinates and produces a haploid gametophyte by mitotic divisions and again produces two kinds of gametes. Fig. 16.1 illustrates a typical life cycle of a homosporous pteridophyte.

In pteridophytes the sporophyte very soon becomes independent of the gametophyte and is the dominant generation. The sporophyte shows greater degree of complexity in structural organisation. It is organised into stem, root and leaves (Fig. 16.1), except in the most ancient fossil pteridophytes and most primitive living members. This complexity of internal organization was partly due to adaptation to a change of habitat from water to land.

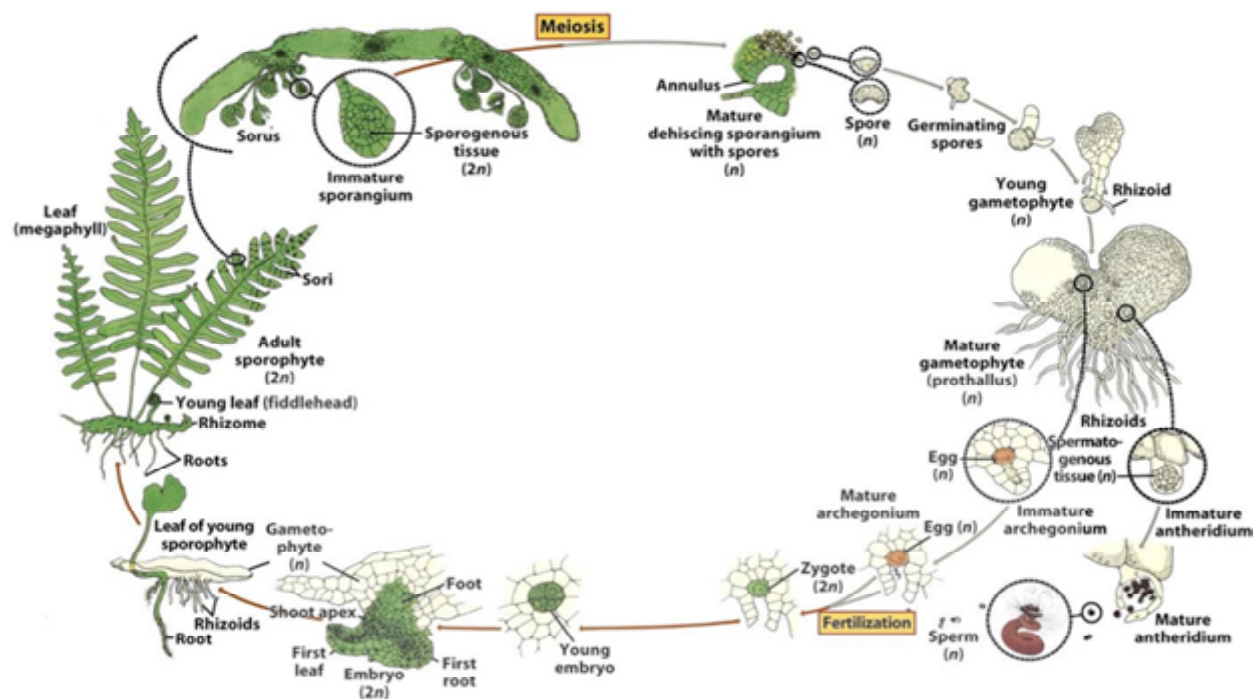


Fig. 16.1: Typical life cycle of a homosporous pteridophyte.

The vascular tissues (xylem and phloem) are developed only in the sporophyte. Furthermore, the aerial parts are covered with a layer of cuticle. On the epidermis there are stomata for the exchange of gases. These anatomical complexities of the sporophyte helped in inhabiting a much wider range of environmental conditions than the gametophyte could.

SAQ 1

Which of the following statements are true or false about pteridophytes. Write (T) for true (F) for false in the given boxes.

- In pteridophytes the sporophyte is differentiated into stem, roots and leaves. []
- The gametophyte and the sporophyte are independent at maturity. []
- Male and female gametes are non-motile. []
- Sporophyte lacks conduction system. []
- Gametophyte is the dominant phase in the life cycle. []

16.2.2 General Characteristics

In the previous section you have studied that in pteridophytes sporophyte is the dominant phase in plant life. It possesses a vascular system and is differentiated into true root, stem and leaves. Pteridophytes exhibit a great variation in form, size and structure. Now look at Fig. 16.2 and study carefully the morphology of sporophyte and reproductive bodies of various genera.

Sporophytes of most of the pteridophytes are herbaceous except a few woody tree ferns. They may be **dichotomously** or **laterally** branched stems that bear **microphyllous** (Fig. 16.2 b, c) or **megaphyllous leaves** (Fig. 16.2 e, f).

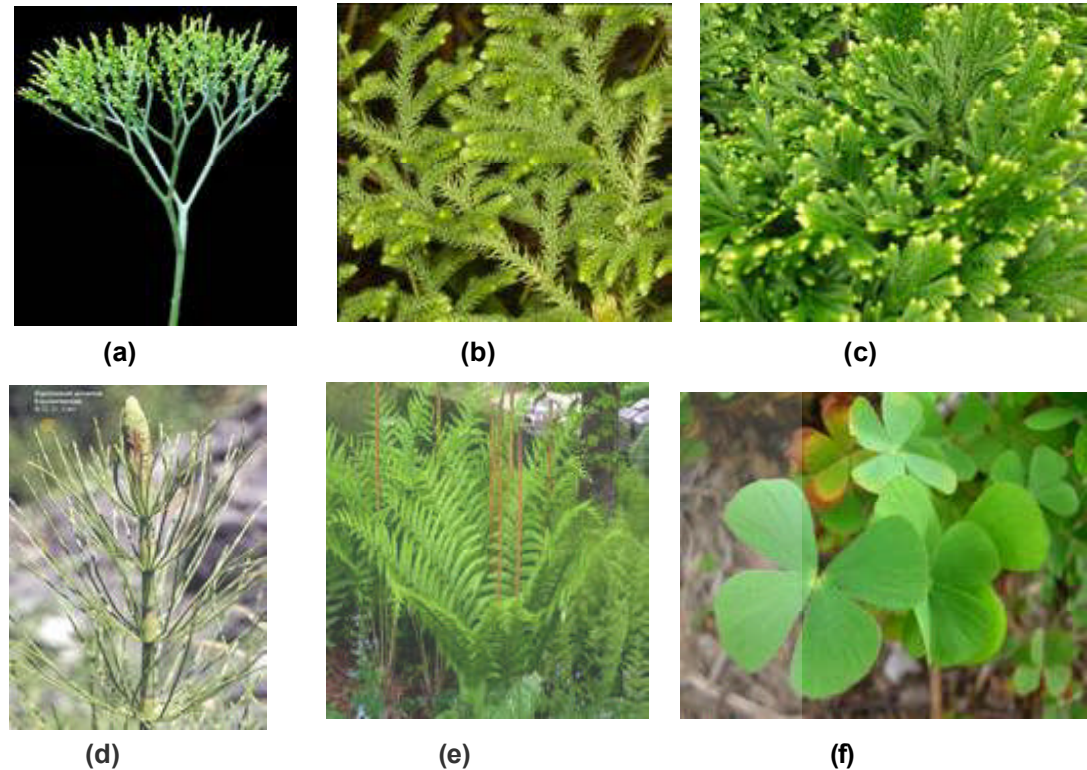


Fig. 16.2: Morphology and reproductive bodies of a few pteridophytes:
 a) *Psilotum*; b) *Lycopodium*; c) *Selaginella*; d) *Equisetum*;
 e) A cultivated fern; and f) *Marsilea*.

The roots are generally adventitious, the primary embryonic root being short-lived. The stems and roots exhibit apical growth.

The spores are produced in a special structure called **sporangium (pl. sporangia)** that is invariably subtended by leaf-like appendages known as **sporophyll** (Fig. 16.3 a). The sporangia may be scattered throughout the vegetative axis or may be restricted in a particular area. In many pteridophytes there are distinct spore producing regions called the **strobili** or the **cones**, (Fig. 16.3 b, c). The sporangia in some cases, may be produced within specialized structures called the **sporocarp** e.g., *Marsilea*, *Salvinia* (Fig. 16.3 d, e).

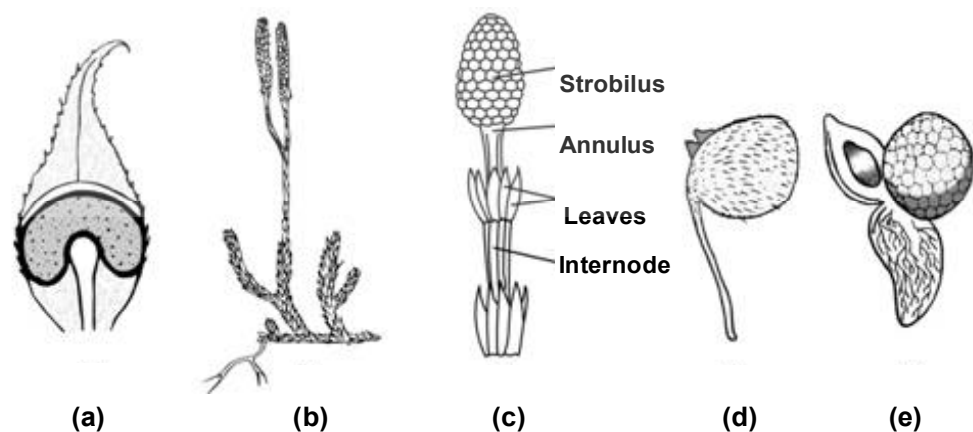


Fig. 16.3 (a-e): Some spore-bearing structures in pteridophytes:
 a) a sporophyll from a strobilus of *Selaginella*; b) Terminal soft compact strobili of *Lycopodium*; c) Hard, terminal cone in *Equisetum*; and d-e) specialized structures- sporocarps in *Marsilea* and *Salvinia* respectively.

Distinct segregation of vegetative and reproductive shoots and leaves have also been observed in some species of *Botrychium*, *Anemia* and *Schizaea* (Fig. 16.4 a-c). Have you ever noticed brown-black dots on the underside of a fern leaf? Each dot is a reproductive structure called sorus. A sorus is a cluster of sporangia.

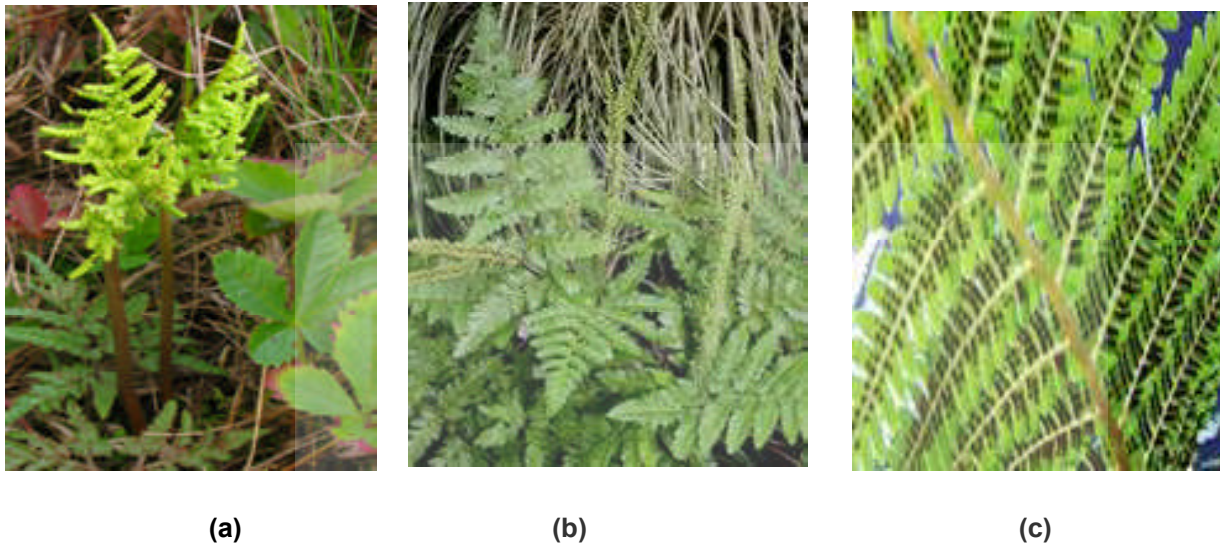


Fig. 16.4: Distinct reproductive shoots of : a) *Botrychium*; b) *Anemia*; and c) *Schizaea*.

Most of the pteridophytes are **homosporous** i.e., they produce only one type of spores (Fig. 16.5 a). However, a few species are **heterosporous** i.e. they produce two types of spores, **microspores** and **megaspores** (Fig. 16.5 b, c). A spore on germination produces a gametophyte. Heterosporous species produce **microgametophytes** as well as **megagametophytes** from microspores and megaspores respectively.

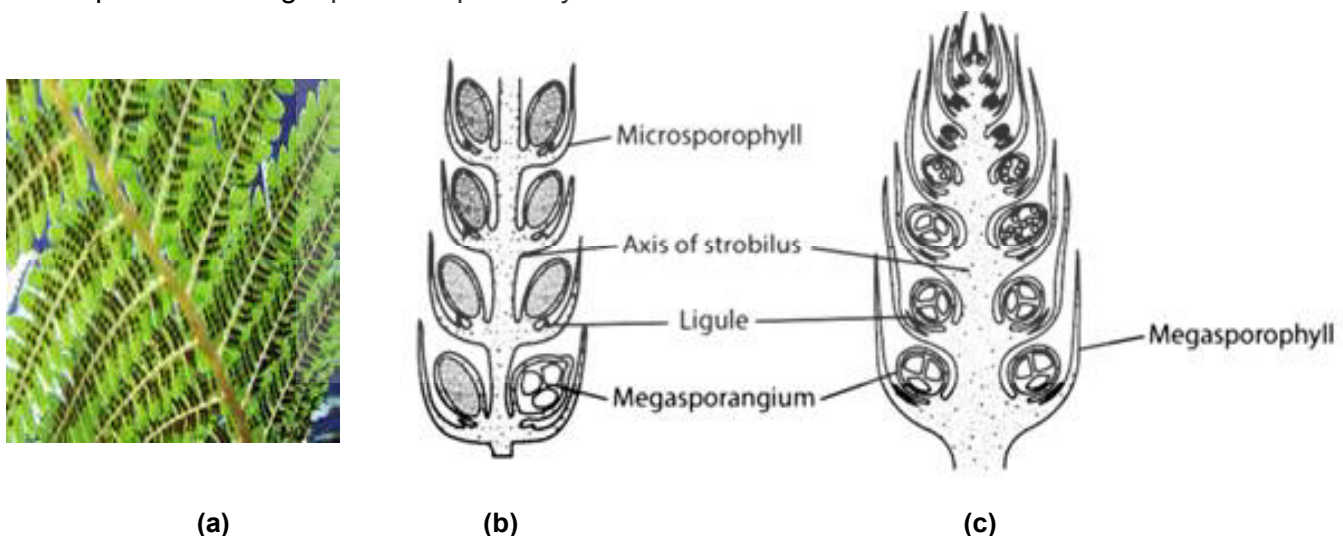


Fig .16.5: Homo and heterosporous pteridophytes: a) Photograph of Homosporous fronds of a fern; b) Microsporangium in *Selaginella*; and c) Megasporangium in *Selaginella*.

The gametophytes of these heterosporous forms are retained within the spore coats i.e., are endosporic whereas in homosporous the gametophytes are exosporic i.e, they are formed outside the spore walls (Fig. 16.6 a, b, c).

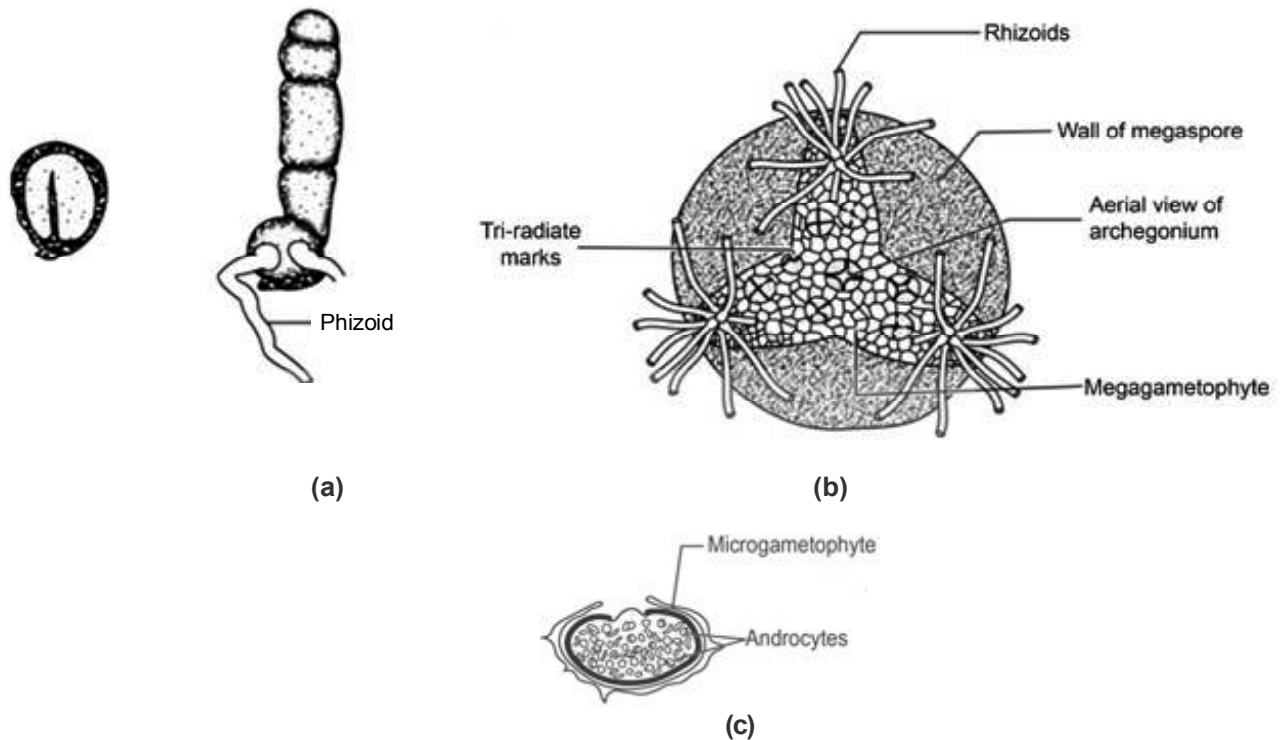


Fig.16.6: Gametophytes in pteridophytes: a) exosporic fern gametophyte; b) endosporic megagametophyte in *Selaginella*; c) endosporic microgametophyte in *Selaginella*.

In general, pteridophytes form green, dorsiventrally differentiated, thallose gametophytes with sex organs restricted to the ventral surface. The sex organs may be embedded or projecting. The female reproductive structure is an archegonium and the male reproductive structure is an antheridium (Fig. 16.7 a, b).

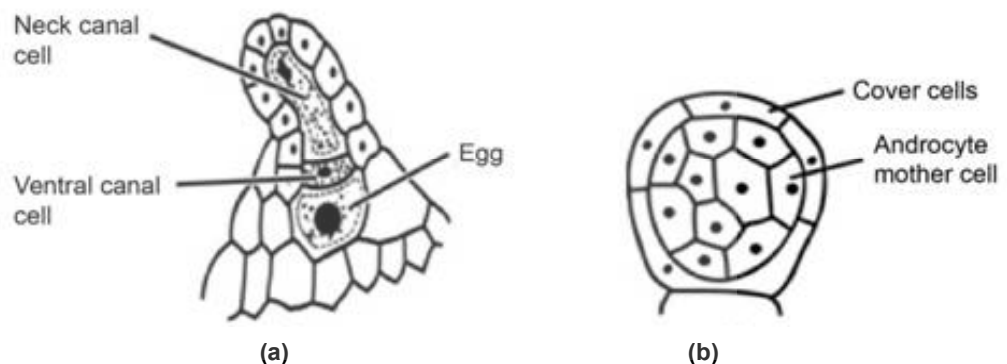


Fig. 16.7 a-b: Sex organs in pteridophytes: a) an archegonium; b) an antheridium.

The archegonium has invariably four longitudinal rows of neck cells whose height varies in different genera. The antheridium consists of a single layer of sterile jacket of cells enclosing a mass of androcytes or antherozoid mother cells. The antherozoids are biciliate in *Lycopodium* and *Selaginella*.

Multiflagellate spermatozoids are common to *Psilotum*, *Equisetum* and ferns (Fig. 16.8 a,b). The opening of the mature sex organs and the subsequent fertilization is still conditioned by the presence of water which is similar to bryophytes.

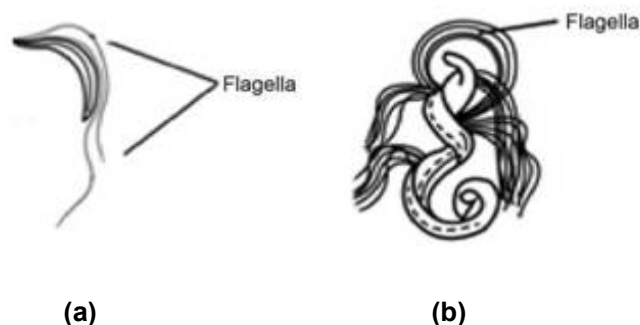


Fig .16.8: Motile male gametes in pteridophytes: a) biciliate spermatozoid in *Selaginella*; b) multiflagellated spermatozoid of a fern.

The sporangia can be distinguished into two types: eusporangium and leptosporangium on the basis of their development. In the former the sporangium originates from a group of initial cells (e.g., *Psilotum* and *Selaginella*), while in latter one their origin is from a single initial e.g., ferns. You will learn about them in the next unit.

16.2.3 Comparison between Bryophyta and Pteridophyta

Now that you have studied the life cycle and the general characteristics of pteridophytes, Let us compare them with bryophytes.

Bryophytes resemble pteridophytes in the following features:

1. Thallose liverworts and pteridophytes show similarity in vegetative structure of gametophytes.
2. Their female and male reproductive structures are archegonium and antheridium, respectively. The female gamete, an egg, is non-motile while the male gametes are motile.
3. The opening of the mature sexual reproductive organs and the subsequent fertilization are conditioned by aqueous medium i.e., both require water for fertilization.
4. They usually show a distinct and clearly defined heteromorphic alternation of generations and the two generations follow each other in regular succession.
5. Meiosis precedes spore formation in both the groups. The diploid mother cells of spores are produced by the last division of the sporogenous tissue. Each of the spore mother cells undergoes meiotic division resulting in tetrads of spores.
6. Development of embryo occurs in the archegonium. The zygotic as well as subsequent cell divisions are mitotic.
7. The young sporophyte or embryo is at least partially parasitic upon the gametophyte.

Now let us study the characteristics which distinguish pteridophytes from bryophytes.

Cryptogams

The plants which do not produce seeds.

Phanerogams An old term for flowering plants which includes Gymnosperms and Angiosperms. It is now replaced by the term Spermatophytes.

1. Unlike bryophytes, where sporophyte is dependent upon gametophyte physically and physiologically, the sporophyte is independent in pteridophytes, and is the dominant phase of life cycle.
2. In pteridophytes the sporophyte has true roots, stem, and leaves and well developed conducting tissues- xylem and phloem, which are absent in bryophytes.
3. Some of the pteridophytes are heterosporous but all the bryophytes are homosporous.

As mentioned earlier, pteridophytes form an important link between bryophytes and seed plants. This suggests that they also resemble in some respects with spermatophytes.

16.2.4 Pteridophytic Features that Resemble Seed Plants

Let us now enumerate some salient characteristics common to both pteridophytes and the seed plants – angiosperms:

1. The sporophyte is dominant, typically photosynthetic phase of life cycle.
2. It is organised into stem, root and leaves.
3. The roots and the leafy shoots are provided with a conducting system made of specialised tissue i.e., xylem and phloem.
4. Gametophytes are very much reduced and developed within the spore wall (in heterosporous genera).
5. Some pteridophytes do approach seed-habit and some fossil pteridophytes had seed-like structures.

Due to their affinities with both bryophytes as well as with higher vascular plants, pteridophytes are also known as “Vascular Cryptogams”.

SAQ 2

Fill in the blanks with appropriate word(s).

- i) Spore-bearing structures in pteridophytes are called
- ii) Strobilus is a distinct region in a sporophyte.
- iii) Ploidy level of spore-mother cell in both bryophyte and pteridophytes is.....
- iv) is a non-motile gamete in pteridophytes.

16.3 FORMATION OF FOSSILS AND THEIR TYPES

In the above account you have learnt about the characteristics of pteridophytes and their relation to other plant groups. Now we will describe the formation of various types of fossils and how they reveal life forms that occurred millions of years ago.

Fossils are the remains and/or impressions of organisms that lived in the past. In its correct sense fossils include the remains of organisms or their parts and

Seed Ferns

A completely fossilised group of plants the Pteridosperms (seed ferns) are regarded as link between Pteridophytes and seed plants.

also anything connected with an organism proving its existence, i.e., anything which gives evidence that an organism once lived.

The actual nature of fossilisation depends on the environmental conditions in which it takes place. Dead plant remains are liable to get disintegrated and it is only rarely that they get fossilized. Chances of fossilisation are better for organisms having stiff tissues/skeletons. The details of fossilisation process are discussed below.

Fossilisation Process

The process of formation of fossils is going on ever since the sedimentary rocks began to deposit and it is going on in nature even now.

In some cases plant parts may be deposited on the site where they grow (*in situ*), such as swamps and small inland lakes. Due to low oxygen content and presence of toxic substances in the water, microbial growth is inhibited, so the plants do not decay. This results in the preservation of the plant remains until they were covered by layers of sediments. European coal forests are the example of this type of fossilisation.

In other cases plant parts are carried down by flowing water and finally sink to the bottom of a lake or estuarine water where they are less susceptible to decay by microbes. Indian Gondwana coal deposits are example of this type of fossilisation.

During fossilisation the protoplasmic contents and softer parenchymatous cells disappear first, while the harder wood and other sclerenchymatous or cutinised tissues resist to the last. The growing pressure of the heavy sedimentary rocks above, first reduces the vacant spaces inside the cells and forces the liquid substances out. Some organic substances may also escape as marsh gas. Naturally, all fossils get highly compressed and the final result depends on how far the conditions were favourable for good fossilisation. In spite of all hazards sometimes fossils are formed, which retain their cellular structure beautifully and sometimes even some of the cell contents.

Types of Fossils

According to the nature of fossilisation, fossils may be of the following types:

i) Petrification

It is best type of fossilisation. In this type buried plant material gets decayed with the passage of time and gets replaced, molecule for molecule by mineral solutions. The impregnation of silica, calcium carbonate, magnesium carbonate, iron sulphide takes place within the tissues. Most of the plant material may get decayed but at least some original cell wall components remain.

ii) Cast or Incrustation

This type of fossilisation is also quite common. The plant part gets covered up by sand or mud. After sometime the plant material inside the plant degenerates leaving a cavity known as mold. This cavity again gets filled up by some rock-forming material which in course of time solidifies into an exact cast of the plant material, showing all its surface features. A

cast fossil does not actually contain any part of the original plant but it is of great use as the cast correctly shows the original features of plant part (Fig. 16.9).



Fig. 16.9: Incrustations.

iii) Impression

These are formed when a leaf or any other part of the plant falls on and leaves an impression on the surface of semisolid clay. In course of time this impression becomes permanent when the clay turns into stone like stomata are clearly seen in good preparations (Fig. 16.10).



Fig. 16.10: Impressions of plant.

Compression

In a compression the organic remains of the plant part actually remain in the fossils but in a highly compressed state. During the process of fossilisation the great pressure of sediments from above causes flattening of plants parts. In the fossil usually a carbonaceous film remains which represents the surface features.

Mostly, fossils consist of fragments of plants. Sometimes it may take many years to find the fossil of a stem to which a particular kind of leaf belonged. Therefore, in the meantime each fragment of fossil plant is described under a separate generic name and such genera are known as "Form genera". In naming such form genera we usually add suffixes, signifying which part of the plant it came from. Following are a few examples:

Leaf (-*phyllum*); Frond (-*pteris*);

Trunk (-*dendron*); Wood (-*xylon*);

seed (-*spermum*, - *carpon*); cone (-*strobis*)

It is the work of palaeobotanists to collect bits of such fossils, i.e., form genera, and to reconstruct the form, structure and mode of life of the plant from which they came. Success has been achieved in reconstructing a few fossil plants.

SAQ 3

Fill in the blank spaces with appropriate words.

- A good type of compressed fossil is in which the organic materials is found very much intact.
- In impression features remain intact.
- are formed when plant material degenerates and in its place rock forming substances are deposited.
- In impregnation of minerals takes place inside the tissue.

The age of the fossil is ascertained from geological time scale (Fig. 16.11).

Geological age		Plant Kingdom	
Cenozoic era	Quaternary period	Age of Angiosperms	Flourishing of angiosperms
	Tertiary period		
Mesozoic era	Cretaceous period	Age of Gymnosperms	Appearance of gymnosperms
	Jurassic period		Flourishing of conifers
	Triassic period		Appearance of cycads
Paleozoic era	Permian period	Age of Ferns	
	Carboniferous period		Tree fern from large forests Appearance of gymnosperms
	Devonian period		
	Silurian period	Age of Algae	Appearance of terrestrial plants
	Ordovician period		Flourishing of algae
	Cambrian period		
Precambrian era			Appearance of green algae Appearance of cyanobacteria Appearance of bacteria

Fig. 16.11: Geological time chart .This chart illustrates the time of appearance of land plants and different groups of vascular plants. Time is given in millions of years ago (MYA) (after Gensel and Andrews).

16.4 CLASSIFICATION

Earlier botanists treated pteridophytes as single unit with four major groups (subdivisions). However, according to International Code of Botanical Nomenclature, a division should have a suffix-phyta. Accordingly, the 4 Divisions of pteridophyta are:

- Division - Psilophyta (the psilophytes)
- Division - Lycophyta (the lycopods)
- Division - Sphenophyta (the horse tails)
- Division - Filicophyta (the ferns)

DIVISION PSILOPHYTA

The plants included in the Division **Psilophyta** are the oldest known vascular plants. They appeared in the Late Silurian and flourished during the Lower and Middle Devonian. The peculiarity of these plants lies in simplicity of structure. Most of the members of the Psilophyta are known as fossils except two living members: *Psilotum* and *Tmesipteris*. Division Psilophyta is characterised by the following features:

1. The sporophytic plant body consists of subterranean rhizome bearing numerous slender, erect and dichotomously branched aerial shoots. The Psilophyta is characterised by some organ differentiation.
2. The true roots are absent; although rhizomes may produce rhizoids.
3. True leaves are usually absent, or, if present, they are small, simple and spirally arranged.
4. The vascular cylinder is a protostele.
5. Cambium is absent.
6. The sporangia are always borne singly at the tips of the branches and are thick walled.
7. The sporangia are homosporous.

Classification of Psilophyta

Division : Psilophyta has been divided into two classes as following:

Class 1 : Psilophytosida. The class includes only one order.

Order : Psilophytales. It is represented only by fossil remains

Family : Rhyniaceae

Family : Zosterophyllaceae

Family : Psilophytaceae

Family : Asteroxylaceae

Family : Pseudosporochnaceae

Class 2 : Psilotosida. The class includes single order.

Order : Psilotales. The order is represented by two living genera: *Psilotum* and *Tmesipteris*

DIVISION LYCOPHYTA

The Lycophyta are the vascular plants with a long ancient history, extending from the Palaeozoic to the present. They are represented by both extinct and living forms. They are characterised by following features:

1. The sporophytic plant body is differentiated into roots, stem and leaves.
2. The plants are characterised by leaves that are small and simple, though a few of the fossil genera had leaves several feet long. Each leaf is generally traversed by a single unbranched vascular bundle.
3. The vascular cylinder is a protostele or siphonostele.
4. Secondary growth does not take place except in *Isoetes*.
5. Sporangia are borne on the upper or adaxial surfaces of the sporophylls.
6. In most cases, the sporophylls are aggregated to form cones or strobili.
7. The plants may be homosporous or heterosporous.

Classification of Lycophyta

The Division Lycophyta has been divided into two classes: **Eligulopsida** and **Ligulopsida**.

Class : Eligulopsida

They are homosporous and their leaves are without ligules. The class includes only one order: **Lycopodiales**.

Order: Lycopodiales

Family: Protolepidodendraceae (represented by fossil remains)

Family: Lycopodiaceae

Class Ligulopsida

The class Ligulopsida differs from the class Eligulopsida in being markedly heterosporous as well as in possessing ligulate leaves. The class includes four orders: Lepidodendrales, Pleuromeiales, Isoetales, and Selaginellales.

Order: Lepidodendrales (represented by fossil remains)

Order: Pleuromeiales (represented by fossil remains)

Order: Isoetales

Family: Isoetaceae

Order: Selaginellales

Family: Selaginellaceae

DIVISION SPHENOPHYTA

The members of this division, commonly known as horsetails, are a group of ancient origin. They grew and flourished in abundance during the Palaeozoic era but have now become almost extinct, being represented today only by a single genus *Equisetum*. The group has the following characteristics:

1. The sporophytes have true roots, stems and whorled leaves.

2. The stems are jointed, with distinct nodes and internodes. The internodes are hollow and are longitudinally ribbed and furrowed.
3. Both protosteles and siphonosteles are found, and are characteristically without the leaf gaps.
4. The leaves are scale-like and are borne in whorls at the nodes of the aerial stem and its branches. The leaves are short lived and the usually united to form a sheath around each node.
5. The branches also arise in whorls from the nodes.
6. The sporangia are borne on structures, called sporangiophores forming strobili or cones.
7. Mostly they are homosporous though some extinct forms were heterosporous.
8. The gametophytes are exosporic and green.
9. Antherozoids are multiflagellated.

Classification of Sphenophyta

The Division Sphenophyta consists of four orders: Hyeniales, Sphenophyllales, Calamitales, and Equisetales.

Order : Hyeniales (represented by fossil remains)

Order : Sphenophyllales (represented by fossil remains)

Order : Calamitales (represented by fossil remains)

Order : Equisetales

Family : Equisetaceae

DIVISION FILICOPHYTA

The Division Filicophyta is the largest group of vascular cryptogams and consists of a series of plants, commonly known as “ferns”. They are widely distributed throughout the earth. They exhibit such a wide range in habit, in leaf form and reproductive structures that it becomes almost impossible to list one constant diagnostic feature of the Filicophyta as a whole. However, they are distinguished from other divisions of vascular cryptogams by following features:

1. Their leaves are large in relation to the size of the stem. Such leaves are described as megaphylls or fronds.
2. The stems are protostelic, siphonostelic or dictyostelic; sometimes polycyclic.
3. The stem, in all the ferns, except those with protosteles, shows leaf-gaps, where the leaf traces are given off to the leaves.
4. Usually, the sporangia are developed either upon the margin or upon abaxial surfaces of leaves.

Classification of Filicophyta

The division Filicophyta has been divided into following four classes:

Class 1: Primofilicopsida (represented by fossil remains)

Class 2: Eusporangiopsida

Class 3: Protileptosporangiopsida (represented by fossil remains)

Class 4: Leptosporangiopsida

Class: Primofilicopsida

This class comprises an extinct group of Filicophyta that arose during the Devonian but disappeared in the Permian. The Primofilicopsida formed the link between Psilophytales and true ferns.

1. Most of the plants were small and had erect or horizontal stems.
2. Leaf and stem were not well differentiated.
3. They had terminal sporangia.
4. The vascular system was protostelic.
5. All were homosporous.

The class has been divided into four orders: **Protopteridales**, **Coenopteridales**, **Cladoxylales** and **Archaeopteridales**.

Class Eusporangiopsida

They are characterised by the following characters.

1. The sporangia are eusporangiate.
2. Each sporangium contains a large number of spores.
3. The sporangia are homosporous.
4. Antheridia are embedded in the gametophytic tissue.
5. Antherozoids are multiflagellated.

The class includes two orders: **Ophioglossales**, and **Marattiales**.

Order : Ophioglossales

Family : Ophioglossaceae

Order : Marattiales

Family : Marattiaceae

Class : Protileptosporangiopsida

This class belongs to an ancient group of ferns with a fossil record extending back to the Permian period. The class has following characteristics:

1. The type of the sporangium development is intermediate to eusporangiate and leptosporangiate.
2. The sporangia do not form sori; indusium is lacking.
3. They are characterised by the relatively late differentiation of parts of an embryo.

The class includes a single order, **Osmundales** with a single family, the Osmundaceae. The family includes three living genera: *Osmunda*, *Todea* and *Leptopteris*.

Class: Leptosporangiopsida

The members of this class are commonly known as “true ferns”, and constitute the largest group of living vascular cryptogams. The characteristics of the class are:

1. The sporangium develops from a single initial.
2. Only a limited number of spores are produced per sporangium.
3. Most of them are homosporous, but water ferns are heterosporous.
4. Antheridia are emergent and raised above the surface of prothallus.
5. Antheridia produce a limited number of antherozoids.
6. During the development of embryo, the primary organs-foot, root, cotyledon and stem of the young sporophyte are referable to single cell of the four celled embryo.

Reimers (1954) and Smith (1955), have divided the class Leptosporangiopsida into three orders: **Filicales**, **Marsileales** and **Salviniales**.

Order : Filicales

Family : Schizaeaceae

Family : Gleicheniaceae

Family : Matoniaceae

Family : Hymenophyllaceae

Family : Dicksoniaceae

Family : Cyatheaceae

Family : Polypodiaceae

Order : Marsileales

Family : Marsileaceae

Order : Salviniales

Family : Salviniaceae

Family : Azollaceae

SAQ 4

Match the characteristics mentioned in the column I to the taxa mentioned in the Column II.

Column I	Column II
a) Leafless, rootless sporophyte	i) Selaginellales
b) Sporophytes bearing ligulate leaves	ii) Filicales
c) Sporophytes with jointed stems with nodes and internodes	iii) Ophioglossaceae
d) Eusporangium	iv) Rhyniaceae
e) Sporangium developing from a single initial	v) Sphenophyta

16.5 EARLY LAND PLANTS

Most primitive genera are included in the Division Rhyniophyta. Now you will study in detail about the following two members of this division: *Rhynia* and *Cooksonia*.

16.5.1 *Rhynia*

Rhyniophytes were the simplest extinct vascular plants. *Rhynia* was discovered from the **Rhynie Chert Bed in Scotland**. These beds are thought to represent a peat bog adjacent to a live volcano. It is believed that 380 million years ago *Rhynia* and other plants grew in marshy environment. The periodic eruptions of the volcano flooded these plants with **silica-rich hot water** that instantly killed them and subsequently infiltrated them. In this way the plants remained preserved and some of them with great perfection. This genus was named after the locality and the two species identified are : *R. Gwynne-vaughani* and *R. major*. These species are very different both morphologically and anatomically, so they are kept in different genera, while *R. Gwynne-vaughani* was retained as the only species of genus *Rhynia* and a new genus *Aglaophyton* was made by renaming *R. major* and was named as *Aglaophyton major*. *A. major* has conducting cells which were devoid of tracheids hence do not have thickenings as other higher plants. *Rhynia* or *Aglaophyton major* is also bigger than *R. gwynne-vaughani* (Fig. 16.12 a, b).

The Rhynie chert deposits are thought to be of late lower Devonian age. This bed was discovered by geologist Mackie in 1913. The plants have been thoroughly worked out by Kidston and Lang. Some other plant fossils found in these deposits are *Horneophyton lignieri* and *Asteroxylon mackiei*.

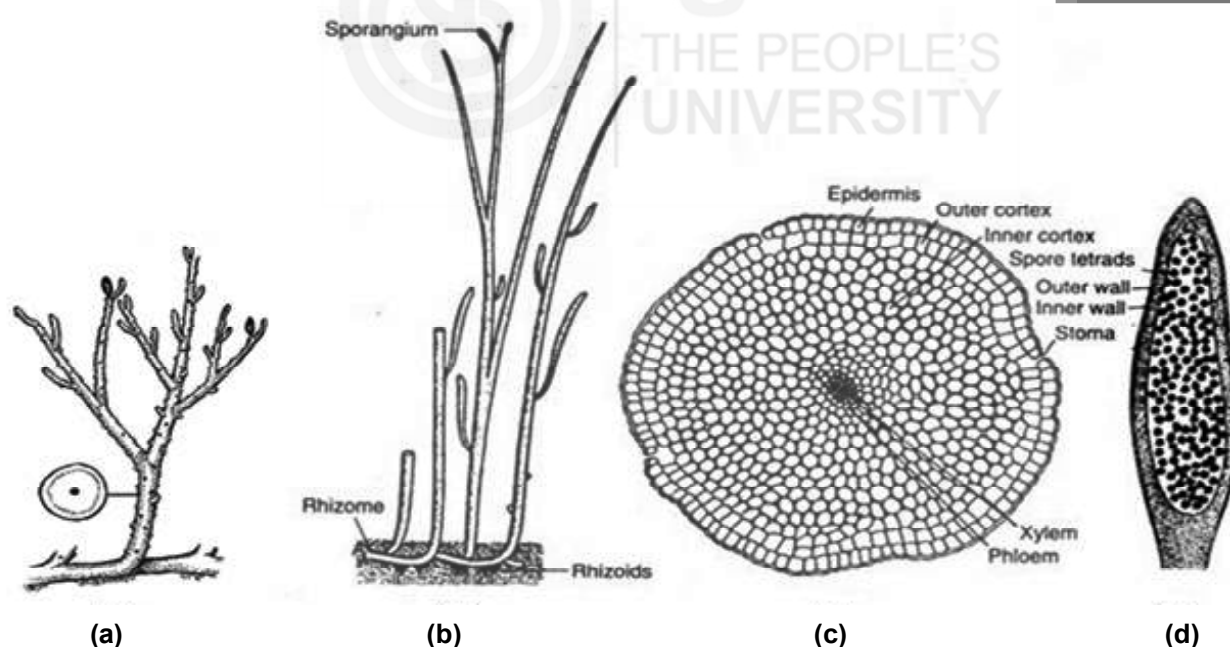


Fig. 16.12: a) *Aglaophyton (Rhynia) major* – note the dichotomous branching and sporangia; b) *Rhynia-gwynne-vaughani*; c) Semi diagrammatic T.S. of an aerial branch of *Rhynia*; d) L.S. of sporangium.

Rhyniophytes were seedless plants, consisting of simple dichotomously branched (evenly forked) axes or stem with terminal sporangia. *Rhynia gwynne-vaughani*, small herbaceous plant of about 18 cm height had cylindrical aerial stems and branches arising from a basal rhizome-like portion (Fig.16.12 a, b). The basal portion was buried in the peat. No much difference

was observed in the structure of the rhizome and the aerial stem except that the rhizome bore at places tufts of rhizoids on its underside. They did not possess roots and the rhizoids performed the dual function – absorption and anchorage. The aerial dichotomously branched stem tapered gradually towards its apex and the aerial shoots ended in pointed tips or bore oval sporangia. Numerous spores can be seen in a L.S. of sporangium (Fig. 16.12d). Stomata were present all over the surface of the aerial shoots. (Fig. 16.12c). Adventitious branches also arose from the aerial shoots.

Internal Structure

Look at drawing of the transverse section of aerial stem in Fig. 16.10 c and you will see following regions.

- i) **Epidermis:** It is the outermost layer and is covered by a thick cuticle. A number of stomata are also present.
- ii) **Cortex:** It is differentiated into a single – layered outer and a multilayered inner cortex. The cells of the outer cortex are larger than those of the inner cortex. The cells of inner cortex have intercellular spaces between them. Note that the intercellular spaces are connected to sub stomatal cavities. The inner cortex was most probably the seat of photosynthesis.
- iii) **Stele:** The centre of the stem is occupied by a very small, simple protostele which has a thin cylindrical column of xylem surrounded by phloem. The xylem consisted of only tracheids which had annular and occasionally traces of spiral thickenings. Sometimes, but not always, the tracheids in the centre of the xylem strand were smaller in diameter than those in the periphery. The phloem was made up of elongated thin-walled cells with oblique end walls.

SPORANGIUM

The sporangia of *Rhynia* are up to about 1.5 cm long and were nearly cylindrical and tapered slightly toward the tip. The jacket of this sporangium is several cells thick and does not have any specific site for dehiscence. The sporangial cavity was without any columella but bears a large number of spores of equal size. Some tetrads could also be observed (suggesting that the spores were haploid and the sporangium being diploid.)

Gametophytes, that were thought to be of Rhyniophytes, have been found in Rhynic beds well-preserved sex-organs, antheridia and archegonia were also observed.

16.4.2 *Cooksonia*

Cooksonia is believed to have inhabited mud flats and known to be the smallest, simplest and at present considered as oldest vascular plant. This plant had naked, straight and dichotomously branched stem (Fig. 16.11 a). Its lower regions are unknown. Five species have been described so far. The largest specimen discovered is about 7 cm long and 1.5 mm wide. The sporangia were terminal, short and wide. They varied in shape from reniform (kidney-shaped) through spherical to oval (Fig. 16.11 b). Not much is known regarding the anatomy of the stem or the internal structure of the sporangium.

Some specimens of *Cooksonia pertonii* from Upper Silurian of Wales show a thin vascular strand of tracheids within the delicate axes. The spores taken out from the sporangia possessed tri-radiate marks, suggesting they are products of meiosis. Hence, sporangium where they are found and the axis bearing the sporangium were diploid. These features suggest that they were land plants. *Cooksonia* can be regarded as the earliest vascular plant so far discovered.

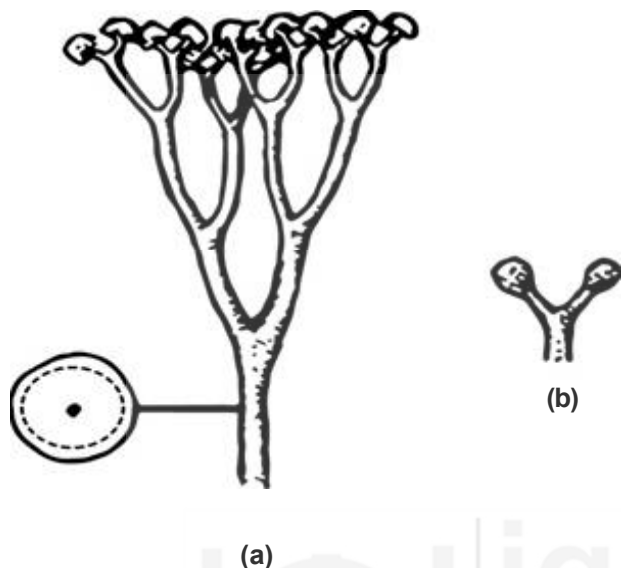


Fig. 16.13 : a) Portion of plant of *Cooksonia caledonica* and T.S. of imaginary stem; b) Sporangium of *C. caledonica*.

SAQ 5

- a) In the following sentences choose the **correct** word given in parentheses.
 - i) *Rhynia* was discovered from Rhynie Chert in (Scotland/Ireland).
 - ii) Rhynie Chert deposits are thought to be of (lower Devonian/upper Silurian).
 - iii) The aerial stem in *Rhynia* is (dichotomously branched/unbranched).
 - iv) Stele in *Rhynia* stem is (protostele/siphonostele).
 - v) In *Rhynia* roots are (present/absent), whereas rhizoids are (present/absent).
- b) In the following statements fill in the blank spaces with appropriate words.
 - i) In *Rhynia* the oval shaped sporangia were present on the of the branches.
 - ii) The spores of *Cooksonia* show mark.
 - iii) In *Cooksonia* the lower regions of the plant are
 - iv) Sporangia in *Cooksonia* are in position.

16.6 SUMMARY

In this unit you have learnt that:

- Pteridophytes are primitive, vascular, non-flowering land plants.
- Like bryophytes they show distinct alternation of generations but instead of gametophyte, sporophyte is the dominant phase of life cycle, water is necessary for fertilization.
- Fossils provide evidence for extinct plants. They are of four types: petrification, cast, impression and compression.
- The earliest land plants like *Rhynia* and *Cooksonia* were rootless. Their dichotomously branched aerial stem bore terminal sporangia. The underground rhizome had tufts of rhizoids, which performed the function of anchorage and absorption.
- The four divisions of pteridophyta are: Psilophyta; Lycophyta; Sphenophyta; and Filicophyta.

16.7 TERMINAL QUESTIONS

1. Describe typical life cycle of homosporous pteridophyte.
2. List the characteristic features of pteridophytes.
3. Differentiate between petrification and compression modes of fossilisation.
4. Enumerate the characteristics of:
 - a) Lycophyta
 - b) Sphenophyta
 - c) Psilophyta
5. How would you classify a pteridophyte as eusporangiate or leptosporangiate. Give one example of each of them.

16.8 ANSWERS

Self-Assessment Questions

1. i) T ii) T iii) F iv) F v) F
2. i) sporangium ii) spore-bearing
 iii) diploid iv) egg

3. i) clay nodule ii) external features iii) cast/incrustation iv) petrification
4. a) iv b) i c) v d) iii e) ii
5. a) i) Scotland
 ii) lower Devonian
 iii) dichotomously branched
 iv) protostele
 v) absent/present
 b) i) tip
 ii) tri-radiate
 iii) unknown
 iv) terminal

Terminal Questions

1. See Sub-section 16.2.1 and Fig. 16.1
2. See Section 16.2.2
3. See Section 16.3
4. See Section 16.4
5. See Sub-section 16.2.2

GLOSSARY

Fossil	: Remains and/impressions of organisms that lived in past.
Frond	: Large, megaphylls of ferns that are larger in size than the stem.
Heteromorphic life cycle	: When the gametophytic and sporophytic generations in an organism differ in morphology.
Heterosporous	: Those organisms which produce two kinds of spores: microspores and megaspores.

Homosporous	: Those organisms which produce only one kind of spores; or where all the spores are similar.
Ligule	: Little 'tongue', a laminate outgrowth on the base of leaf on its upper surface, e.g., <i>Selaginella</i> leaf.
Megaphyll	: Leaves which leave leaf traces in the stem.
Microphyll	: A leaf which leaves no leaf-trace in the stem.
Sporocarp	: A specialized structure bearing sporangia.
Strobilus	: Distinct spore-bearing structures on the stem-axis.



UNIT 17

PTERIDOPHYTES : TYPE STUDIES

Structure

17.1 Introduction

Objectives

17.2 *Selaginella*

Distribution and Morphology

Anatomy

Reproduction

17.3 *Equisetum*

Distribution and Morphology

Anatomy

Reproduction

17.4 *Pteris*

Distribution and Morphology

Anatomy

Reproduction

17.5 Summary

17.6 Terminal Questions

17.7 Answers

Glossary

17.1 INTRODUCTION

In the previous Unit 16, you studied about the general characteristics and classification of a group of vascular plants placed in pteridophyta. You were also introduced to the concept of fossils and modes of fossilisation. You also studied the morphological and reproductive characteristics of two fossil genera: *Rhynia* and *Cooksonia*.

In this unit you will study the distribution, morphology and the anatomy of stem, root and leaf of three representative genera: *Selaginella*, *Equisetum* and *Pteris*.

This unit will also help you to understand the structure of spore producing bodies, gametophytes, sex organs, male and female gametes, mode of gamete transfer as well as development of the embryo and also the young sporophyte in two homosporous and one heterosporous genera of pteridophyta.

Objectives

After studying this unit, you should be able to:

- ❖ understand the habit and habitat of the genera *Selaginella*, *Equisetum* and *Pteris*;
- ❖ describe the morphology of sporophytes of the genera *Selaginella*, *Equisetum* and *Pteris*;
- ❖ describe and compare the anatomical characteristics of vegetative organs in these genera;
- ❖ describe structure and organization of spore bearing organs of these genera;
- ❖ list general characteristics of reproductive organs of these genera;
- ❖ represent diagrammatically the life-cycles in these genera; and
- ❖ highlight heteromorphic homosporous as well as heterosporous and alternation of generations in these genera.

17.2 SELAGINELLA

Systemic Position

Division – Lycophyta

Class – Ligulopsida

Order – Selaginellales

Family – Selaginellaceae

17.2.1 Distribution and Morphology

Most of the species of *Selaginella* are restricted to damp areas of the tropical and subtropical regions of the world and are called spike moss or club moss. A few species are markedly xerophytic and inhabit desert regions. These are sometimes called “resurrection plants” because of their extra-ordinary power of recovery after prolonged drought. The plant may be prostrate, erect or sub-erect. Only a few are epiphytic. Some form delicate green mossy cushions, others are vine-like, with stems growing to a height of several meters, while many have creeping axes, from which arise leafy branch systems that bear a striking superficial resemblance to the frond of a fern.

Stem: Hieronymus (1900) divided *Selaginella* into two subgenera viz. Homoeophyllum and Heterophyllum.

- i) Homoeophyllum – species included in this genera are isophyllous and have spirally arranged leaves e.g. *Selaginella rupestris* (Fig. 17.1 c, d). The stem in Homoeophyllum is somewhat erect and shows a dichotomous branching which later on becomes monopodial.
- ii) Heterophyllum – species included in this genera exhibit markedly dorsiventral symmetry and anisophylly. The leaves are arranged in four rows along the axis, two rows of small leaves attached to the upperside

and two of the larger ones attached laterally (Fig. 17.1 a, b). The fertile regions, however, are isophyllous and the cones are four-angled, which make them very clearly distinguishable from the vegetative regions.

Heterophyllum the stem is prostrate to suberect with lateral branching.

Branching in *Selaginella* is characteristic, terminal and unequal, forming weaker and stronger branches. At each dichotomy there are one or two angle meristems on either side. These angle-meristems develop into cylindrical outgrowths known as “rhizophores” (Fig. 17.1 a, c, d). In most species only the ventral angle-meristem develops into rhizophore, while the other remains as dormant papilla. The rhizophores grow downwards into ground and give rise to a small tuft of adventitious roots at their tips.

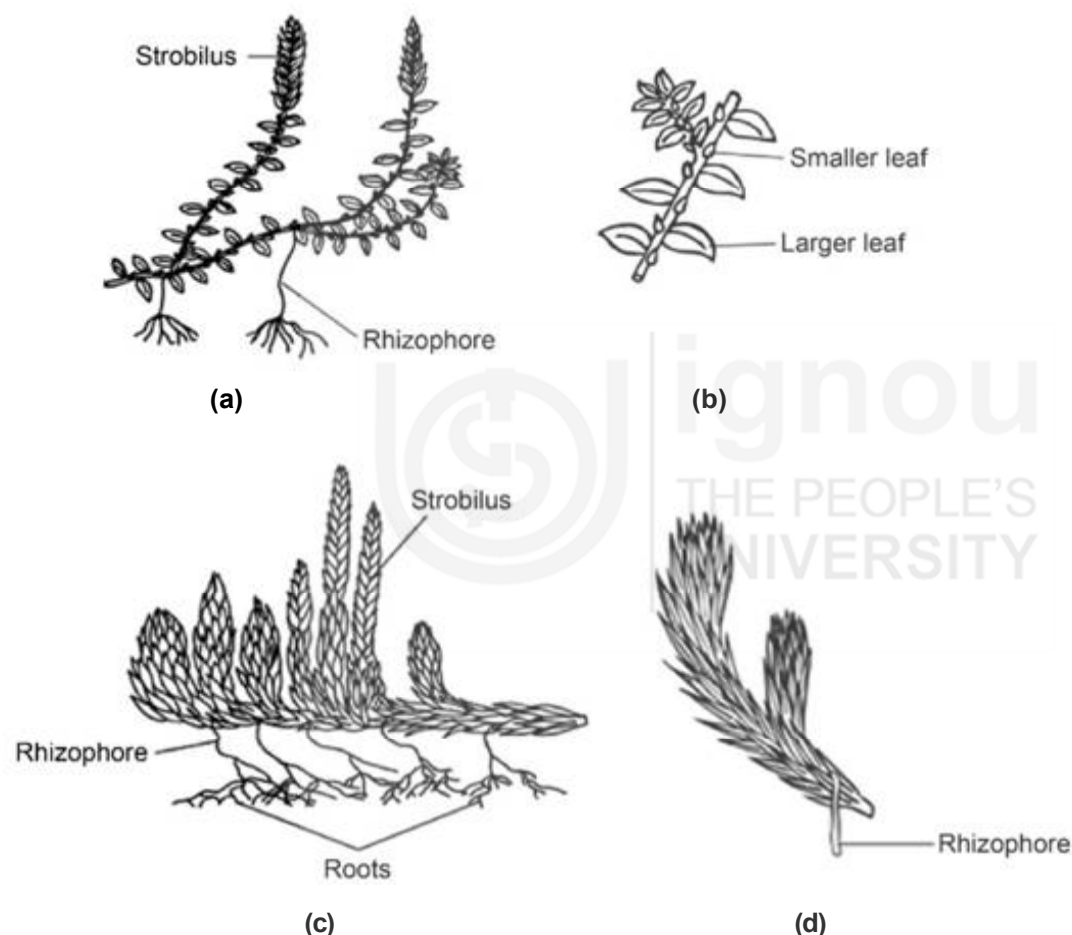


Fig. 17.1 : *Selaginella*, habit : a-b) Sub-species heterophyllum; c-d) Sub-species homoeophyllum.

In *Selaginella* the leaves are simple, small, thin and ovate to lanceolate in shape, sessile with a single unbranched vein (Fig. 17.2 a). Each leaf has a thin membranous finger like structure called ligule at the base of adaxial surface. The ligule is present in or near the axil of each leaf as a laminate outgrowth (Fig. 17.2 b). It differentiates and matures very early in the ontogeny of leaf. A mature ligule can be tongue-or-fan-shaped or fringed shaped. Its basal region is made up of tubular, hyaline cells forming the sheath. Below the sheath is a hemispherical region of thin and greatly vacuolated cells referred to as **glossopodium** (Fig. 17.2 b). The remaining cells are isodiametric. The apical region is one cell thick and is made up of elongated cells with scanty

contents. Apical growth in *Selaginella* takes place by a single cell and its derivatives or by an apical meristem comprising a group of cells.

The following are the functions of the ligule:

- i) conservation of water and thereby preventing shoot from desiccation, and
- ii) upward movement of inorganic salts by compensating for smaller and less effective leaf primordia.

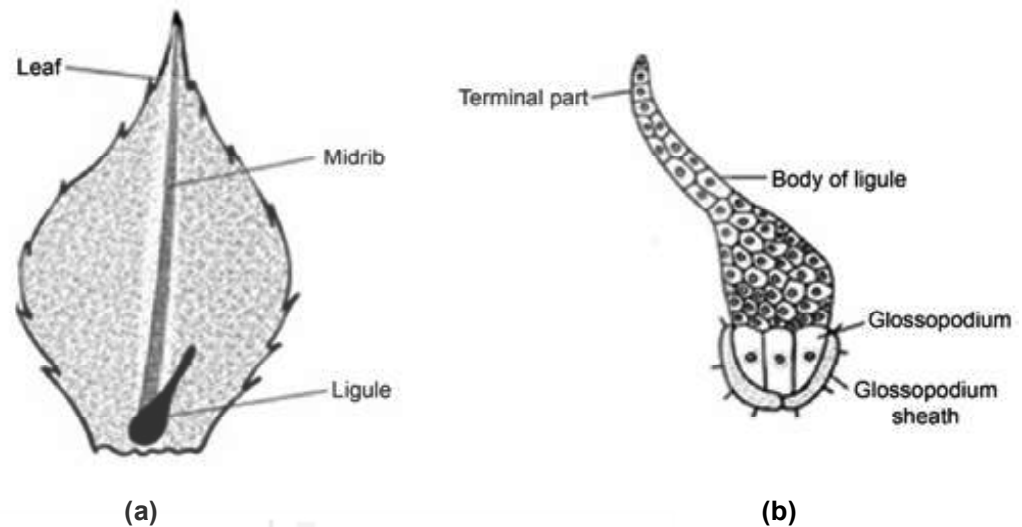


Fig. 17.2: *Selaginella* Leaf structure: a) Adaxial surface of a leaf showing ligule; b) v.s. of a ligule.

Roots

The primary root is short-lived and roots are adventitious. In most of the species, delicate and sparingly branched structures which develop at the distal ends of "rhizophores" are described as roots.

Rhizophore

In general in *Selaginella* sp. at the place of branching stem, a leafless structure arises toward the lower side, which is called rhizophore. The tip of rhizophore becomes branched and several adventitious roots are formed. The morphological nature of rhizophore has been controversial. It has been held to be a (a) root, (b) a branch of stem, and (c) a structure *sui generis* (falling in neither of the categories). Earlier investigators reported the following unique combination of characters of rhizophore:

- i) exogenous origin from the stem at the time of branching,
- ii) lack of root cap,
- iii) production of roots endogenously behind the tip, and
- iv) ability, in some instances, to be converted into leafy shoots. Since these features are not typical of root these outgrowths are called rhizophores.

The features suggestive of their root nature are:

- i) positive geotropic,
- ii) anatomical organization, monarch xylem, and
- iii) in some species when these structures are less than 1 mm. the root cap develops, In *S. martensii* cap differentiates when it nears the soil.

Using labelled auxin (C^{14} IAA) it has been shown that auxin transport in rhizophores of *Selaginella* is acropetal as in case of angiosperms root, (whereas it is basipetal in stems). Therefore, now the term “rhizophore” as well as the arguments regarding its nature are of historical significance. However, the results of electrophoretic patterns of polypeptides of rhizophores, stem and roots shows that these pattern in rhizophores resemble more with that of stem rather than root.

17.2.2 Anatomy

Leaf

You can see the anatomy of leaf of *Selaginella* in a transverse section (Fig 17.3). You will find that leaf is bounded by upper and lower layer of epidermis. Upper epidermis is one cell thick. In some species the upper epidermis consists of conical cells with very large chloroplasts, without stomata. The lower epidermis is also one cell thick and possesses stomata. The mesophyll between upper and lower epidermis is usually composed of similar, more or less elongated, chlorophyllous cells with intercellular spaces. The chloroplasts vary in number and shape in different species. In the centre of each chloroplast there are many spindle-shaped, pyrenoid-like bodies, each of which may be transformed into a rudimentary starch grain. There is single concentric median vascular bundle in the middle. The leaf traces join the stele of the stem. The xylem consists of four to five tracheids, one of which is annular while others are spiral ones. Surrounding the xylem is a layer of phloem, composed chiefly of elongated narrow parenchyma cells, and sieve cells. Outside the phloem is a single-layered bundle-sheath.

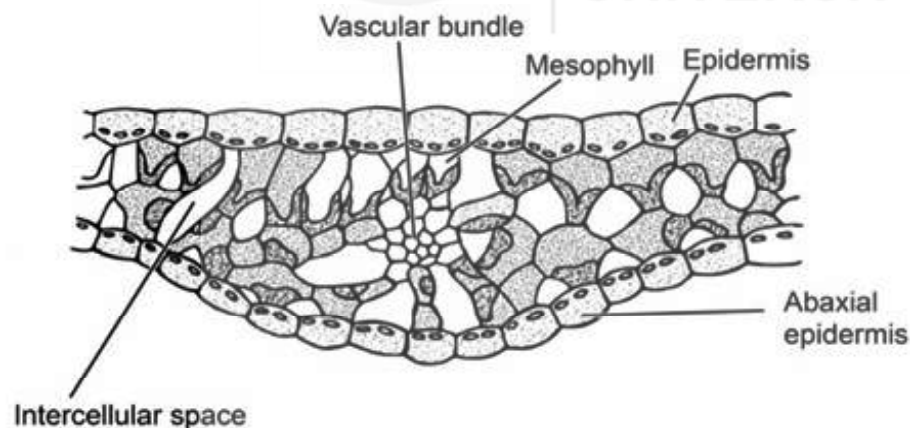


Fig. 17.3: T.S. of a leaf.

Stem

The stem is differentiated into outer layer of epidermis, middle layers of cortex and a centrally located stele. The epidermis is made up of single-layer of thick-walled cells covered with cuticle, with or without stomata. Multilayered cortex is composed of angular cells without intercellular spaces. In larger stems the cells of outer region are sclerenchymatous. The stele is separated from the cortex by a few radially elongated endodermal cells. These are termed as **trabeculae**, a characteristic of *Selaginella*. There is a prominent air space in the stelar region.

Young plants invariably are monostelic (with single stele). In adult forms the number of steles varies from two to sixteen (Fig. 17.4). Stele is circular or ribbon-shaped in outline and it may be protostelic to polycyclic siphonostele depending upon the species. It is surrounded by single layered pericycle. Xylem is surrounded by two or three layers of parenchyma and outside this is a single layer of sieve cells all around except the region radial to the protoxylem. In some isophyllous species true vessels occur. Large bundles reveal both mesarch and exarch conditions.

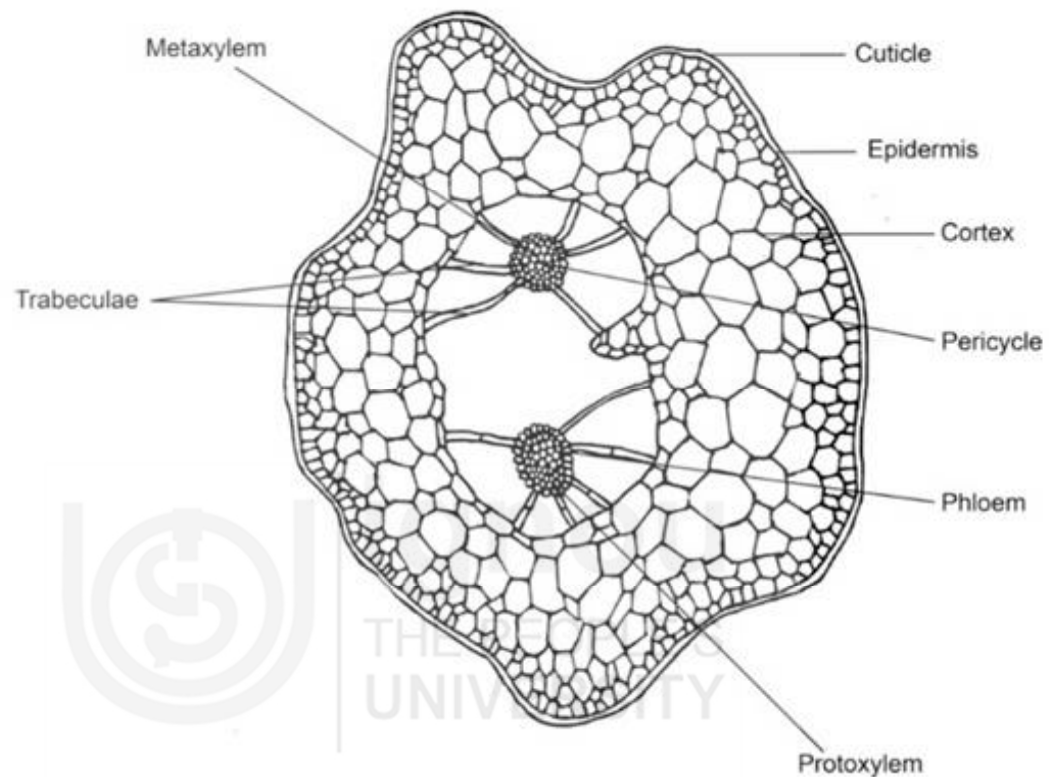


Fig. 17.4: T.S. of a stem (distelic).

Root

The outline of the root is circular where stele is centrally located and surrounded by multilayered cortex and possesses a single layered epidermis. From the large cells of epidermis the root hair arises. The cortex may either be wholly made up of thin-walled parenchyma, or in some species may be a hypodermis of three to five layers of sclerenchymatous cells. The endodermis layer in most of the species is not well defined. The pericycle is composed of two to three layers. Roots are simple monarch to tetrarch and with exarch condition. You can see that T.S. of root shows a very small monarch stele with one phloem and one xylem group and the protoxylem is situated towards the periphery. The phloem more or less surrounds the xylem (Fig. 17.5).

Rhizophore

Rhizophore is surrounded by a single-layered cuticularised epidermis without root hair. A few layered parenchymatous cortex has 2-3 cell thick hypodermis on outside. Endodermis and pericycle are one-layer thick. The stele is protostele which is monarch and exarch (Fig. 17.6).

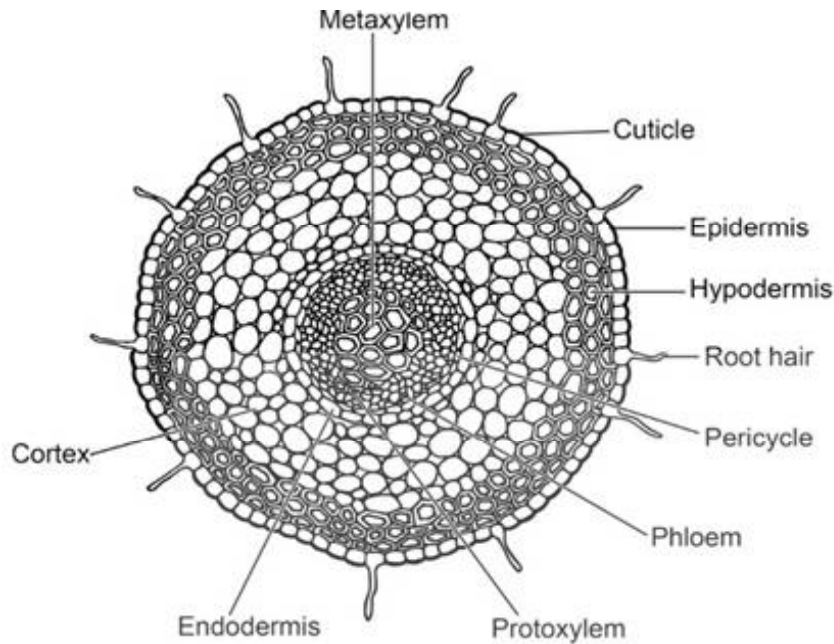


Fig. 17.5: T.S. of a root.

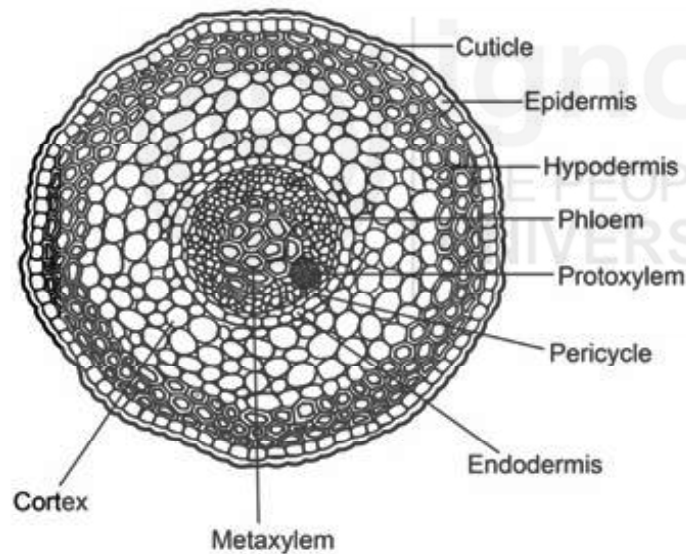


Fig 17.6: T.S. of a rhizophore.

SAQ 1

- a) In the following sentences fill in the blanks with appropriate words:
- Selaginella* is called plant because it can recover after a prolonged period of drought.
 - The function of ligule is to water and help in the upward movement of
 - Tufts of adventitious roots develop from
 - The cortex and stele of the stem is connected by elongated endodermal cells known as

- b) Define:
Monarch, exarch, ligule, sessile, rhizophore.
- c) Which of the following statements are true and which are false? Write **T** for true and **F** for false.
- i) In stem of *Selaginella* trabeculae are formed by pericycle. []
 - ii) In *Selaginella* stem branching is dichotomous. []
 - iii) Roots are adventitious in *Selaginella*. []
 - iv) Leaves are ligulate in *Selaginella*. []
 - v) In the rhizophore of *Selaginella* auxin transport is acropetal. []

17.2.3 Reproduction

You have studied in Unit 16 that in most of the genera of pteridophytes only one type of spores are produced in the sporangia i.e., these forms are homosporous. There are certain pteridophytes in which two distinct types of spores are produced, which are called heterosporous and *Selaginella* is an example of heterosporous plant.

Vegetative Reproduction

Selaginella reproduces vegetatively by means of fragmentation, bulbil formation, tuber formation and resting bud formation.

Reproductive Bodies

Some of the heterosporous pteridophytes are *Isoetes*, *Salvinia*, *Azolla*, *Regnellidium*, *Marsilea*, *Pilularia* and *Selaginella* (Fig. 17.7 a). They produce two types of sporangia. The larger ones are known as megasporangia and contain large spores called megaspores. Smaller ones are microsporangia and produce smaller spores, which are called microspores. Depending on the type of sporangium the sporophyll is called megasporophyll or microsporophyll. The sporophylls form cones or strobili measuring up to 4-5 cm in different species. These are terminal either on the main stem or branches. The strobili are not very conspicuous and sporophylls are similar to vegetative leaves. In some species due to continued meristematic activity vegetative leaves are produced above the strobilus. The sporophylls are always spirally arranged upon the strobilus axis, but the spiral is generally so condensed that sporophylls appear to lie opposite each other in pairs and in four distinct vertical rows. Normally megasporophylls (Fig. 17.7 c) and microsporophylls (Fig. 17.7 b) are borne on the same strobilus, the former at the base and the latter in the upper part. In some species, there may be two vertical rows of each type of sporophylls. In *Selaginella selaginoides* basal sporangia are non-functional.

In *Selaginella* sporangia are reniform (kidney-shaped) to ovoid and have a short stalk. They are borne on the adaxial face between ligule and base of the sporophyll (Fig. 17.7 a, b). At maturity the sporangia are almost axillary in position. Generally, megasporangia are much larger than microsporangia (Fig. 17.7 b, c). However, in some species they are of the same size. Microsporangia are slightly elongated. The growth of the strobilus is apical.

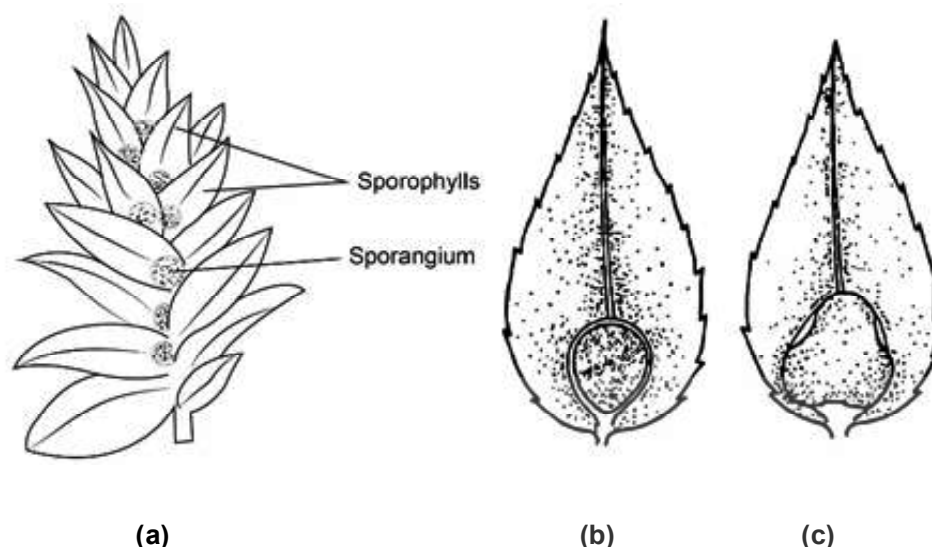


Fig. 17.7: *Selaginella*, Reproductive structures : a) A strobilus bearing a number of sporophylls; b) Adaxial surface of a microsporophyll showing a microsporangium; c) Adaxial surface of a megasporophyll showing a megasporangium.

The development of a sporangium is eusporangiate type.

All sporogenous cells of the last generation in the sporogenous tissue within a microsporangium are potential sporocytes. In microsporangia most of the sporocytes form microspores and about 10-20 per cent sporocytes degenerate and provide nourishment to the developing spores (Fig. 17.8 c). In contrast, in a megasporangium all sporocytes degenerate except one. This surviving or functional sporocyte divides meiotically and forms four megaspores.

Depending on their survival, varying number (1-4) or megaspores are formed in a megasporangium in different species (Fig. 17.8 d). Only one megaspore per megasporangium is formed in *Selaginella sulcata*. In *S. rupestris* each megasporangium contains usually two megaspores. In some species there are more than one functional sporocytes may be up to twelve or rarely more megaspores result. Although both types of sporangia occur on the same plant, but in no instance one sporangium produces two types of spores. At maturity both microsporangia and megasporangia are stalked structures.

The wall in adult sporangium is 3-layered thick. The outer layer is composed of usually columnar cells which contain chlorophyll until after the spores are shed. The inner layer consists of flattened cells. The tapetum is the innermost layer which survives for a long period. In a mature sporangium, only the outermost wall layer persists and rest decomposes before dehiscence. Spore dispersal takes place due to dehiscence of sporangium in the apical region. It is brought out by hygroscopic changes in the cells. In *Selaginella rupestris* though dehiscence of megasporangium takes place, but the megaspores are not shed. The spores (micro-and megaspores) are tetrahedral with a prominent tri-radiate mark and characteristic ornamentation. The overall events of development of a functional microspore and a functional megaspore within a microsporangium and a megasporangium are termed microsporogenesis and megasporogenesis respectively.

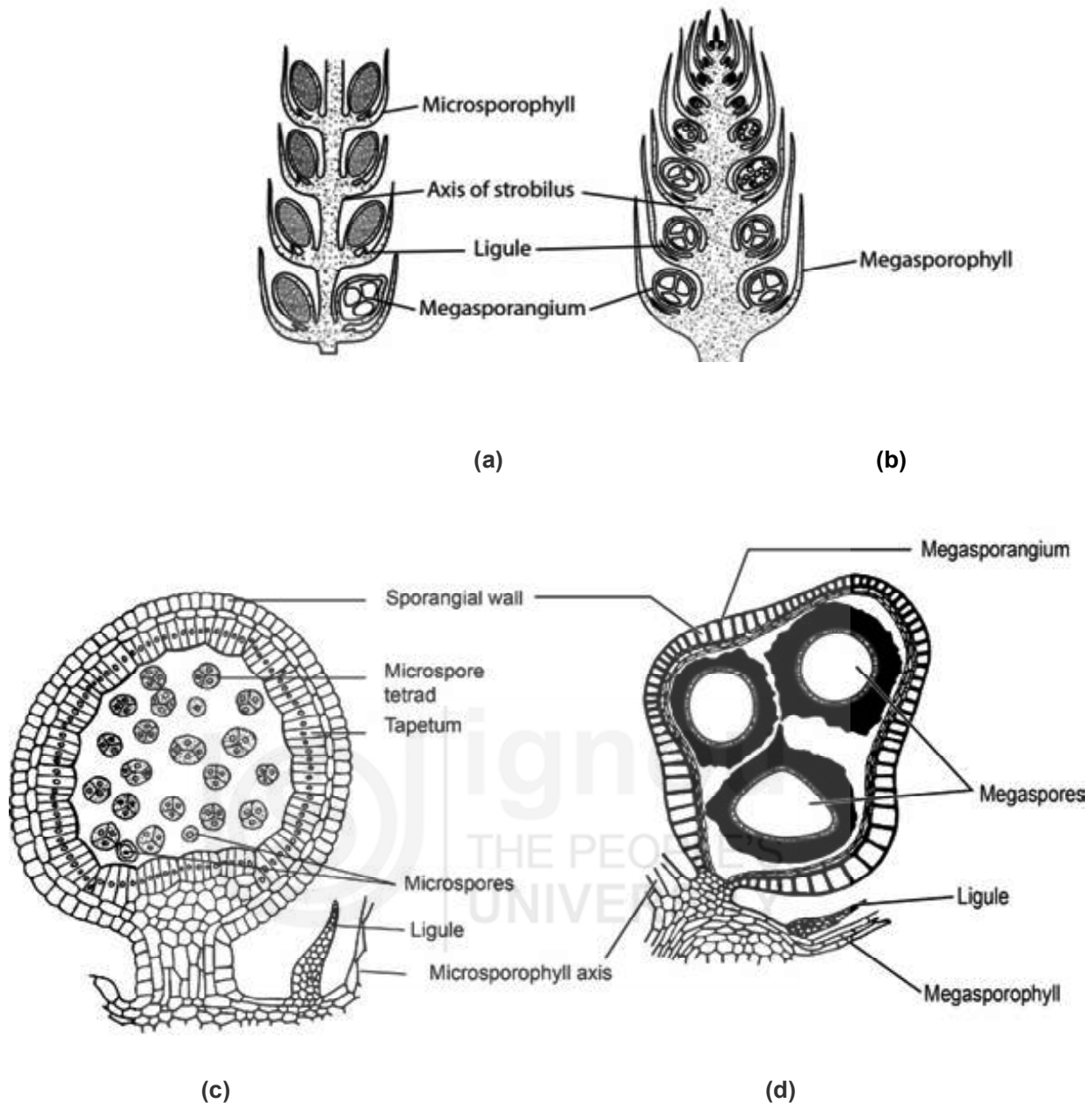


Fig. 17.8: a-b) L.S. Strobilus-note the placement of microsporophyll and megasporophyll in a strobilus; c) L.S. of microsporangium; and d) L.S. of a megasporangium.

Development of Gametophyte

In *Selaginella* difference in the size of spores is associated with the difference in function. On germination these two types of spores produce two distinct types of prothalli; the microspore (Fig. 17.9 a) forms microgametophyte (Fig. 17.9 a, b) and the megaspore (Fig. 17.10) forms the megagametophyte (Fig. 17.10 a) also called macrogametophyte and the entire sequence of these events are termed as microgametogenesis and megagametogenesis respectively. With heterospory a new mode of gametophyte development is introduced in the life cycle. The gametophytes are formed within the spore wall i.e., development is *endosporic* (Fig. 17.9 a, b; Fig. 17.10 a, d). Nuclear divisions begin in spores before their dispersal. As a result of the gametophytes are in various stages of

development at the time of dispersal of spore. At the time of liberation, the male gametophyte normally consists of 13 cells; one small prothallial cell, eight jacket cells and four androgonial cells.

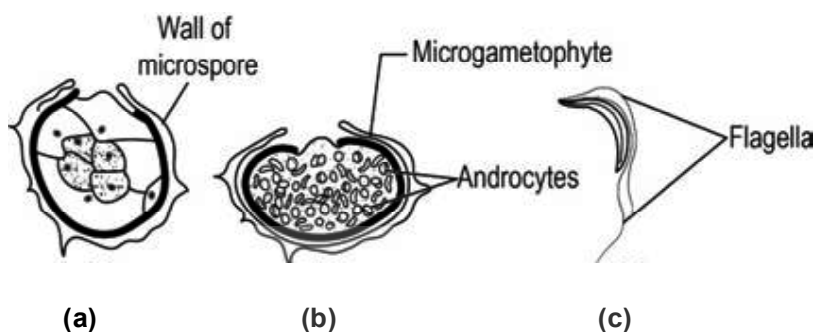


Fig. 17.9 : *Selaginella* (a-c) : a) A developing microgametophyte; b) A mature microgametophyte; c) A biflagellate antherozoid.

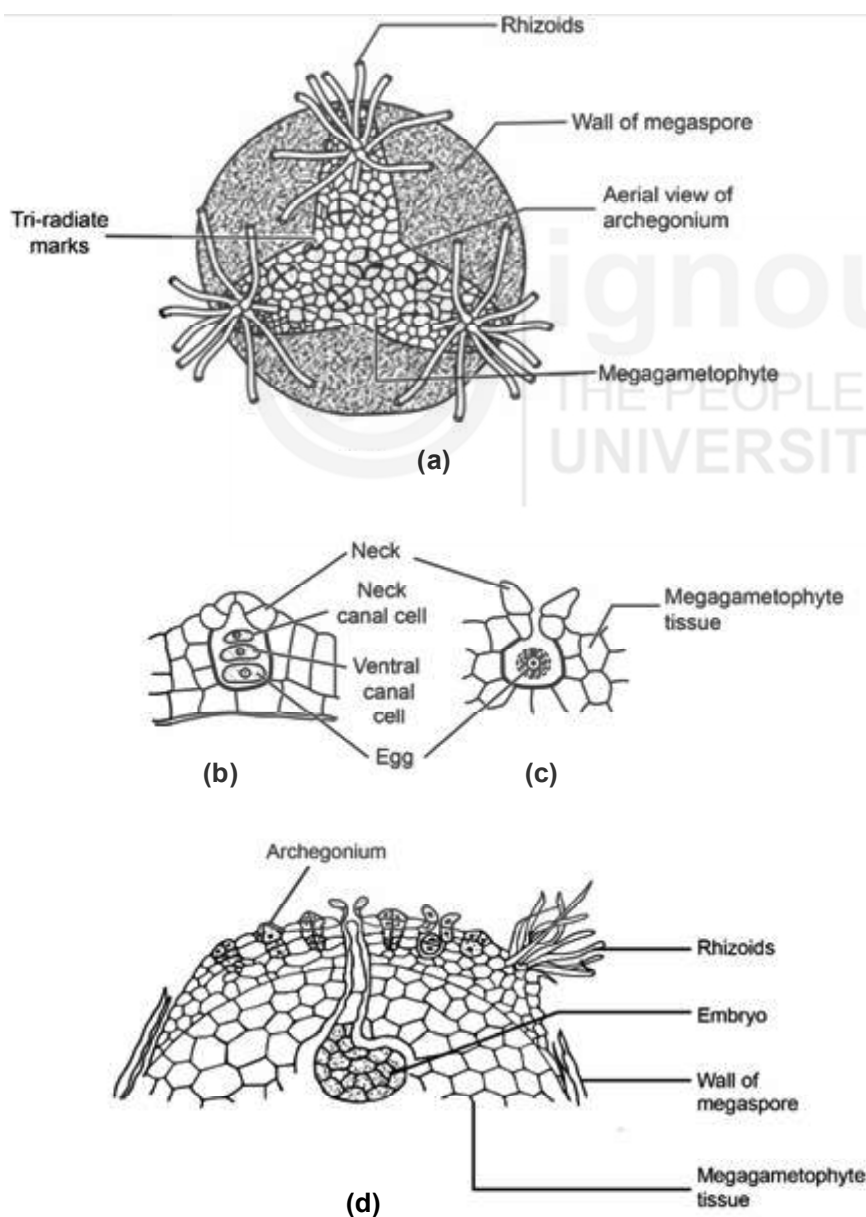


Fig 17.10: a) Top view a mature megagametophyte; b) An archegonium; c) An archegonium with mature egg cell; d) L.S. of a part of megagametophyte showing archegonia and a developing embryo.

By further divisions spermatogenous cells produce 128 or 256 antherozoids (Fig. 17.9 b). Each antherozoid has two terminal flagella (Fig. 17.9 c). You have read in Unit 13 that bryophytes also produce such biflagellated antherozoids. *Selaginella* also differs from other pteridophytes such as *Equisetum* and *Marsilea* that have multiflagellated sperms or antherozoids. The sperms of *Selaginella* are smallest in among the vascular plants.

Generally, the development of megagametophyte in most species begin *in-situ*, i.e., megagametophyte starts developing while the megaspore is still within the sporangium. Development of megagametophyte starts with considerable increase in the size of megaspore. Soon the megaspore nucleus divides repeatedly, but there is no cytokinesis (cell wall formation). Megaspore develops a prominent central vacuole. The multinucleate cytoplasm is restricted to a thin layer next to the spore wall. With the increase in number of nuclei, the cytoplasmic layer begins to thicken and the nuclei increase in size. After some time enlargement of multinucleate gametophyte slows down and cytoplasmic layer becomes thicker and thicker, eventually obliterating the central vacuole. The cytoplasmic layer is much thicker at apex, i.e. pyramidal end of the megagametophyte. In this region nuclei are arranged in a single layer and cell wall develops simultaneously. The cells formed in the central region are regularly hexagonal and uninucleate, whereas cells present near the margins and below may contain 2 or more nuclei. For some time cell formation occurs in the apical region only and a lens-shaped cushion of tissue is formed which is 3-celled thick in the middle and only one cell in thickness at margins. A very prominent diaphragm is formed by thickening of lower walls of lowermost layer which separates (at first) the apical cellular tissue from the non-cellular spore cavity.

The multinucleate layer of the spore cavity below the diaphragm rapidly becomes thicker and cellular. It is composed of large multinucleate cells of variable shape filled with reserve food materials like albuminous granules, oil and starch. These cells provide nutrition to the developing embryo until it becomes independent.

Eventually the exospore ruptures along the arms of tri-radiate ridge. The apical tissue projects above the tripartite cleft at its apex (Fig. 17.10 a). Most of the superficial cells of this tissue are potential archegonial initials, and many of these develop into archegonia (Fig. 17.10 b, d). At maturity the neck cells of archegonia spread apart and a passage is formed for the entry of antherozoids (Fig. 17.10 c).

Fertilization may take place while the megagametophyte is still within the sporangium or after it has fallen to the ground. The microgametophyte enclosed by the old microspore walls are brought to the megaspores by wind or gravity. The microspores drift among the megaspores with megagametophytes bearing archegonia. The antherozoids are set free and then they swim to the archegonia in a thin film of dew or rain water.

After fertilization the zygote secretes a protective wall and develops into an embryo. Further divisions in the embryo result in the differentiation of stem apex, cotyledons and a root-like structure-rhizophore (Fig. 17.11).

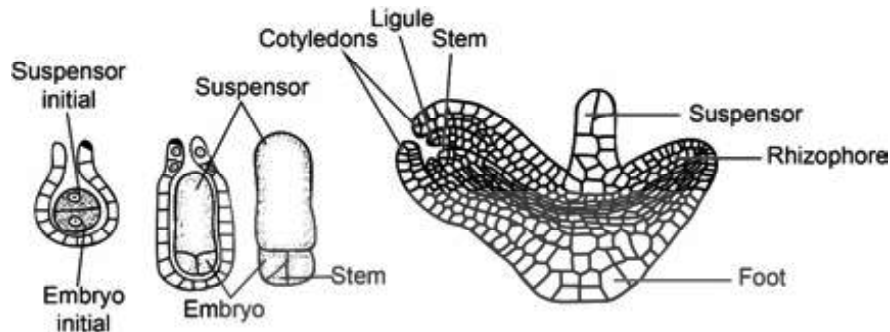


Fig. 17.11: Stages of development of embryo.

The developing embryo eventually grows in the surrounding of gametophytic tissue-the stem and its appendages growing upward and the rhizophore growing downward. This juvenile sporophyte is quite different from that of other pteridophytes in having the cotyledons borne directly on the stem and in having a conspicuous hypocotyledonary stem portion below the level of the cotyledons. Diagrammatic representation of life cycle of *Selaginella* is given in Fig. 17.12.

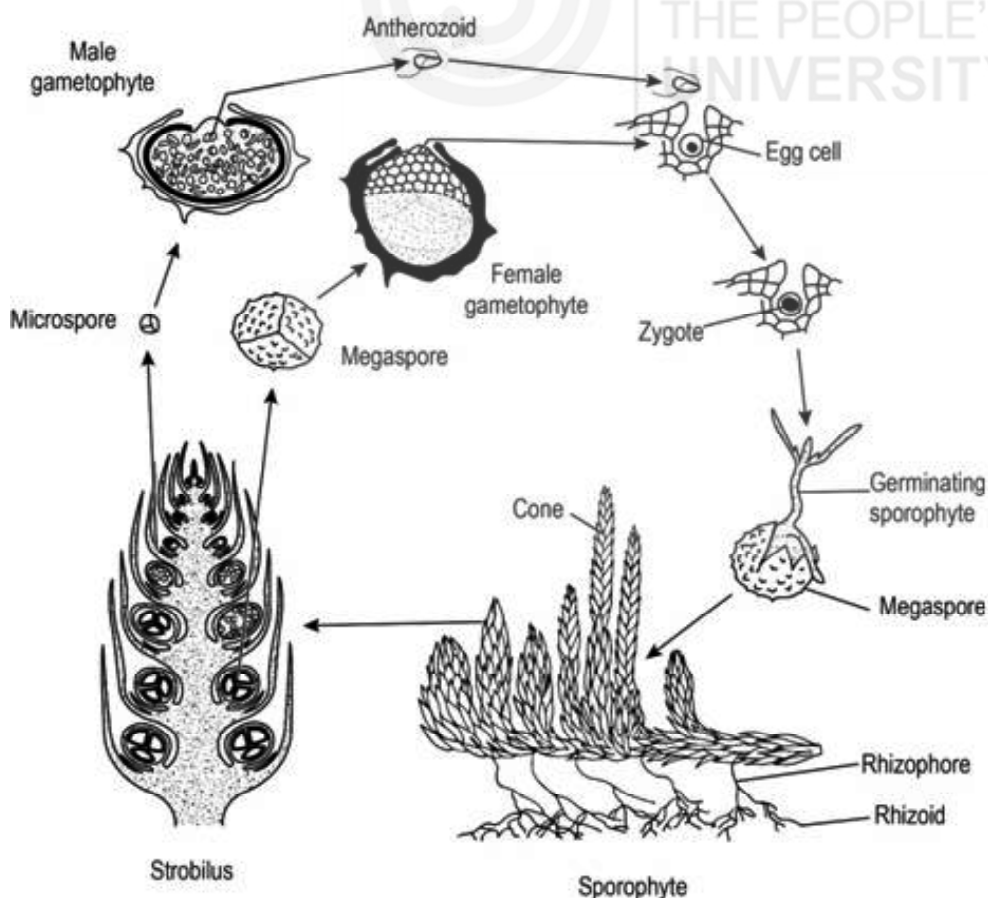


Fig. 17.12: *Selaginella*, a diagrammatic representation of life cycle.

SAQ 2

- a) Which of the following statements are true and which are false? Write **T** for true and **F** for false in the given boxes.
- i) Sporangia in *Selaginella* are of two types. []
 - ii) Strobili in *Selaginella* are lateral. []
 - iii) The development of female gametophyte and fertilization in *Selaginella* take place while megaspore is still within the sporangium. []
- b) In the following statements choose the correct alternative word given in parentheses (in relation to *Selaginella*).
- i) Sporangial development is of (leptosporangiate/eusporangiate) type.
 - ii) Megaspangia are (smaller/larger) than the microsporangia.
 - iii) Antherozoids are (multiflagellate/biflagellate).
 - iv) Female gametophyte develops (within/outside) megasporangium.
- c) Draw a diagrammatic labelled sketch of a mature microsporangium and a mature megasporangium of *Selaginella*.

Equisetum sp. are distributed throughout the world except Australia and New Zealand.

In *E. giganteum*, which grows in tropical America, the aerial branches may reach a maximum height of about 13 metres, but are relatively slender being less than 2.5 cm in diameter.

17.3 EQUISETUM

Systemic Position

Division	–	Sphenophyta
Class	–	Sphenopsida
Order	–	Equisetales
Family	–	Equisetaceae

17.3.1 Distribution and Morphology

Equisetum can grow in different habitats, it can be found in ponds in marshy conditions, damp and also in dry land and open grass field but best suited places are damp and amphibious conditions.

Equisetum arvense is popularly known “as horsetails” or “scoring rushes”. *Equisetum* is the only representative genus of the class sphenopsida that is alive today. All the species are herbaceous and perennials. In all species there is a horizontal, underground rhizome from which arise erect, aerial axes that branch profusely in some species, or remain quite unbranched in others (Fig. 17.13 a). The aerial shoots are usually annual but may be perennial. They range in height from only a few centimeters (15 cm) to several metres, but most of the species are not more than one metre in height.

Leaves in *Equisetum* are very small, simple, uninerved, slender and scale-like. They are usually without chlorophyll, photosynthesis being carried out entirely by the green stems. They are arranged in whorls and are more or less fused laterally at their bases into a sheath, closely enveloping the base of the internode, with longer or shorter tooth-like free tips (Fig. 17.13 b).

The stem is differentiated into nodes and internodes (Fig. 17.13 d) and is ridged. Each ridge corresponds to a leaf in the above internode and the ridges in successive internodes alternate with one another. At each node the branch primordial are equal in number to the leaves, and alternate with them. In some species all the branches primordial develop into branches with the result that there is a regular whorl of branches at the nodes. The stem exhibits intercalary growth. The rough texture of plant is due to deposition of silica on the outer surface. Silica helps to protect the plant against predators and pathogens and also prevents water loss.

Rhizome

The rhizome is long creeping well branched and divisible into nodes and internodes. Several scaly leaves are present on nodes (Fig. 17.13 b). These are small, slender and united laterally with each other to form a sheath on the node. From the rhizome towards upper side the aerial shoot or stem arises (Fig. 17.13 a, c, d). Generally the aerial shoots are of two types (i) sterile (Fig. 17.13 a) and fertile (Fig. 17.13 c, d). The sterile shoots are well branched, green and photosynthetic in function while fertile shoots are unbranched, colourless and bear cones and are reproductive in function.

Roots

Roots develop either from node of rhizome or from the base of stem. They are adventitious, well branched, long and slender (Fig. 17.13 d). These roots survive for several years but definite persistent root system is not found in *Equisetum*.

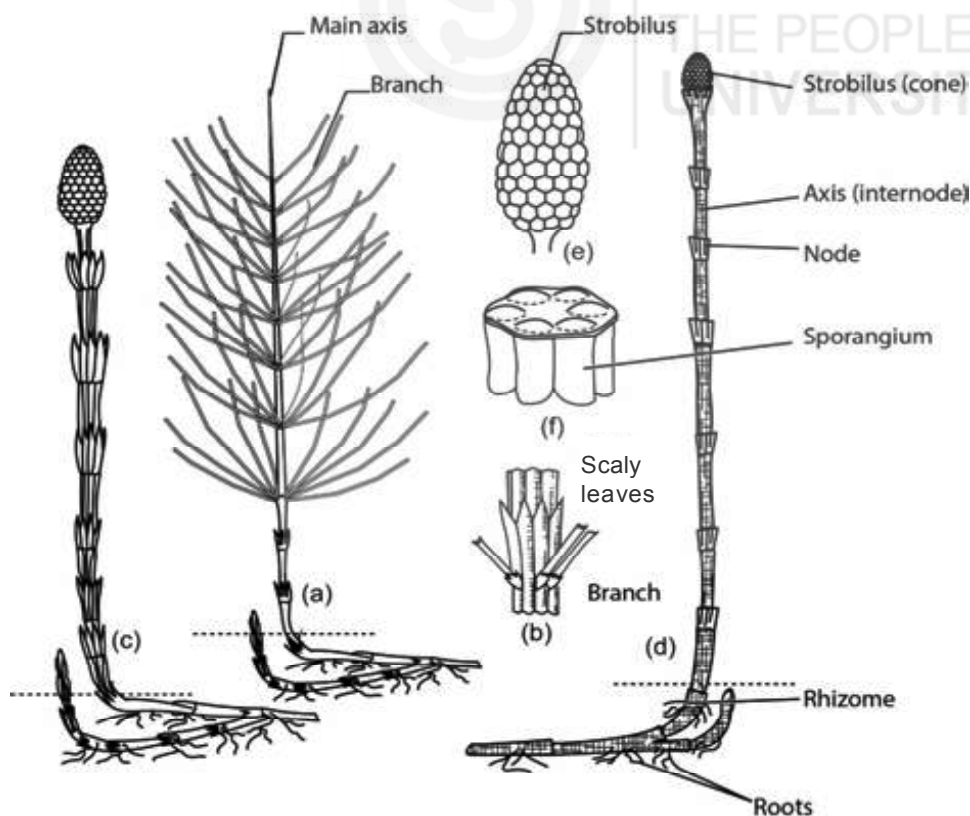


Fig. 17.13: *Equisetum*: a) A vegetative plant showing horizontal rhizome and upright shoot; b) A part of showing ridged node, internode, branches, a whorl of scaly leaves fused at the base; c) Reproductive shoots with terminal; d) sporangia (fertile shoot); e) A strobilus (cone); f) A sporangiophore with sporangia.

17.3.2 Anatomy

Stem

The peripheral single layer of epidermis is composed of elongated cells which have thick and undulated walls. These cells contain deposit of silica on their outer and lateral walls which makes the surface rough. Stomata are restricted to the furrows between the ridges and are deeply sunken into pits whose openings may be partly covered by a layer of cuticle. Characteristic rib-shaped silicious thickenings are present between the subsidiary and guard cells.

A well developed cortex (Fig. 17.14 a) divided into outer and inner cortex is present. The outer cortex is differentiated into two types of cells. The sclerenchymatous cells are present below the ridges in large patches. There is an equal number of smaller groups of sclerenchyma beneath the epidermis of the furrows but are absent beneath the stomata. The chlorenchymatous cells lie lateral and below the sclerenchyma forming a curved band and form the assimilatory region of the stem.

The inner cortex consists of a few layers of larger parenchyma. In this region very large air spaces are present and these spaces are known as vallecular canals (Figs. 17.14 b). Each of these lies below the furrow of the external surface and is thus close beneath the photosynthetic tissue. Vascular bundles lie beneath the ridges of the stem and have characteristic appearance (Fig. 17.14 a).

Xylem is endarch and protoxylem cells are replaced by a carinal canal, formed by the dissolution of protoxylem elements. Phloem lies on the outside of each carinal canal and on the same radius. On both sides phloem is surrounded by metaxylem. In some species each internodal bundle is surrounded by its own separate endodermis, in others there is a single endodermis running round outside all the bundles, while in yet some other species there are two endodermis one on the outer side, and other on the innerside of all the bundles. A large pith cavity is present in the centre.

At the nodes you will not find any vallecular or carinal canals. Central part instead being hollow is solid and possesses pith diaphragm. The stele is found in form of continuous cylinder of xylem from this arise leaf traces and branched traces. Vallecular canals occur in this region but carinal canals are absent.

This type of arrangement of air channels in addition to a very reduced vascular tissue, are features commonly found in aquatic plants. In contrast, thick cuticle, sunken stomata and reduced leaves are characteristics of xerophytic plants.

Thus, anatomy of the stem of *Equisetum* presents an interesting combination of xeromorphic and hydromorphic characters, together with a vascular system which is unique in the plant kingdom, and its correct morphological interpretation has long been the subject of discussion.

Rhizome

Rhizome resembles the shoot or stem except ridges and grooves are not very prominent. In the cortex region chlorenchyma are absent and sclerenchyma

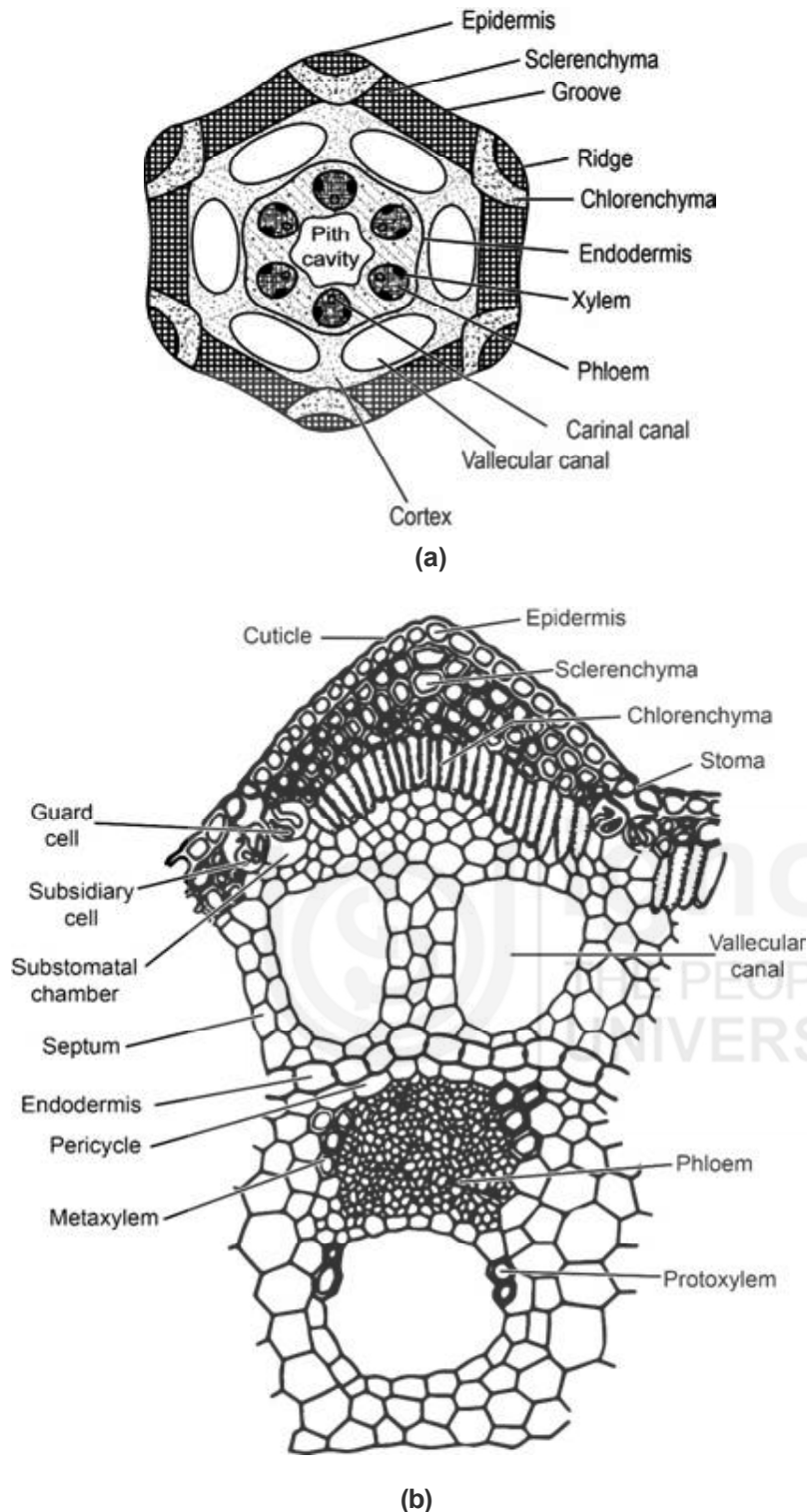


**Fig. 17.14 : *Equisetum*: a) T.S. internode of aerial shoot (diagrammatic);
b) T.S. internode of aerial shoot a cellular part magnified.**

are poorly developed. Stomata are absent in epidermis. Pith cavity is ill developed and sometimes it would be completely cellular.

Root

Roots which are apparently borne on a horizontal rhizome are in fact borne by the axillary buds hidden within its leaf sheaths. Let us now study the anatomy of a root (Fig. 17.15). The root is differentiated into epidermis, cortex and stele. Epidermal cells are elongated with thin and straight wall. Beneath it lies cortex composed of several layers of parenchymatous cells.

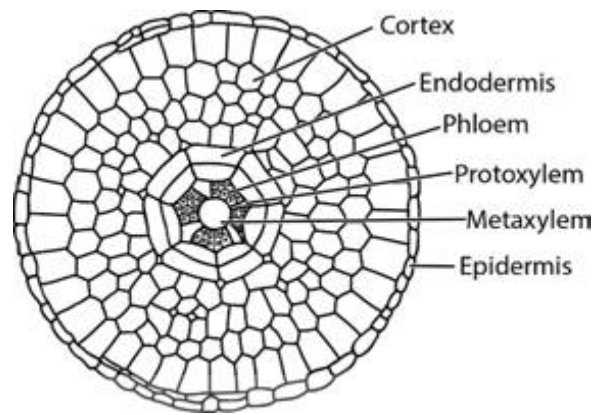


Fig. 17.15: *Equisetum*: T.S. root near the growing apex.

The outer cortical cells may be thick-walled and lignified with multiple layers of thin walled parenchyma cells beneath. In some species the larger roots possess air spaces in the inner cortex. The slender, adventitious endogenous roots are tri to hexarch with 3 to 6 protoxylem elements surround a single axial metaxylem element at the centre. The angle between protoxylem are completely filled up with phloem. Pericycle is absent. Inner of the 2-layered epidermis functions as pericycle.

SAQ 3

a) Which of the following statements are True and which are False? Write **T** for true and **F** for false in the given boxes.

- | | |
|---|-------|
| i) Plants of <i>Equisetum</i> are annual. | [] |
| ii) Leaves in <i>Equisetum</i> are alternatively arranged. | [] |
| iii) Aerial system in <i>Equisetum</i> is differentiated into nodes and internodes. | [] |
| iv) Stem of <i>Equisetum</i> shows ridges and furrows. | [] |
| v) Stomata in <i>Equisetum</i> are not sunken. | [] |
| vi) Vallecular canal in internodes of <i>Equisetum</i> is present below the ridge. | [] |

b) Draw and label a T.S. of *Equisetum* stem and list its special features.

17.3.3 Reproduction

Equisetum is homosporous and the sporangia of *Equisetum* are borne on stalked structure which is known as sporangiophores. These sporangiophores are quite different from the ordinary leaves and are grouped together forming a strobilus. Strobili are terminal in position and solitary (Fig. 17.16 a). In most of the species of *Equisetum* there is no segregation between fertile and sterile shoot. So in these species the aerial shoots perform dual function of photosynthesis and reproduction. Generally whorled branches of aerial shoots do not bear strobili.

The strobilus of *Equisetum* is quite peculiar. Each strobilus has a thick central axis called cone axis. It is composed of a central thick axis. On these axes a

number of T-shaped peltate sporangiophores are densely packed in successive whorls alternating with one another. The number of sporangiophores in each whorl varies from a few to many. A ring-like outgrowth also appears near the base of the strobilus and this is known as annulus. This is regarded as a protective structure by some botanists.

The sporangiophore can be divided into two regions (i) a small proximal cylindrical stalk-like portion attached at right angles to the axis of the strobilus (Fig. 17.16 b, c) and (ii) a shield-like peltate disc attached to the distal or outer end of the stalk. A number of sporangia (usually 5-10) (Fig. 17.16 b) are produced from the under surface in the form of ring near the edge of this disc. The peltate heads of sporangiophores are so packed that sporangia are concealed. The disc acquires a hexagonal shape due to mutual pressure.

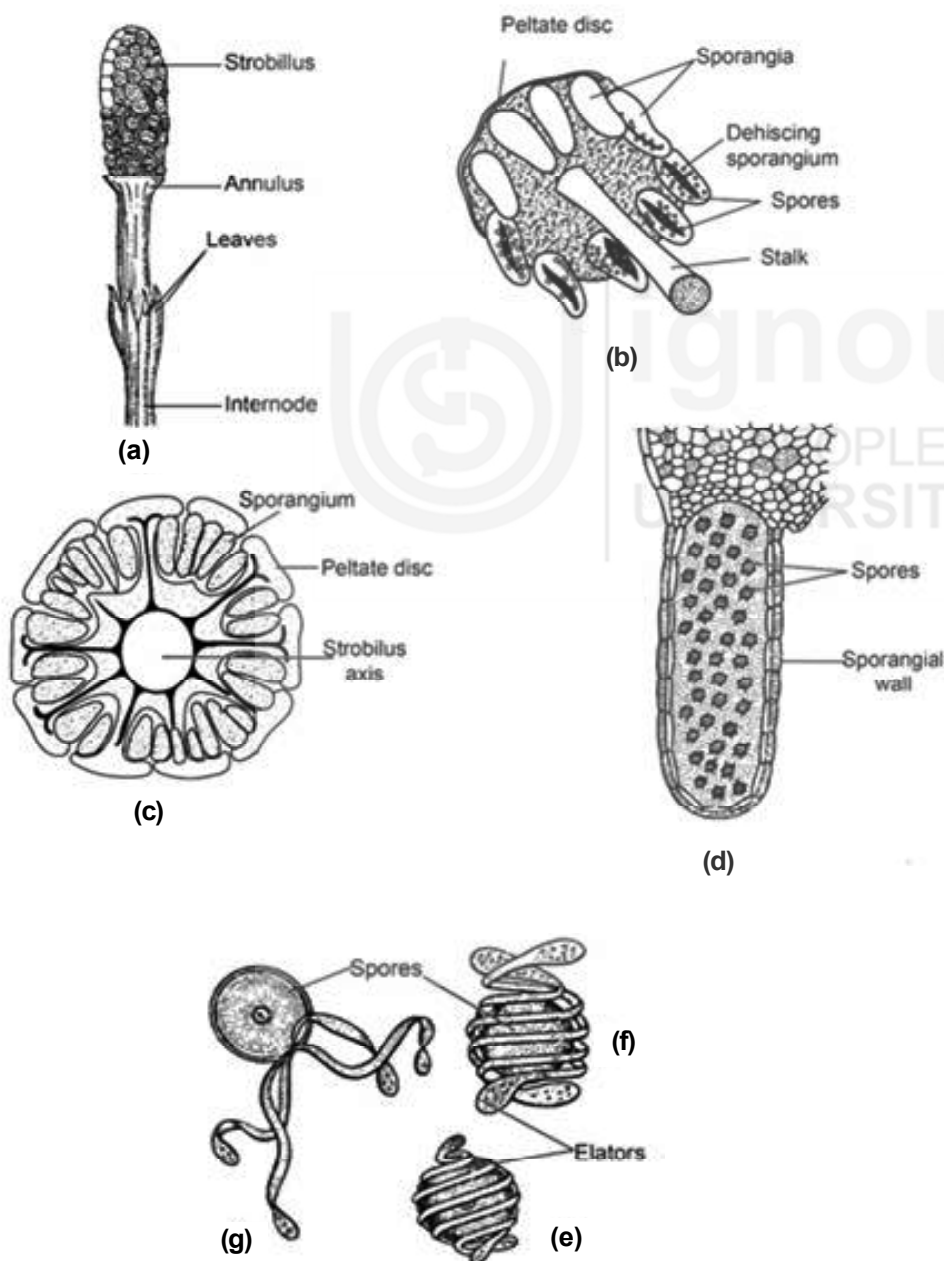


Fig 17.16 : *Equisetum*, Reproductive structures: a) Terminal region of a fertile shoot with a strobilus; b) Ventral view of a sporangiophore showing sporangia; c) T.S. of a strobilus; d) L.S. of a sporangium e-f) Spores with elaters; g) A spore with uncoiled elaters.

At maturity the axis of the strobilus elongates slightly and this results in the separation of the sporangiophores from each other. Later due to loss of water the sporangiophores shrink and fall apart exposing the sporangia. The sporangia dehisce by longitudinal slits down the side next to the sporangiophore stalk and the spores are dispersed.

The spore wall is composed of four layers: outermost episore, middle perisore, followed by exospores and the innermost is endospore. The episore divides along several spiral lines into two long bands which until maturity remain closely bound around the spore (Fig. 17.16 e). These bands are detached from each other except at one point. The tips of the bands are slightly expanded or spoon-like (Fig. 17.16 f). They are known as elaters and is spirally wrapped around the species. They are hygroscopic and remain coiled around the spores in moist air. During dry conditions the elaters stretch themselves out crosswise, remaining attached only in the middle of their length at one point so that they appear as four distinct appendages (Fig. 17.16 g).

In the previous units you have read about elaters in bryophytes (*Marchantia*). Compare the elaters of *Equisetum* with that of liverworts (*Marchantia*). You will find that in bryophytes elaters are formed from complete cells, not from the wall of spore. They are diploid and have spiral thickenings. But in *Equisetum* they are haploid and do not have spiral thickenings.

The elaters help in dehiscence of sporangium and the dispersal of spores. At maturity when the sporangia lose water, elaters get uncoiled and exert pressure on the wall of the sporangium and by doing so they act like parachute for the spores. These results in the opening of sporangium along the longitudinal slits and the spores are dispersed in masses. Spores of *Equisetum* do not have tri-radiate mark.

Gametophyte

Spores of *Equisetum* remain viable for 5-20 days. The spore is the first cell of gametophyte. It germinates within 2-3 days under suitable conditions such as sufficient oxygen and moisture. The spore increases by absorbing water and its wall ruptures. The elaters are cast off. It is followed by an unequal division of the spore into a smaller lenticular rhizoidal and a large prothallial cell. The stages involved in the development of gametophyte are shown in (Fig. 17.17 a-c).

In the mature prothallus three distinct regions can be recognized:

- i) The upper erect, green, photosynthetic portion in the form of spongy, irregularly-shaped lobes.
- ii) The middle basal prostrate region of light-yellow colour.
- iii) The lowermost region of colourless cells that gives off rhizoids.

Internally prothallus is differentiated into two zones: (i) an upper spongy portion. The disc is composed of non-chlorophyllous large cells which are compactly arranged and are full of starch grains. The disc has outer marginal meristematic rim which increases the diameter of disc and forms new erect lobes as well as rhizoids, and (ii) lower compact rounded parenchymatous portion forming the disc.

The prothallus is generally attacked by a fungus in the upper cells of the lobes. Typical Arbuscular Mycorrhizal association has been reported with prothallus of *Equisetum bogotense*

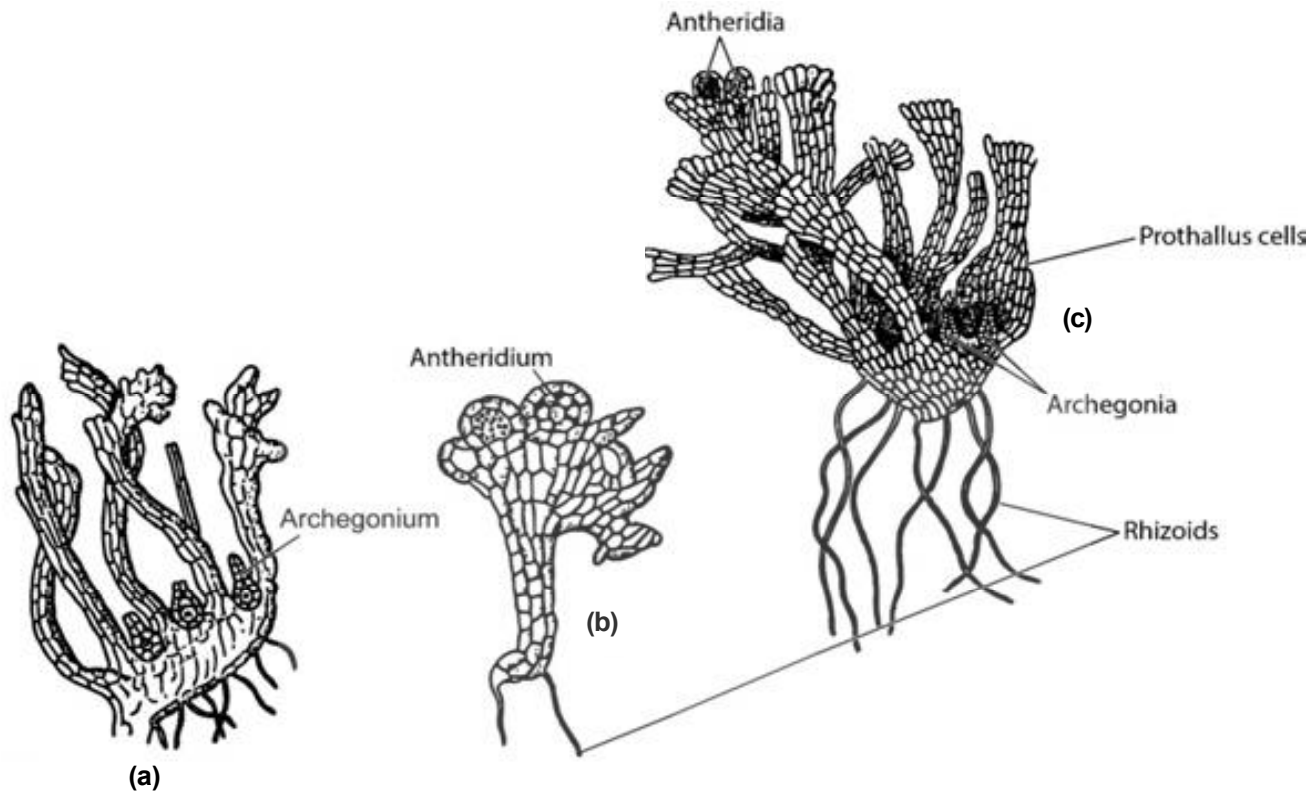


Fig. 17.17 : *Equisetum*: a) A bisexual prothallus; b) A female prothallus with archegonia; c) A male prothallus with antheridia.

The spongy upper portion is composed of densely crowded green vertical lobes which completely cover the disc below. The lobes are irregular, plate-like expansions of chlorophyllous tissue several cells thick at the base but higher up becoming thinner and thinner, the ultimate part being only one cell in thickness. They are either spherical or more or less lobed. Sometimes lobes are arranged in a compact manner so that the space between them is narrow and the prothalli appear to be spongy.

Three types of prothalli may develop:

- i) Deep green female prothalli,
- ii) Light green male prothalli, and
- iii) Bisexual prothalli with thin male branches and thick and fleshy female branches.

Mature prothalli or gametophytes of *Equisetum* are dorsiventral, prostrate with dull brownish-green thalloid structures. They are generally found in abundance in shady places on the surface of clayey soil along the banks of streams and rivers.

In most species the prothalli are monoecious i.e., both sex organs are produced on the same prothallus. Mature sex organs are present between the plates or the lobes (Fig. 17.17 a). It has been observed that generally the crowded and starved prothalli produce male sex organs, while those which get sufficient food produce female sex organs. So, prothalli of *Equisetum* are usually monoecious but show tendencies towards dioecism (Fig. 17.17 c).

The archegonia are found near the base and between the lobes. The prothallus ceases to grow after fertilization of the first-formed archegonia. The

mature archegonia have the sunken base in the prothallus tissue with only its neck protruding (Fig. 17.17 a). The neck is short consisting of four rows with usually 3 or 4 cells in each row. The neck cells of the upper most tier are divaricated (bent back) at maturity thus leaving a wide opening for the entry of the sperms. The axial row consists of the egg cell, the ventral canal cell, and one or two neck canal cells (Fig. 17.18 c, d). At maturity there is the usual gelatinisation of all axial cells except the egg.

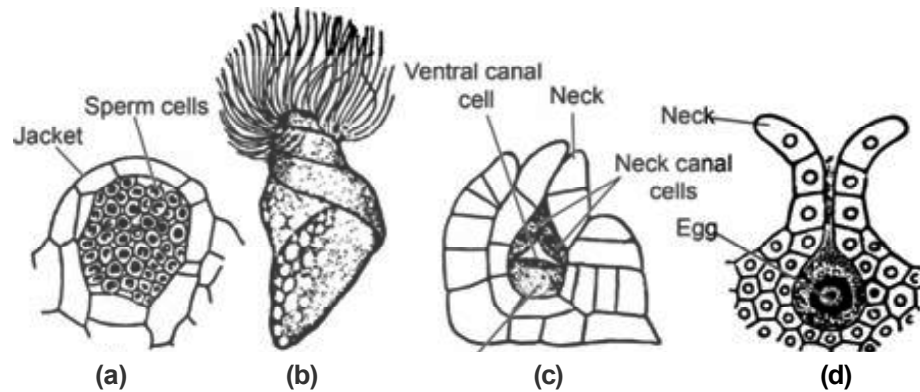


Fig. 17.18 : *Equisetum*, antheridium and archegonium : a) An antheridium; b) An multiflagellated antherozoid; c) A mature archegonium; d) An archegonium ready to receive antherozoids.

The antheridia develop later when the prothallus is several months old. They are produced in large numbers mainly in non-chlorophyllous part. They develop in an acropetalous succession and are of two types: embedded and projecting type. (i) the embedded type develops on the lower massive and cushioned part of the prothallus, (ii) projecting type usually develops in starved prothalli and are found at the apices of the margins of the erect lobes. Mature antheridium is a more or less globular sessile structure. The jacket of the antheridia is single layered (Fig. 17.18 a). It encloses a large number of multiflagellated spermatozoids (Fig. 17.18 b) and it dehisces by absorbing water. The wall of the antheridium forms a slit-like aperture through which antherozoids escape.

Water is also essential for fertilization. A number of spermatozoids enter the neck and reach the venter but only one is able to complete fertilization. The fusion of a male gamete and a female gamete (egg) results in the formation of zygote or the oospore. Many archegonia are fertilized on one prothallus.

Sporophyte

The zygote divides by a transverse wall into an upper epibasal cell and a lower hypobasal cell without any suspensor. Two more longitudinal divisions result in the formation of octant (eight cells). The embryo is exoscopic, the apical region first stem apical cell is formed and from entire lower half root may arise or from one side root arises while other side foot is formed. Out of the epibasal octant the largest cell functions as the shoot apical cell. Various stages of development of sporophyte are shown in Fig. 17.19 a-d. The lower part of the young embryo is the foot; the root arises from the side of the foot. Thus whole upper part is the shoot and there is no suspensor in the embryo.

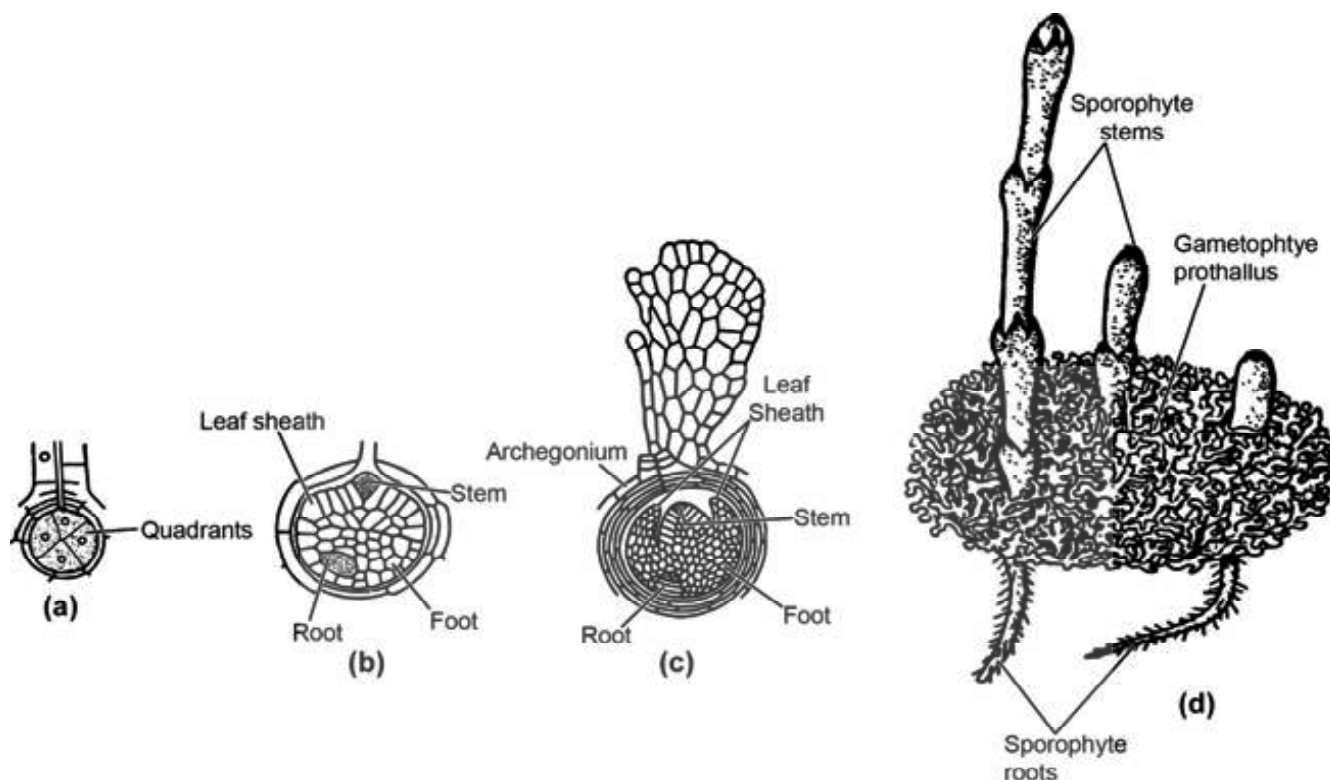


Fig. 17.19: *Equisetum*: a-d) Stages of developing of embryo within venter; Young sporophytes developing from a gametophyte.

SAQ 4

- a) Which of the following statements are True and which are False? Write **T** for true and **F** for false.
- i) Spores of *Equisetum* have elaters. []
 - ii) *Equisetum* is heterosporous. []
 - iii) Prothalli of *Equisetum* are generally dioecious. []
 - iv) There is no suspensor in the embryo of *Equisetum*. []
- b) In the following statements fill in the blank spaces with appropriate words.
- i) Sporangia of *Equisetum* are borne on stalked structures called
 - ii) Sporangophores are in *Equisetum*.
 - iii) Spore wall is composed of layers.
 - iv) Spoon-shaped.....are present on spores.
 - v) Sporangia dehisce by slits.
 - vi) Growth of prothallus of *Equisetum* takes place by the activity of meristems.

17.4 PTERIS

Systemic Position

- Division – Filicophyta
- Class – Leptosporangia
- Order – Filicales
- Family – Polydiaceae

17.4.1 Distribution and Morphology

Pteris is a widely distributed genus with about 250 species. It grows abundantly in cool, damp and shady places in tropical and subtropical regions of the world. In all there are 19 species recorded from India (Fig. 17.20 a-i).

Pteris vittata is a fern which grows at low altitude brings out new leaves throughout the year. It is very common along mountain walls and grows up to 1200 metres above sea level.

Pteris quadriaurita grows abundantly along roadsides and in the valley throughout North-Western Himalayas. Another species, *Pteris cretica* grows well from 1200 to 2400 metres above sea level. Parts of fertile and sterile fronds of some of *Pteris* species found in India are shown, in Fig. 17.20.

In *Pteris* the primary root is in transitory phase and soon it is replaced by several adventitious roots. These roots develop all over the surface of rhizome. The roots are small and branched.

The Rhizome

P. grandiflora have creeping rhizomes while erect in *P. biaurita* and *P. vittata*. In *P. cretica* the rhizome is erect without any branching, stout and stumpy. The rhizome is differentiated into nodes and internodes and its entire surface is covered with scales. Hairs are absent.

Leaves

If you have seen a fern, you may have noticed that the most conspicuous part of a fern plant is its leaves which are called fronds. The leaves are compound in most species but a few species have simple leaves. Look at Fig. 17.20 a, the stalk of leaf continues as rachis and bears leaflets called pinna.

In *Pteris vittata* the pinna present near the base and tip are smaller than those in the middle. The leaf apex is occupied by an odd pinna. Every pinna is transverse by a central mid rib which gives off lateral veins that bifurcate. The pinnae are sessile and broader at the base gradually decreasing in width towards the apex (Fig. 17.20 b). The leaves are bipinnate in *P. biaurita*. The pinnules are rough in texture. The young leaves show typical incurving known as circinate vernation.

The leaves bear spore producing structures on the underside of the leaflets. They appear as rows of brown dots (sori, singular–sorus). Each sorus is a cluster of sporangia.

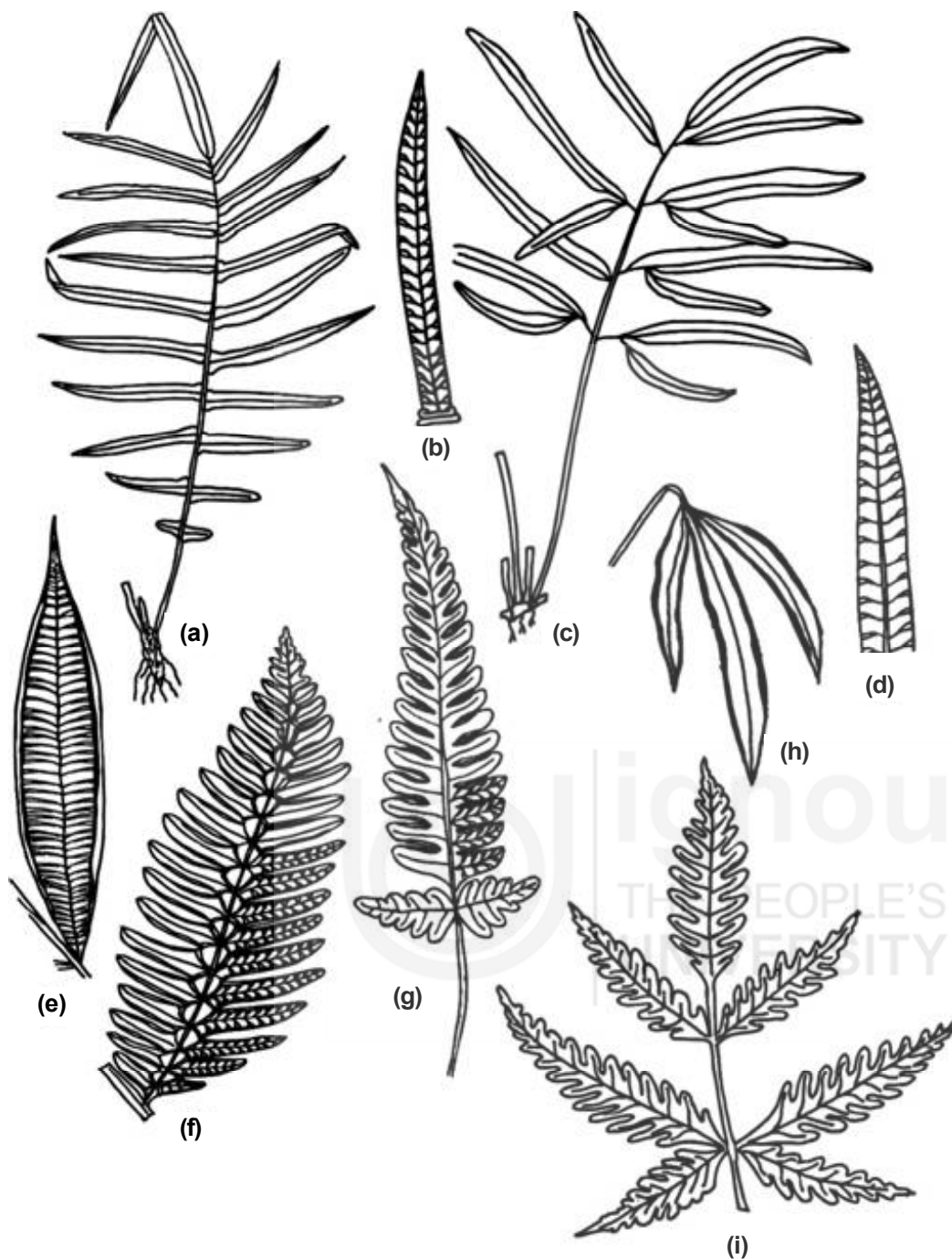


Fig. 17.20 : Some *Pteris* plants of India (a-i): a) *Pteris vittata* plant with rhizome, roots and vegetative frond; b) *P. vittata* abaxial surface of a pinna; c) *P. multiaurita* plant with rhizome, roots and vegetative frond; d) *P. multiaurita* abaxial surface of a pinna; e-i) Abaxial surface of Pinnae of some *Pteris* species: e) *P. pellucida*; f) *P. longipinnata*; g) *P. subindivisa*; h) *P. stenophylla*; i) *P. grivilleana*.

In *Pteris* there is no lower indusium the upper indusium is actually margin in its origin, appearing as a direct continuation of the marginal segmentation of the blade. It is termed as false indusium. The sporangia arise superficially from the lower surface of the blade. The development of sporangia in a sorus shows only slight signs of graded sequence, and is of a mixed type from an early stage of development.

17.4.2 Anatomy

Rhizome

Outer most layer of rhizome is single layer epidermis followed by few layers of thick sclerenchymatous hypodermis and a broad parenchymatous cortex.

The stelar organisation of rhizome of *Pteris* varies from protostele to dictyostele depending upon the species and sometimes in the same species. In the lower region of younger branches of the rhizome the stele is a mixed protostele. It becomes siphonostelic a little higher up and finally it becomes solenostelic near the apex. In the main rhizome dictyostelic condition is also found (Fig. 17.21 a,b). The stele becomes a dicyclic dictyostele in the apical region of the rhizome. Each meristele has a band or plate like mesarch xylem surrounded by phloem. Each stele is bounded by its own endodermis.

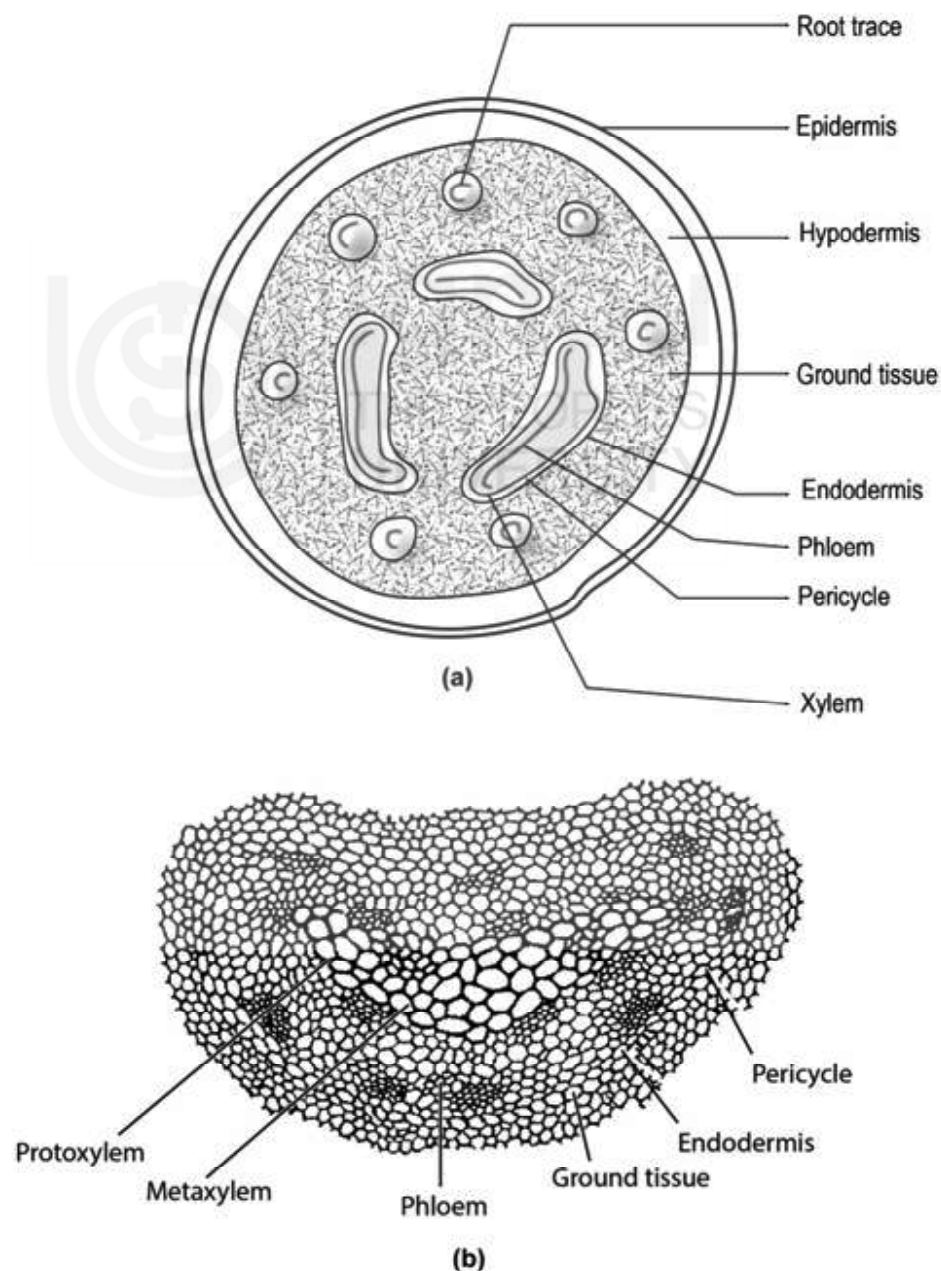


Fig. 17.21: *Pteris*; Anatomy of rhizome: a) Diagrammatic sketch of T.S. of a rhizome; b) A cellular diagram of a meristele.

Leaf

The pinnule has upper and lower epidermis. The cells of upper epidermis are larger and have less sinuous walls. The stomata are restricted to lower epidermis which have smaller cells with more sinuous walls. The mesophyll consists of green parenchymatous cells. The midrib region has single vascular strand with distinct endodermis.

Rachis

The rachis has a similar arrangement of tissue as is observed in rhizome. However, the large number of vascular strands are arranged in a shape of V, U-or a horse-shoe-shape and not in a ring (Fig. 17.22).

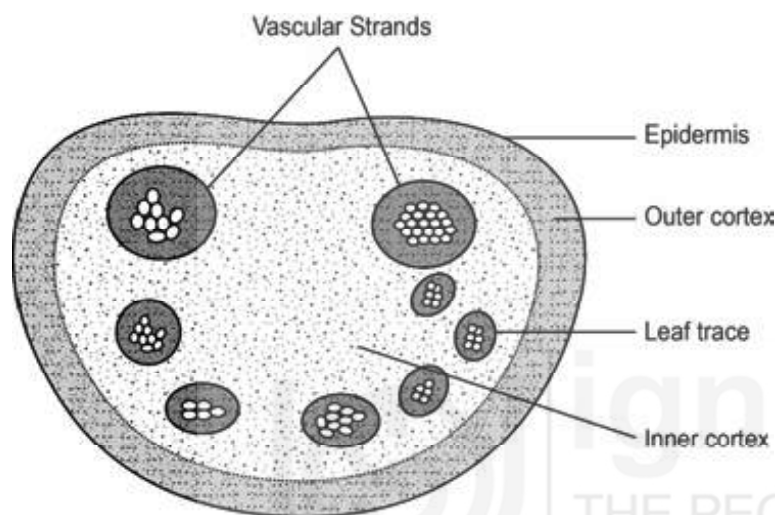


Fig. 17.22: *Pteris*: Diagrammatic representation of T.S. of rachis.

Root

Outer most single layer of cells is epidermis; the epidermis has numerous root hairs. The cortex is differentiated into outer multilayered parenchymatous zone and inner zone of a few layers having thick-walled cells. The endodermis, the innermost of the cortical cells comprises of a single-layer. The cells of endodermis have casparian strips on their radial walls. Inner to the endodermis lies pericycle. It consists of cells with thin walls. The stele is diarch and exarch.

SAQ 5

Fill in the blank spaces with appropriate word(s).

- The rhizome in *Pteris* is or.....
- Leaves of most species of fern are compound and are the most.....part of the plant.
- The stele in rhizome may be.....or
- The young leaves of *Pteris* show typical incurving which is termed as
- The rhizome of *Pteris* is covered with no.....

17.4.3 Reproduction

In the preceding sections you have studied the structures associated with reproduction in fern-allies such as *Selaginella* and *Equisetum*. Now you will study reproduction in a true fern, *Pteris*.

Reproductive Bodies

As you have learnt that in fern – allies the spores are produced within sporangia, which are arranged in the form of cones or strobili. In *Pteris* sporangia do not form cones or strobili instead they occur in small or large groups known as sori (sing, sorus). The sorus of *Pteris* is called coenosorus.

In *Pteris* any leaf or leaflet can bear sori on its under surface and there is no distinction between fertile and sterile leaves. The sori become confluent and appear as a single continuous linear sorus called coenosorus (Fig. 17.23 a). These sori are protected by the inwardly turned margins of the leaflets. Such a protective device is called false indusium (Fig. 17.23 b,c).

In *Pteris* old and young sporangia occur together and show no regular arrangements in sorus. Each sporangium produces 48 spores. A sporangium has two parts: i) stalk or the pedicel; and ii) capsule or the spore sac (Fig. 17.23). The stalk is formed by 3 rows of elongated cells. The capsule is more or less oval and appears like a biconvex lens. A mature sporangium possesses a single layered capsule wall surrounding the spores (Fig. 17.23 d).

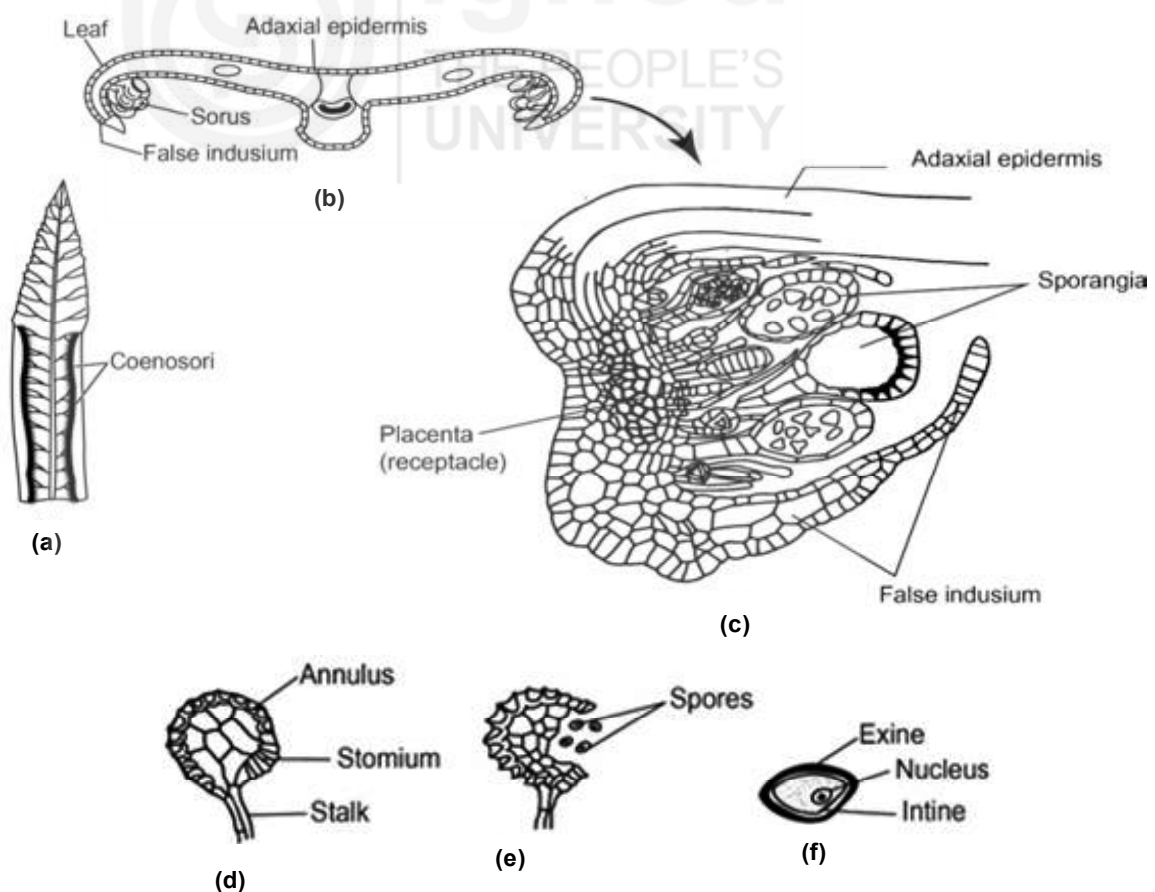


Fig. 17.23: *Pteris*: a-e) Reproductive structures: a) Abaxial surface of a sporophyll with sub marginal coenosori; b) V.S. of (a) showing sori and false indusium; c) A part of sorus modified as coenosorus; d) A sporangium; e) a dehiscing sporangium; f) a spore.

Capsule wall is composed of thin-walled, flattened polyhedral and transparent cells. These cells have wavy cell walls along the two flattened sides of the sporangium. Around the edge of the capsule a vertical row of about 16 cells, with specially thickened radial and inner tangential walls, forms the **annulus**. It stretches over about two-third of the circumference of the capsule connecting the sides and forms an incomplete ring annulus in completely overarches the sporangium. The remaining one-third portion has a small group of long, flat and thin-walled cells. It is known as *stomium*. In the stomium two cells are narrow and radially elongated. These form the lip cells. The annulus and stomium are associated with the dehiscence and dispersal of spores (Fig. 17.23 d-f). The development of sporangium is of leptosporangiate type.

All the spores are structurally and functionally alike, thus *Pteris* is homosporous. Spores are somewhat triangular with a distinct tri-radiate mark. The sizes of spores also vary in different species. The spore wall is thick and composed of an outer exine and inner intine (Fig. 17.23 d). The exine is variously sculptured in different species. The sporangia dehisce transversely along the stomium with the shrinkage of annular cells. Dispersal of spores is through air to a moderate distance.

Gametophyte

Under favourable conditions germination of spore takes place. The exine ruptures and uninucleate contents protrude out in the form of a small cylindrical structure. Due to transverse mitotic cell divisions it forms a small filament of cells which ultimately develops into prothallus (Fig. 17.24 a, b).

The mature prothallus is thin, green, heart-shaped with an apical notch (Fig. 17.24 c). Cell divisions are mainly restricted to the region behind the notch and in the lateral wings. The prothallus is about 0.3 to 0.5 mm in diameter. There is also a thick central cushion which is formed as a result of divisions in the cells behind the apical notch. From the posterior region of the prothallus numerous rhizoids arise.

In *Pteris* the sex organs and rhizoids develop on ventral side of adult prothallus (Fig. 17.24 c). Normally such prothalli are monoecious. The antheridia are near to rhizoids whereas the achegonia are restricted to the cushion behind the apical notch.

An antheridium develops from a superficial bulging cell of prothallus which divides by transverse division into a basal cell and initials. Ultimately 32 spermatids are formed and each spermatid metamorphoses into a multiflagellate spermatozoid (Fig. 17.24 d,e,f). At maturity the outer wall of the antheridium is made up of three cells: (i) the basal cell (first ring cell) which may be funnel shaped (ii) the annular or the second ring cell and (iii) the apical cap cell or the cover cell. During dehiscence the cap cell is thrown off. It often collapses during the process.

At maturity the archegonium (Fig. 17.24 g,h) has two distinct parts: neck and venter. The neck is composed of 4 longitudinal rows of cells with four cells at the top. Inside the neck is present neck canal cell(s). The lower swollen venter region contains an egg and a ventral canal cell.

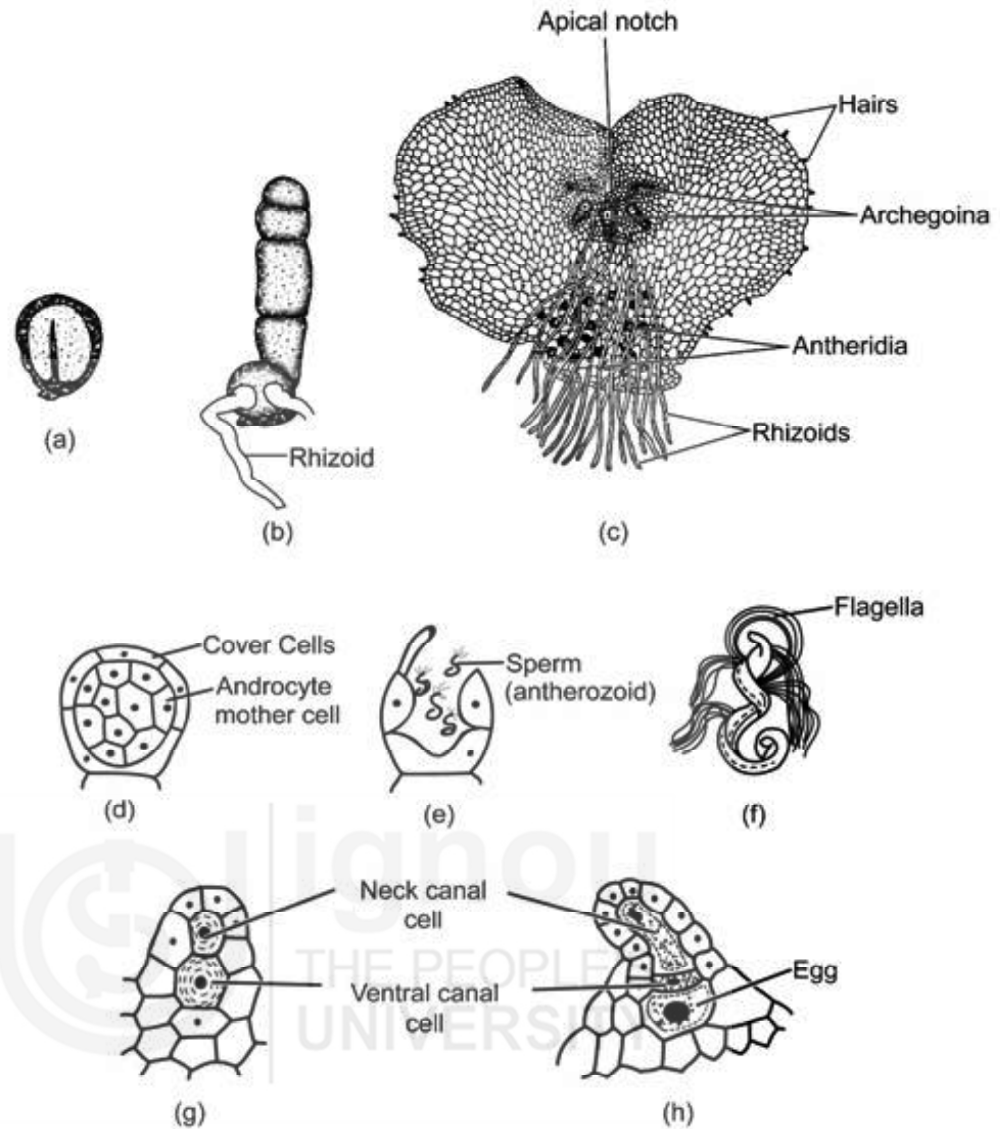


Fig. 17.24 : *Pteris* a-h) Gametophyte (prothallus): a) A spore; b) A young filamentous gametophyte; c) A heart-shaped bisexual gametophyte with sex-organs; d) An antheridium; e) An antheridium dehiscence to liberate multiflagellate antherozoids; f) A multiflagellate antherozoid; g) A young archegonium; h) A mature archegonium.

Fertilization requires water as male gametes are flagellated. Water is available in the space between the ventral surface of the prothallus and the soil. Both kinds of sex organs are in contact with moist substratum and open on the lower surface of the prothallus. The antherozoids or sperms are attracted by malic acid which diffuses out into the water from the mucilage exuded by the open necks of the archegonia. When they finally enter the neck, one of the antherozoids fuses with the egg. The fertilized egg secretes a wall around it. The egg of only one archegonium is fertilized in each prothallus. After fertilization the growth of the prothallus ceases.

The first division of the *zygote* is parallel to the long axis of the archegonium and unequal (Fig. 17.25 a). The smaller cell towards the apex of the prothallus is the epibasal cell and the larger is the hypobasal cell (Fig. 17.25 b). Further divisions result in the formation of multicellular embryo, and differentiation of

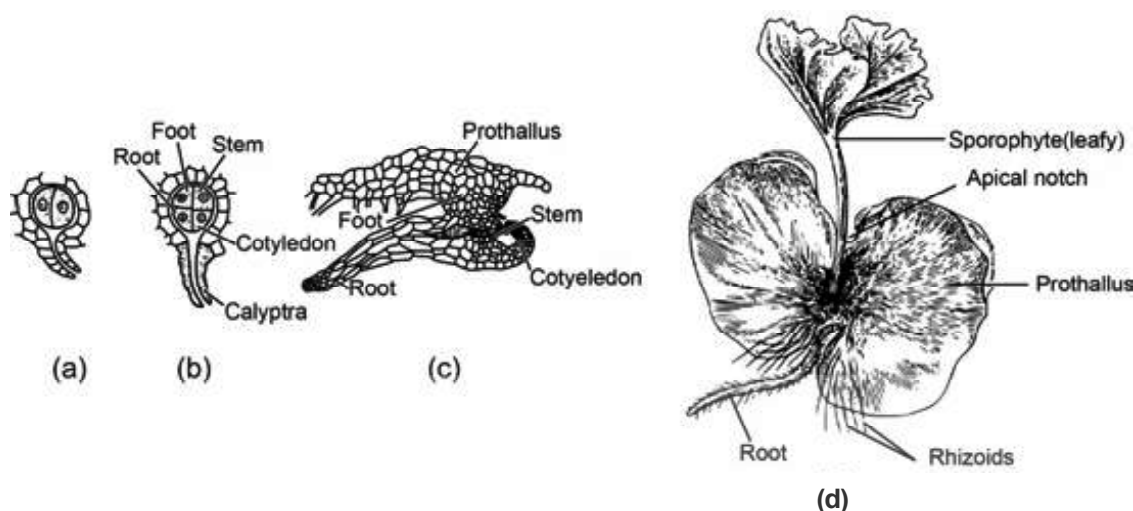


Fig. 17.25 : *Pteris* a-d) Embryo and young sporophyte: a) 2-celled pro-embryo in venter of an archegonium; b) Young proembryo; c) T.S. of a gametophyte prothallus showing an embryo; d) A prothallus supporting a young developing sporophyte.

various organs is evident at 32-celled stage. The anterior superior octant forms shoot. The first leaf arises from anterior inferior octant, whereas root develops from the posterior inferior octant and the foot is formed by posterior superior octant. During further development root grows rapidly and establishes contact with soil and the first leaf emerges out of the prothallus and finally a new plant is formed (Fig. 17.25 c-d).

17.5 SUMMARY

In this unit you have studied:

- In general, in pteridophytes sporangia bear spores which under favourable conditions germinate and produce prothalli. The jacketed sex organs are borne on the prothalli. Male gametes are flagellated and number of flagella varies in different groups.
- In *Selaginella* the main stem may be prostrate, semi-erect, branched or unbranched. It possesses microphylls which are spirally arranged on the stem and are ligulate. The stele in the stem is protostelic or siphonostelic with exarch protoxylem which is attached to the cortex with the help of trabeculae. Roots are monarch. The sporangia are borne on leaves known as sporophylls which form strobili at the apices and microspores and megaspores are produced inside the microsporangium and megasporangium, respectively. The formation of gametophytes is endoscopic.
- *Equisetum* is erect, herbaceous, perennial plant. The stem has nodes and internodes. Leaves at the nodes are fused laterally to form a sheath and are arranged in whorls. Adventitious roots develop from the base of stem. Stele is ectophloic siphonostele with nodal rings. The anatomy of stem shows association of xeromorphic and hydromorphic characters. Vascular bundles are collateral and each with a carinal canal. Vallecular

cavities are present in the cortex, each corresponding to a furrow. Cones or strobili are situated singly at the apices of fertile shoot. In *Equisetum* sporangia are produced on stalked, peltate sporangiophores. Spores of *Equisetum* have elaters.

- *Pteris* has a creeping rhizome which bears scales or branched hairs. The plant is characterized by prominent pinnately compound or digitate leaves. Stellar organization varies from protostele to dictyostele depending upon the species. The root is diarch. The sporangia are generally grouped together in sori. Sporangia are produced on the margins of fertile leaves and they are protected by false indusium. Sporangia have well defined annulus and stromium which help in the dispersal of spores. Sex organs are highly reduced.
- The gametophytes of *Equisetum* and *Pteris* are independent, undifferentiated sporophytes, thalloid, chlorophyllous and bear sex organs. They support the early periods of growth in new sporophytes.

17.6 TERMINAL QUESTIONS

1. Compare the distribution of *Selaginella*, *Equisetum* and *Pteris*.
2. Enumerate hydromorphic and xeromorphic characteristics of *Equisetum*.
3. Draw a diagrammatic sketch of life cycle of a heterosporous pteridophyte.
4. Allocate the following characters to the genera, *Selaginella*, *Equisetum* and *Pteris*.

Megasporophyll, heart-shaped prothallus, elators, false indusium, carinal canal, ligule, trabeculae, dictyostele, silicified cells.

5. Provide explanation for the following terms:
 - a) sporangium;
 - b) sporophyll;
 - c) sorus;
 - d) vallecular canal;
 - e) rhizophore

17.7 ANSWERS

Self-Assessment Questions

1. a) i) resurrection ii) conserve inorganic salts iii) rhizophore
iv) trabaculae
b) Refer Sub-section 17.2.1 and 17.2.2
c) i) F ii) T iii) T iv) T v) T
2. a) i) T ii) F iii) T
b) i) eusporangiate ii) larger iii) biflagellate iv) within
c) See Figs. 17.9 and 17.10.

3. a) i) F ii) F iii) T iv) T v) F vi) F
b) Refer Sub-section 17.3.2, Fig. 17.14
4. a) i) T ii) F iii) T iv) T
b) i) sporangiophore ii) with peltate heads iii) four iv) elators
v) longitudinal vi) marginal
5. i) creeping, semi-erect ii) pinnately, conspicuous iii) protostele,
dictyostele iv) circinnate v) scales, hairs

Terminal Questions

1. see Sub-section 17.2.1, 17.3.1 and 17.4.1
2. see Sub-section 17.3.2
3. see Sub-section 17.2.3 and Fig. 17.12
4. *Selaginella* : megasporophyll, ligule, trabeculae
Equisetum: elators, carinal canal, silicified cells
Pteris: heart-shaped prothallus, false indusium, dictyostele
5. Kindly see Subsection a) 17.2.3; b) 17.2.3; c) 17.4.1; d) 17.3.2; e) 17.2.1

GLOSSARY

Carinal canal	: Small air cavities occurring near the protoxylem points in the stems of <i>Equisetum</i> .
Leaf gap	: A discontinuity in the vascular system of a stem.
Megaphyll	: A large, broad, flattened leaf with branched vascular strand.
Peltate	: Hanging
Pinnate	: The form of a compound leaf in which leaflets (pinnae) are arranged linearly along a common axis.
Prothallus	: Thalloid gametophyte.
Protostele	: A simple type of vascular cylinder with a central core of primary xylem surrounded by primary phloem.
Rachis	: The axis of the leaf.
Rhizome	: A horizontal underground stem from which roots, shoots and leaves arise.
Stele	: A vascular cylinder and any associated parenchymatous tissue in a plant root or shoot.
Trabeculae	: A row of cells, endodermal in origin that cross over an intercellular space to connect to stele.

UNIT 18

PTERIDOPHYTES : IMPORTANCE AND EVOLUTION

Structure

18.1 Introduction Objectives	18.5 Ecological and Economic Importance of Pteridophytes Landscape and Floral Industry/ Horticulture Food and Feed Plants Medicinal Plants Biofertilizer Fossil Fuel Other Uses Ecological Importance
18.2 Telome Concept Enation Theory Telome Theory	18.6 Summary
18.3 Stellar Structure and Evolution	18.7 Terminal Questions
18.4 Heterospory and Seed Habit Incipient Heterospory Fossil Records and Heterospory Biological Significance of Heterospory Significance of Heterospory in <i>Selaginella</i>	18.8 Answers Glossary

18.1 INTRODUCTION

In the previous Units (16, 17) you have studied about the distribution, general characteristics, morphology and reproduction of some selected genera of different groups including some of the primitive land plants. You must have noticed that in spite of some basic similarities in morphology and process of reproduction, there is a gradual advancement in many characters starting from primitive forms like *Rhynia* and *Cooksonia* to most advanced true ferns such as *Pteris*. This advancement is seen in the structure of leaf, stellar structure as well as in reproductive organs, especially the heterosporous genus, *Selaginella*. In the following account we will study some of these trends.

Objectives

After studying this unit, you should be able to:

- ❖ explain telome concept and define planation, overtopping, syngensis, reduction and re-curving;
- ❖ discuss the evolution of stele in pteridophytes;
- ❖ describe heterospory and origin of seed habit; and
- ❖ list the ecological and economic importance of pteridophytes.

18.2 TELOME CONCEPT

In vascular plants leaves are a prominent part of sporophytic plant body. In early vascular plants such as *Cooksonia* and *Rhynia* leaves were absent. Some extant pteridophytes – such as *Psilotum* and *Lycopodium* possess simple leaves. True ferns like *Lygodium* and *Gleichenia* have leaves with indeterminate growth and can attain length up to 7 metres. As you already know that in pteridophytes there may be two types of leaves (i) microphyll and (ii) megaphyll. In a microphyll a single unbranched vein is present which is not connected to the main vascular cylinder of the stem whereas megaphylls exhibit a complex branching pattern which results in breaking of stem vascular cylinder into many smaller units. You may recall that vascular plants evolved during Devonian period (419-358 millions year ago). Devonian fossils such as *Sawdonia*, *Asteroxylon* and *Baragwanthia* suggest that microphylls originated as simple outgrowths.

There are different views regarding the origin and evolution of leaves. The two widely accepted theories are:

- 1) Enation theory
- 2) Telome theory

18.2.1 Enation Theory

Bower (1935) proposed 'Enation theory' which deals with phylogenetic origin of leaves. According to this theory microphyllous leaves started as bulges or outgrowth of a protuberance called enation which arises from a naked surface or a leafless progenitor as *Rhynia* initially were without vascular supply. Later a vein which did not have connection with vascular cylinder of the stem appeared, and in the final stages of evolution it established connection with vascular cylinder of stem.

Bower revised enation theory and recognised two general types of leaves: small or microphylls and large or megaphylls and suggested that they have originated from different line of evolution of leaf. Only the microphylls have evolved from the enations. This provides an adequate explanation of origin of microphyllous leaves.

18.2.2 Telome Theory

The 'Telome theory' was proposed by Zimmermann (1930) to explain the origin of the megaphyll as well as of reproductive branches in vascular plants. According to him all vascular plants evolved from a very simple leafless ancestor like *Rhynia* which had sterile and fertile axes.

Let us first understand the term telome. Look at Fig. 18.1 and note the part labelled telome. The terminal axis bearing sporangia is called **fertile telome** and the one without it the **sterile telome**. Telomes are single-nerved extreme portions (at base or apex) of the plant body from the tip to next point of branching. Thus, telome is a simple, ultimate terminal portion of a dichotomously branched plant axis. A telome ends downwards at the point of junction with another telome, i.e., at the first subadjacent branching. The parts of the plant body connecting the telomes (i.e., the internodes between each two forkings) are called mesomes (Fig. 18.1 a). In the course of ontogeny

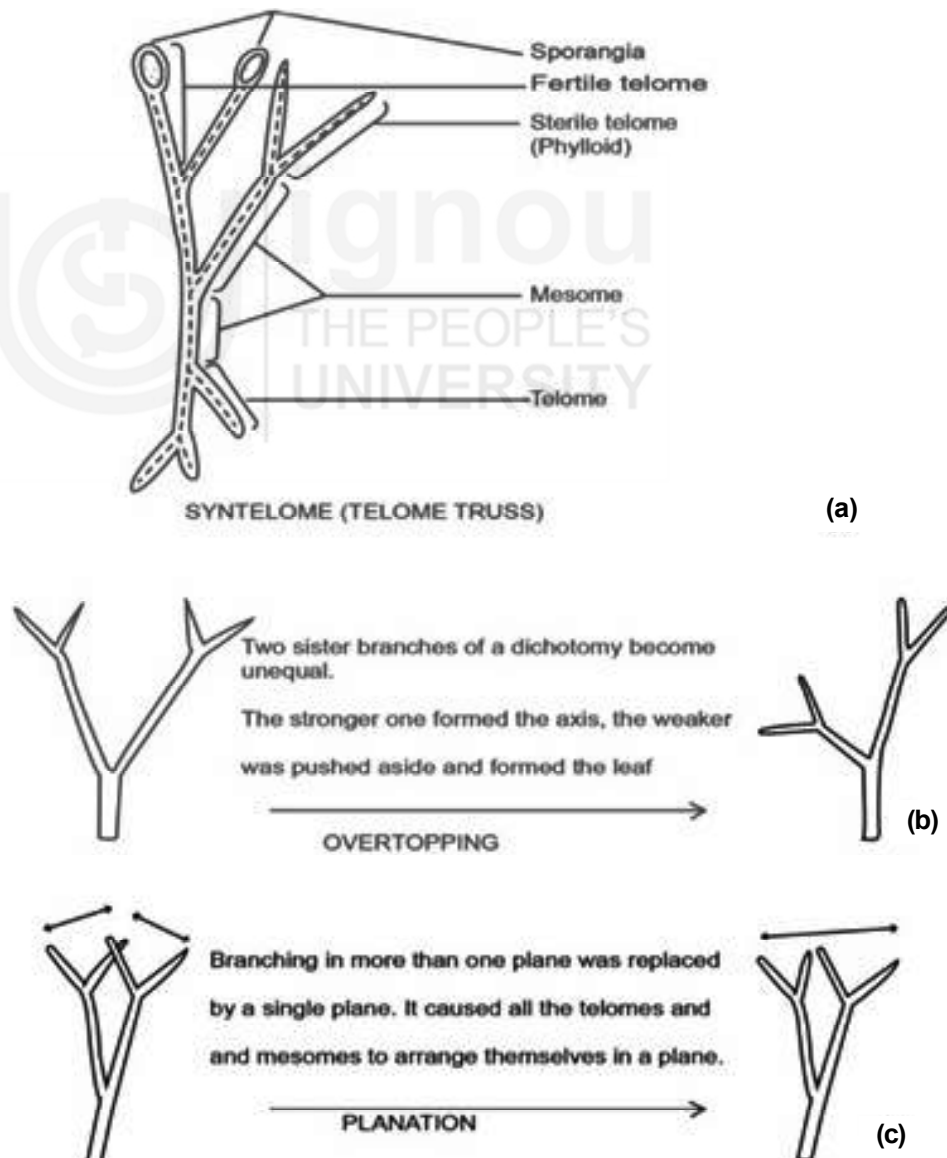


Fig. 18.1: Telome concept: a) Diagrammatic representation of early land plant showing telomes and mesomes; b) Process of overtopping; c) Process of planation.

each mesome was first a telome, being transferred to the mesome position as growth continued. Telomes may be fertile bearing sporangia or sterile (vegetative) also known as phylloids. Following evolutionary development, telomes may be grouped together in various ways to form more complex bodies known as “syntelomes”. Syntelomes are composed of either sterile or fertile telomes or mixture of the two. Fertile telomes are grouped into fertile telome trusses or sporangial trusses. United phylloids from which sterile leaves and axes have been differentiated are “phylloid trusses”. From the syntelomes or telome trusses of the early land plants, the sporophyte of higher plants evolved throughout geological time along three major independent lines. These were Lycopsid, Sphenopsid and Pteropsid trends of evolution.

Now the question is how the shoot axis and the leaves of the higher vascular plants evolved from the earliest land plants? Zimmermann suggested the following elementary processes:

- i) Overtopping
- ii) Planation
- iii) Syngensis (fusion or webbing)
- iv) Reduction
- v) Recurving

We have mentioned that the primitive sporophyte was visualised as a system of equal dichotomies in planes successively at right angles to each other. These elementary processes listed above either operated separately or in combination with each other.

Let us now try to understand these elementary processes and see how they formed different types of leaves, sporophylls and steles.

Overtopping: It refers to unequal growth of two sister branches of a dichotomy (Fig. 18.1 b).

In the most primitive forms the branches were equal. Due to overtopping or unequal growth, the stronger branch became vertical and formed the axis, and the lesser developed branch was pushed aside. So an axis with lateral appendages such as leaves was formed. This resulted in a change in the pattern of branching from dichotomous to monopodial.

Planation: As mentioned earlier, in primitive sporophytes branches of successive dichotomy were at right angle to each other i.e., all branches were not in the same plane. During planation branching in more than one plane is replaced by a dichotomy in a single plane. It caused the telomes and mesomes to arrange themselves in a single plane (Fig. 18.1 c). By this process a radially symmetrical organ became bilaterally symmetrical. Planation played major role in the evolution of leaf.

Syngensis (fusion or webbing): This process is also called webbing. During this process connection developed between the telomes and mesomes (Fig. 18.2 a).

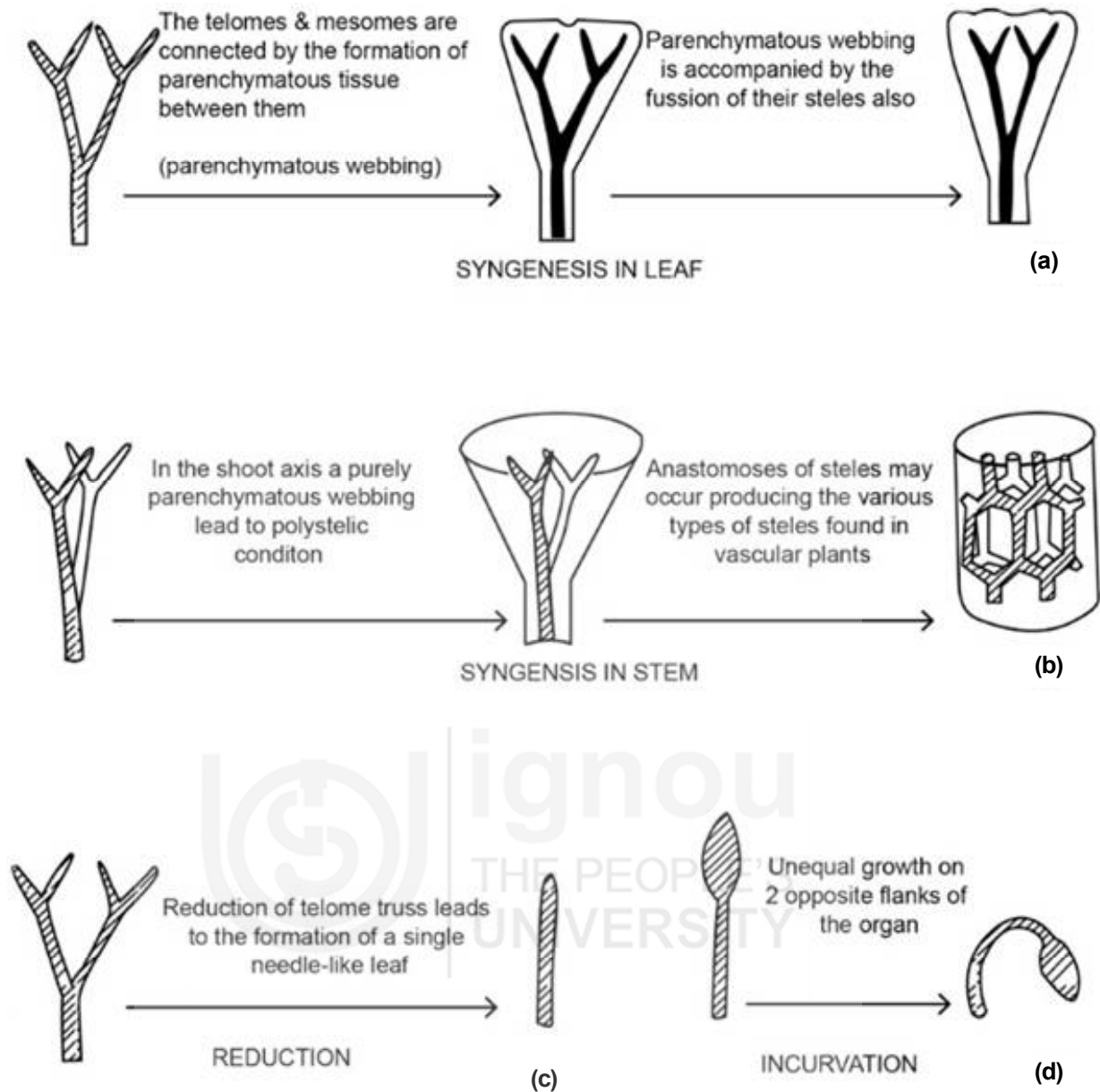


Fig. 18.2: Elementary processes in Telome concept: a) Syngensis in leaf; b) Syngensis in stem; c) Reduction; d) Incurvation.

These connections were formed by parenchymatous webbing. It was also accompanied by the fusion of their steles (Fig. 18.2 a, b). Syngensis is a very important process because it affords an explanation of the origin and evolution of both the leaf and the stele of the stem.

Reduction: In this process a simplification of the telome trusses occurred which resulted in the formation of a single needle-like microphyllous leaf (Fig. 18.2 c) found in the leaves of xerophytic Lycopods such as *Lycopodium*, *Selaginella* and *Isoetes*. Here you can find that the leaves have reduced to a scaly or needle-like shape

Recurving: During this process the fertile telomes were supposed to become reflexed. As a result the sporangia assumed an inverted position. This process is also known as incurvation (Fig. 18.2 d).

18.3 STELAR STRUCTURE AND EVOLUTION

As you have read earlier that pteridophytes are the first vascular land plants. They possess conducting tissues. This development of conducting tissues played an important role in their successful invasion of land. Xylem and phloem are the main conducting tissues involved in the conduction of water and food, respectively. In the following description you will read how these two vascular elements are organised in various members to form various types of steles which also show an evolutionary trend.

The term stele refers to a central core in the axis of sporophytic plant body in vascular plants. It consists of xylem and phloem, pericycle and sometimes medullary rays and pith and is limited externally by an endodermis.

Arrangement of xylem and phloem within an axis varies in different groups of plants. Based on the kind of stelar organization in different groups, some botanists have recognized an evolutionary sequence in the vascular plants. Van Tieghem and Doulit (1886) developed a theory called Stelar Theory. According to them cortex and the stele are the fundamental parts of a shoot and both these parts are separated from each other by the endodermis and this is the basis of the stelar theory and stele is a real entity and present universally in all axes of plants.

Types of Steles: On the basis of the stelar theory various types of vascular cylinder can be recognised in the roots and stem. Most of the scientists have recognised two main types of stelar system i.e. protostele and siphonostele.

Protostele: The stele, in which a central solid core of xylem is surrounded by peripheral layer of phloem and without a pith is known as protostele. This type of stele occurs in certain primitive vascular plants such as *Rhynia* (see Unit 16 and Fig. 16.10). It is a fundamental stelar type for the vascular plants in general and for the pteridophytes in particular. It is suggested that all other types of steles have been derived from it in the course of evolutionary specialization. Almost all pteridophytes in the sporeling stage possess a protostelic stem. It is permanently retained in the adult stems of many extant pteridophytes, e.g., *Selaginella*, *Lycopodium* and *Lygodium*. Depending upon the shape of xylem, protostele may be classified into **haplostele**, **actinostele** or **plectostele**.

1. **Haplostele:** The haplostele is circular in cross section, is a solid core of xylem surrounded by a uniform layer of phloem, (Fig. 18.3 a). The name haplostele was given by Brebner (1902). It is found in *Selaginella kraussiana*, *S. chrysocaulos* and *Lygodium*.
2. **Actinostele:** The central xylem tissue extends in the form of radiating ridges in the matrix of tissue (Fig. 18.3 b). In this type of stele the xylem core is star-shaped or stellate. The phloem does not form an uniform cylinder around xylem but occurs in form of separate groups, which alternate with distant ends of star-shaped xylem e.g. *Asteroxylon*, *Psilotum* and *Lycopodium*.

Sometimes in an actinostele the xylem core is plate-like. A number of such plates lie parallel to one another (Fig. 18.3 c). The phloem is

arranged in alternate transverse bands or plates. Such protostele are usually termed as **plectostele**. This type of stele is present in the stem of *Lycopodium volubile* and *L. elavatum*.

3. **Siphonostele:** Next type of stele in the evolutionary series is siphonostele. You may recall that in this type of stele, centre of stele is occupied by pith which is surrounded by xylem and phloem. Thus such a modified protostele is called siphonostele. A siphonostele can be of two types: **ectophloic** and **amphiphloic**.

- i) **Ectophloic siphonostele:** The xylem cylinder lies next to the pith and is surrounded by the phloem cylinder on the outside only e.g. *Osmunda*, *Schizaea* (Fig. 18.3 d).

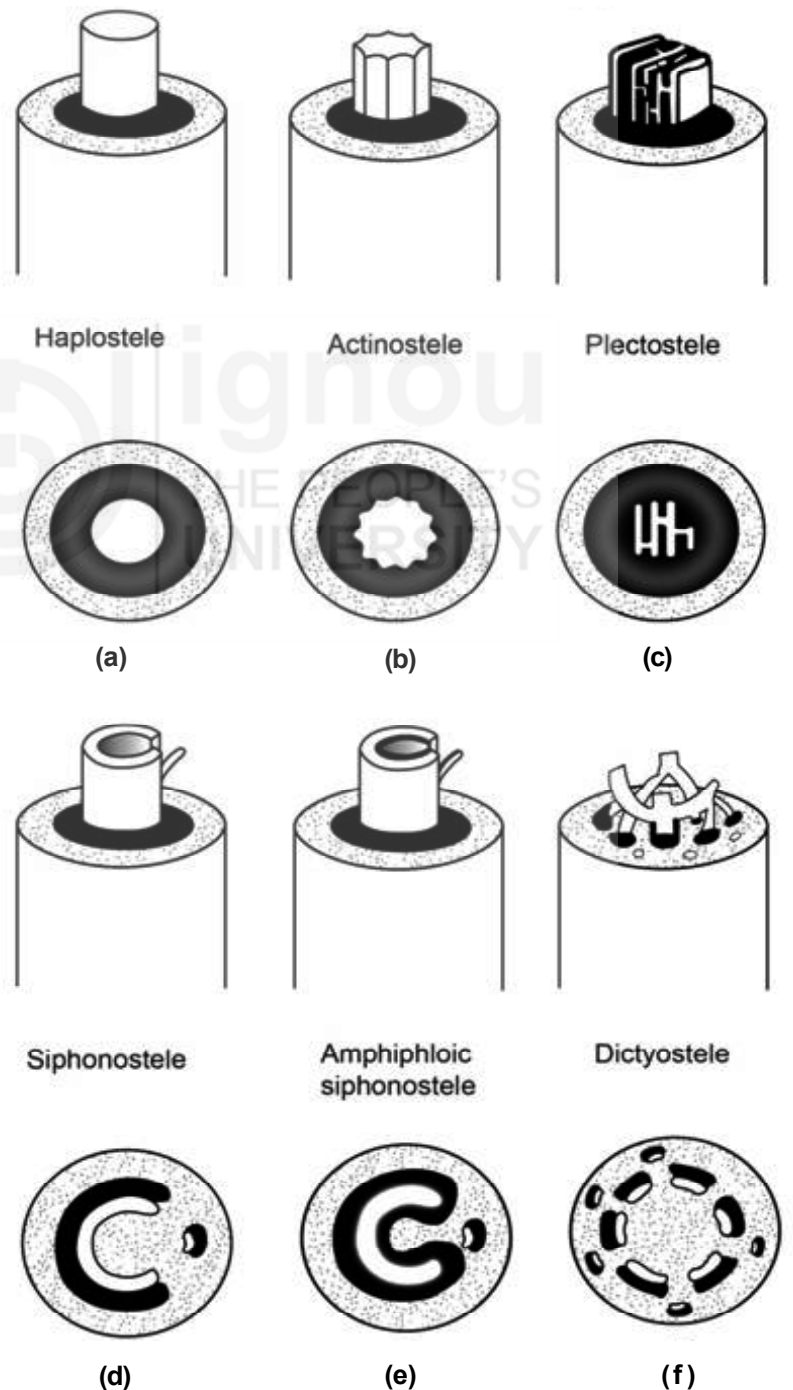


Fig. 18.3: Various types of steles.

- ii) **Amphiphloic siphonostele:** Phloem is present on the both sides of xylem cylinder and pith is present in the centre (Fig. 18.3e). Amphiphloic siphonostele is found in stem of *Marsilea*.

In higher vascular plants a small vascular supply from the main vascular cylinder diverges into a leaf or branch. These are known as leaf traces or branch traces respectively (Fig. 18.4). Immediately above the point of departure of leaf trace, small parenchymatous areas appear in the vascular cylinder of stem. These parenchymatous areas persist only for a limited distance and higher up the vascular tissue is present in direct line above the diverged leaf or branch trace. Such parenchymatous areas in the vascular system of the stem located above the point of departure of the leaf traces and the branch traces are known as “*leaf gaps*” and “*branch gaps*” respectively.

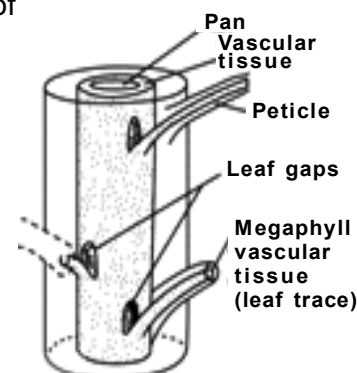


Fig. 18.4: Diagrammatic representation of leaf trace and leaf gap.

The siphonostele has no leaf gaps, for example some species of *Selaginella*. But in some true ferns where leaves are not closely placed the leaf gaps are relatively smaller so that there is no overlapping of successive leaf gaps and xylem appears horse-shoe shaped. This type of stele is known as **solenostele**. In many species of ferns the shoot axis is short and the leaves are inserted on it in close succession. In such cases the successive large gaps overlap so that the vascular cylinder of the stem appears dissected into a tubular network of interconnected longitudinal strands separated from one another by vertical strips of parenchymatous tissue i.e. leaf gaps. Each strand is known as **meristele**. These meristeles as seen in a T.S. are arranged in the form of a ring. Each meristele is separated from its neighbours by a leaf gap on either side. Such a siphonostele is known as dissected siphonostele or dictyostele (Fig. 18.3 e, f). In a dictyostele each meristele has the general structure of a protostele.

Polystele : Sometimes more than one stele are present in the axis of some pteridophytes, such condition is known as polystelic e.g., *Selaginella* spp.

SAQ 1

- a) Which of the following statements are true and which are false? Write **T** for true and **F** for false in the given boxes.
- i) Telome Concept was proposed by Zimmermann. []
 - ii) A telome is the ultimate, terminal portion of a dichotomously branched axis. []
 - iii) Overtopping refers to equal growth of two sister branches of a dichotomy. []
 - iv) In planation there is a change in the symmetry of an organ from bilateral to radial. []
 - v) During syngeneses development of connection between telomes and mesomes occurs. []
 - vi) During reduction fertile telomes became reflexed. []

- b) Choose the correct alternative among the ones provided in the parentheses.
- i) Stele refers to central conducting strand in the axis of (sporophytic/gametophytic) plant body.
 - ii) Xylem is star-shaped in case of (plectostele/actinostele).
 - iii) In (plectostele/actinostele) xylem is in the form of parallel plates.
 - iv) In (siphonostele/haplostele) there is no pith in the centre of xylem core.
 - v) When (xylem/phloem) is present on both sides of phloem cylinder the stele is amphiphloic siphonostele.
 - vi) Protostelic organization is more (primitive/advanced) than a siphonostele.

In bryophytes *Macromitrium* is only species that shows some amount of heterospory by producing small and large spores.

18.4 HETEROSPORY AND SEED HABIT

You have already read in Unit 17 that *Selaginella* produces two types of spores which are different in size as well as in number per sporangium. These two types of spores also behave differently. On germination smaller spores or microspores produce male gametophytes whereas larger spores or megaspores produce female gametophytes. This phenomenon of production of two kinds of spores which are different morphologically as well as physiologically is known as **heterospory**. It is now generally believed that the heterosporous condition arose as a result of reduction in spore number in certain sporangia, associated with an increase in the size of those remaining. It is thought that these remaining megaspores received more nutrients than many small spores or microspores. The reduction occurred in megaspore number either through decrease in the number of spore mother cells, as in *Selaginella* or by disintegration of developing spores as in *Marsilea*.

18.4.1 Incipient Heterospory

In *Equisetum* all the spores are morphologically similar i.e. homosporous, but on germination they produce two types of gametophytes; smaller ones are male gametophytes and larger ones are female gametophytes. If fertilization is delayed due to some reason, antheridia start developing even in the female prothalli. In a population the proportion of male and female gametophytes is influenced by environmental conditions. This is called incipient heterospory. The word incipient means 'beginning to happen or develop'.

Another homosporous fern *Ceratopteris*, a water fern which is homosporous but produces separate male and female gametophytes, and their proportion is not influenced by environmental conditions and female gametophytes produce antheridia if fertilization is delayed. *Platyzoma* is intermediate between forms showing incipient heterospory and complete heterospory. Although all sporangia are similar in size but the size of spore and number of spores in each sporangium is different. There are 16 megaspores in a megasporangium, whereas there are 32 microspores in a microsporangium. On germination microspores form filamentous male gametophytes, whereas

megaspores form female gametophytes which may develop antheridia only when fertilisation is delayed. Therefore, it is a heterosporous form with a latent heterospory in evolution. These observations suggest that heterothallism might have preceded heterospory in evolution.

18.4.2 Fossil Records and Heterospory

Fossil records suggest that the earliest vascular land plants were homosporous. Although isolated spores large enough to represent megaspores (larger than 200 μm) appeared about 370 million years ago and became more common in middle Devonian between 370 and 359 million years ago. By the late Devonian or early Carboniferous period heterospory was evident in early vascular plants. Some of the plants such as *Lepidostrobus*, *Pleuromeia*, *Lepidocarpon*, *Mazocarpon* (all belong to Lycopodiophyta); and *Palaeostachya*, *Calamostachya*, *Calamocarpon* (all belong to Equisetophyta) showed an advanced level of heterospory and approached the seed condition which is considered an advanced stage of heterospory.

The initial steps in the evolution of heterospory presumably are indicated by two species of *Calamostachys*. Some species of *Calamostachys* were homosporous, producing numerous spores in tetrads, but frequently all the four spores of a tetrad were not equal and one or more members of the set grew larger than the others. In other species of *Calamostachys* some of the sporangia contained numerous small spores and in some sporangia a few spores three to four times larger were present. These sporangia with large spores also contained small, apparently aborted spores.

More extensive spore abortion leading to a reduction in spore number was evident in another fossil form *Stauropteris* of lower Carboniferous period. In *Stauropteris* the number of megaspores in a megasporangium was reduced to two. In *Lepidocarpon* and *Calamocarpon* only one megaspore tetrad developed in each megasporangium, and in most cases three spores of the tetrad aborted and only a single megaspore matured. The early stages in the pattern of abortion of some spores and consequent enlargement of others can be seen in *Bowmanites dawsoni* and *Lepidostrobus braidwoodensis* in which each megasporangium contained a single large megaspore about 2 mm in diameter accompanied by three dwarfed members of the original tetrad.

The above observations are summarized below.

Fossil showing the stage	
Stage 1 Homosporous- numerous spores in tetrads, one or more spores becoming larger than the others	<i>Calamostachys binneyana</i>
Stage 2 Heterosporous – microsporangia (small spores) megasporangia (lesser in number, spores 3 to 4 times larger, also small spores, apparently aborted)	<i>C. casheana</i>

Stage 3 Heterosporous – more extensive spore abortion leading to further reduction in spore number (in each tetrad 2 large megaspores and 2 aborted spores)	<i>Stauropteris burntislandica</i>
Stage 4 Heterosporous – only one megaspore tetrad developed, and in most cases 3 spores of tetrad aborted and a single megaspore matured.	<i>Lepidocarpon</i>

The eight genera of living pteridophytes that exhibit heterospory are: *Selaginella*, *Isoetes*, *Stylites*, *Marsilea*, *Pilularia*, *Regnellidium*, *Salvinia* and *Azolla*.

18.4.3 Biological Significance of Heterospory

Heterospory offers great advantage on account of the fact that a large female gametophyte derives its nutrition from the food synthesized by the sporophyte and it is not dependent on environmental conditions for its survival. It thus forms a better starting point for the juvenile embryo, than an independent green prothallus which has to manufacture its own food. During the course of evolution heterospory was responsible for the development of seed habit.

The following is the outcome of heterospory.

- i) It has resulted in considerable decrease in the size of gametophytic tissue.
- ii) There is unusually early germination of spores.
- iii) There is partial and ultimately complete retention of the megasporangium and female gametophyte on the sporophyte.
- iv) The number of megaspores in a megasporangium is reduced to one.
- v) The number of male gametes is also reduced.
- vi) There is organic union between the megaspore and the megasporangium.
- vii) It has brought along with it the phenomenon of pollination.

Seed Habit

All these new developments are vital for seed habit. These changes have gradually developed in vascular plants and led to seed habit.

- i) Evolution of heterospory.
- ii) Decrease in the number of megaspores to a single functional spore in the megasporangium.
- iii) Development of megagametophyte within the megaspore.

- iv) Retention of megagametophyte within the megaspore present inside the megasporangium, fertilization of egg, and embryo formation while still *in situ*.
- v) Apex of megasporangium (nucellus) is modified as a site for reception of pollen.
- vi) Envelopment of the megasporangium (nucellus) by an integument, except at the apex, thus forming the micropyle.

Let us consider whether fossils provide any evidence for the evolutionary stages, enumerated above that led to the seed habit.

Fossil evidences suggest that heterospory was evident in Devonian period. The earliest indication of reduction in the number of megaspores to one per megasporangium was found in *Cystosporites devonicus* in which tetrahedral tetrads comprised one large, presumably fertile spore, with three smaller abortive spores arranged at the apex. These observations suggest that the seed habit had already evolved during the upper Devonian period. The seeds had a lobed integument like that of some Carboniferous seeds.

The earliest seed-like structure is shown by the fossil *Genomosperma kidstonii*. The structure consisted of an apically borne elongate nucellus (megasporangium) with pollen receiving modification at the apex. It was formed by 6-8 finger-like straight projections that were fused only at their bases. In other fossil form *Genomosperma latens* such finger-like processes bent towards the apex of the nucellus and formed a rudimentary micropyle. These two species of *Genomosperma* indicate two early stages in the evolution of integumented ovule from a measporangium. In another seed called *Salpingostema dasu* the integument was composed of 5 or 6 lobes fused upto about the half of their length. Degree of lengthwise fusion of the integumentary lobes gradually increased in *Physostoma* and *Eurystoma*. In the *Eurystoma* original components were evident only as lobes at the apex of the seed-like structure. In *Stamnostoma hattonense* the fusion was complete and there were no remains of the finger-like tips.

Thus, the above mentioned Carboniferous ovules can be arranged in a sequence based on the relative degree of fusion of integumentary lobes. Further, the integument may be interpreted as being the product of the fusion of a number of slender branches at the base of the nucellus and extending over it.

18.4.4 Significance of Heterospory in *Selaginella*

You have read about the process of reproduction and structure of reproductive organs in *Selaginella*. Let us see in what respects it approaches seed habit. You may recall that in *Selaginella* megaspores start germination within the megasporangia. In some species of this genus the number of megaspores is reduced to one and the megaspore is never shed.

Fertilization and development of embryo upto the formation of rhizophore, stem and cotyledons takes place while the megaspore is enclosed within the megasporangium, which retains its connection with the parent plant.

Although heterosporous vascular cryptogams like *Selaginella* approached seed habit, it failed to develop true seeds because of lack of protective structures like integuments around their megasporangium. Megaspore is not permanently retained within the megasporangium. There is no organic union between the megaspore and the megasporangium. Further, embryo shows no resting period in its development.

It would be pertinent here to examine the homologies of reproductive structures of *Selaginella* with that of lower spermatophytes as given below:

<i>Selaginella</i>	-	Lower Spermatophytes
Megasporangium	-	Nucellus of the ovule
Megaspore	-	Megaspore
Megagametophyte (Female gametophyte)	-	Endosperm
Archegonium	-	Archegonium
Egg	-	Egg
Microsporangium	-	Anther
Microspore	-	Pollen
Microgametophyte	-	Germinating pollen
Antherozoid	-	Sperm

Now have a good look at Fig. 18.5 showing the reproductive structures in gymnosperms and angiosperms. You may like to compare them with those of pteridophytes.

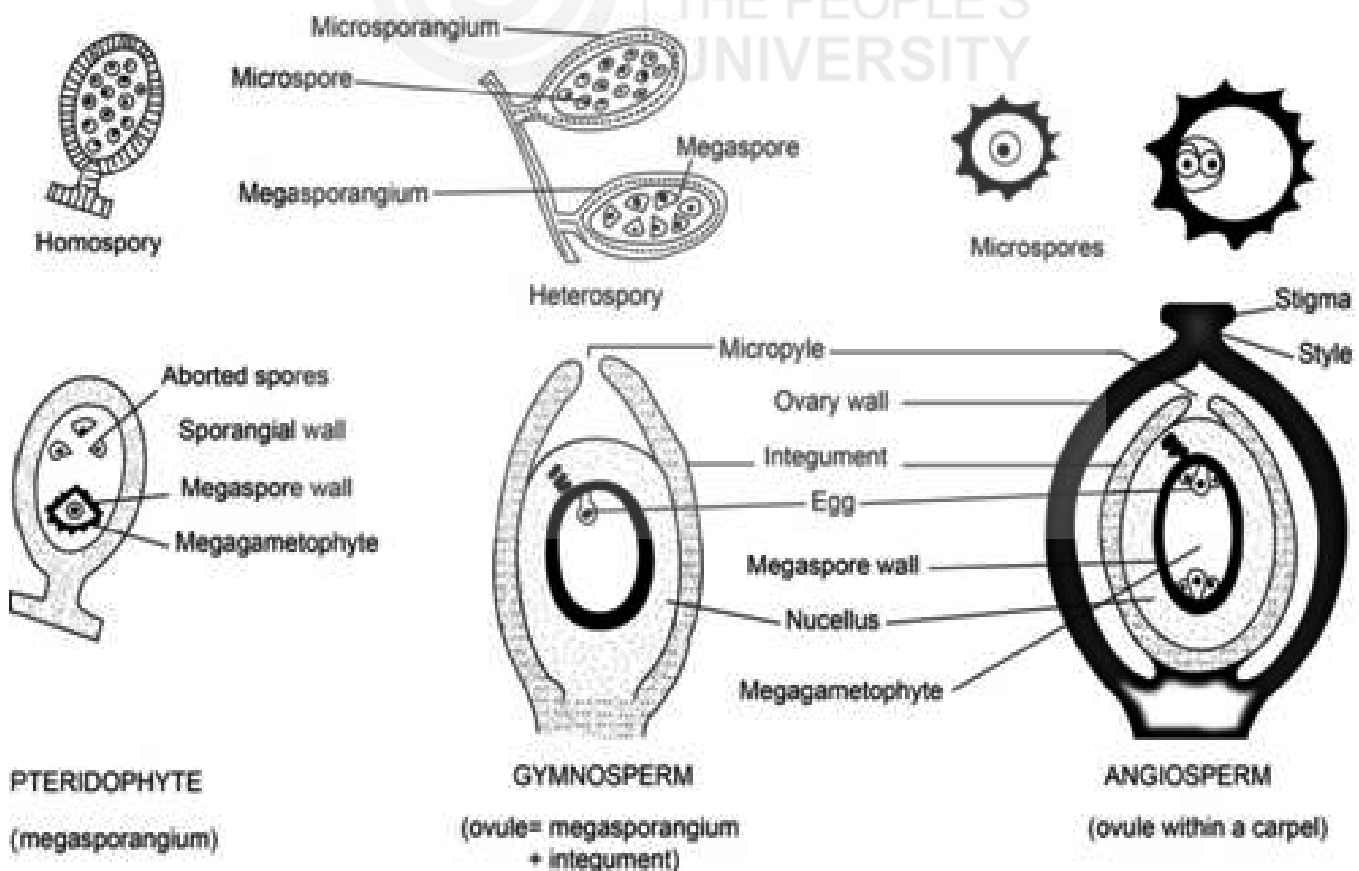


Fig. 18.5: Reproductive structures in pteridophytes, gymnosperms and angiosperms.

SAQ 2

Fill in the blanks spaces with appropriate words.

- i) The phenomenon of production of two types of spores which are different morphologically as well as physiologically is known as
- ii) The phenomenon in which a plant produces morphologically similar spores which behave differently is known as.....
- iii) shows incipient heterospory.
- iv) Heterospory, reduction in the number of megaspores to one, and retention of functional megaspore within the megasporangium ultimately led to the development of
- v) *Selaginella* although approaches to seed habit, but fails to develop true seeds because it has no around the megasporangium.

18.5 ECOLOGICAL AND ECONOMIC IMPORTANCE OF PTERIDOPHYTES

Pteridophytes are not as important economically as seed plants but have considerable importance in horticulture, as food plants, as delicacies and also as substitute during scarcity of food. Some of the pteridophytes are used as medicine, as biological fertilizer, serving as substitute for green manure, indicator of mineral contents in the soil, also valued for their insecticidal properties. Some are obnoxious weeds which are difficult to eradicate.

18.5.1 Landscape and Floral Industry/Horticulture

Ferns enhance the beauty of landscape and play an important role in floral industry due to their attractive foliage. Ferns are used for floral arrangements and bouquets e.g. *Nephrolepis exaltata*, *Nephrolepis cordifolia* (Sword fern), *Asplenium nidus* (bird nest fern) *Pteris* sp. and *Ruhmora adiantiformis* (Floral fern). The fronds of floral fern resist wilting so they are extensively used in the cut flower arrangements. *Angiopteris* and *Marattia* are magnificent ferns which find their places in green-houses because of their elegance. Other ornamental pteridophytes which are used in horticulture are some species of *Selaginella* which are delightful subjects for table decoration because of their feathery moss like foliage and various shades of dark to light green. *Selaginella willdenovii* and *S. caesia* are remarkable for their metallic and many hued tints, especially bronze and bluish colours. This is due to reflection of light rays by the particles present in the cutin of epidermis. Another interesting species of *Selaginella serpens* periodically changes colour of its leaves. A few species of *S. lepidophylla* and *S. pilifera* are sold as curiosities under the name; resurrection plants. It rejuvenates when it comes in contact with water.

Several species of *Lycopodium obscurum* are widely used in Christmas wreaths and other decorations, hence they are commonly known as "Christmas Greens". *L. volubile* is used for table decoration. The roots and stems of *Osmunda* provide fiber which is used by orchid growers for the

cultivation of epiphytic orchids and other epiphytic plants as they are very resistant to decay. Some species of *Osmunda* are grown as ornamentals for their beautiful foliage. *Psilotum* another green house plant is a leafless dichotomous branched plant and multiplies by rhizome cuttings.

18.5.2 Food and Feed Plants

Although not as a staple diet, ferns provide some sustenance for some groups of people. *Polystichum munitum* and *Polypodium glycyrrhiza* rhizomes are roasted or steamed and eaten by native Americans. Fiddleheads of ostrich fern (*Mattencchia struthiopteris*), cinnamon fern (*Osmunda cinnamomea*) and vegetable fern (*Diplazium esculentum*) are the varieties eaten. The underground modified stem corm of *Isoetes* is used as food by ducks and other aquatic animals. *Marsilea* is used as a substitute for clover to feed the animals.

The rhizomes of Bracken fern (*Pteridium revolutum* syn. *P. aquilinum*) is widely used as food during scarcity. The tender fronds are used as vegetables and also in soups. They are also used in brewing beer and as stock feed for pigs. Edible fern crosiers (young leaves with coiled hook-shaped tips) are supposed to be delicacy in certain parts of the world. *Azolla* has been used as food supplement in fresh, dried or silage form for pigs, cattle, rabbits and chicken.

18.5.3 Medicinal Plants

Pteridophytes have various medicinal properties. The leaf and root decoction of *Adiantum lunulatum* syn. *A. philippense* has been used in the treatment of bronchitis and fever and as diuretic and also as tonic. The fresh fronds of *Blechnum orientale* are used as poultice for boils in Malaya. Its rhizome is used to cure intestinal worms and bladder complaints. The rhizomes of *Discranopteris linearis* is used as anthelmintic in Assam while its fronds are used for treating asthma in Madagascar. The rhizome of bracken fern (*Pteridium revolutum*) is used in diarrhoea and inflammation of gastric and intestinal mucous membrane. The entire plant of *Equisetum arvense* has been recognized by the German Pharmacopoeias under the name Herba Equiseti and is used as diuretic. It has haemostatic and haemopoietic properties. *Equisetum* is also among the most important plants containing silica in therapeutically active form. The ash of this plant is used in relieving acidity and dyspepsia. *Equisetum debile* and *Selaginella bryopteris* yields a medicine which relieves gonorrhoea. The rhizome of *Lycopodium flexuosum* is used to cure skin diseases. *Lycopodium* species are used in homeopathy.

18.5.4 Biofertilizer

Azolla, an aquatic fern (also called mosquito fern) is used as biological fertilizer in the paddy fields due to its ability to fix nitrogen from the air and make it available to other plants. *Azolla pinnata* has a symbiotic association with nitrogen fixing blue-green alga, *Anabaena azollae*. Due to this property,

the agronomic potential of *Azolla* as biofertilizer for rice has been recognized in many countries including India. *Azolla* also improves soil fertility by increasing total available nitrogen, carbon, phosphorus and potassium. Other uses of *Azolla* include hydrogen production, biogas production and also used as an ingredient in soap production. Due to its rapid growth it has been used as a green manure since ages.

18.5.5 Fossil Fuel

Ferns are economically important in an indirect way. Ferns were the dominant plants in the landscapes many million years ago. When they died, they formed a thick layer of foliage and detritus, along with other trees and foliage. These layers buried deep underground and were subjected to heat and pressure for millions of years before eventually becoming coal which has tremendous economic importance.

18.5.6 Other Uses

Handicrafts – Petioles of certain ferns are used in making baskets.

Dye – *Pteridium* leaves are used for making green dye.

Soil Indicator – Species of *Equisetum* are used as indicator of mineral content of the soil in which they grow and are therefore of some value in prospecting for new areas of deposits.

Fireworks – The spores of *Lycopodium* (club mosses) are highly inflammable and used in manufacture of fireworks under the name of “Vegetable Brimstone”. They have been also used in stage lighting for the theatre.

Polishing and Cleaning – Many species of *Equisetum* are used for polishing wood and scouring pewter dishes. The spores are also used as flash powder in photography and also as finger print powder in forensic investigations.

Obnoxious Weeds – *Pteridium aquilinum* is obnoxious weed which can rapidly colonize the open forest land leading to the exclusion of other plants and is hard to destroy because of its perennial rhizome. *Salvinia*, a water fern is also a troublesome weed. It can occupy the entire water surface in lakes and irrigation reservoirs and can block boating and free flow of water in irrigation canals. Many species of *Equisetum* are harmful weeds in poorly drained soil.

18.5.7 Ecological Importance

Ferns are very good indicators of their immediate environment. Conducting surveys of fern flora in an area provide a valuable ecological tool to measure environment up to micro level. Studies of ferns also help in studying the ecology of the region.

Pteridophytes are best known bioaccumulators of many metals and metalloids. *Pteris vittata*, *Marsilea minuta*, *Equisetum debile*, *Salvinia molesta* and *Azolla pinnata* had been found as a hyper accumulator of carcinogenic

heavy metals viz., cadmium, mercury, copper, arsenic and chromium respectively. In West Bengal arsenic has been found to be a major problem in the area of high water fed regions and paddy fields. So *Pteris vittata* can be utilized for the management of arsenic. Infact, *Pteris vittata* serves as an excellent model to study arsenic uptake and for phytoremediation of arsenic contaminated soil and water.

Pteridophytes form dense mats which trap leaves and soil. They are pioneer plants in succession and forms a dense lower stratum in the climax community.

18.6 SUMMARY

In this unit you have studied that:

- Bower proposed enation theory to explain the evolution of microphyllous leaves and Zimmerman proposed the telome theory to explain the evolution of megaphyllous leaves as well as reproductive branches in vascular plants.
- Telome is the single nerved extreme portion of plant body of primitive land plants like *Rhynia*. Telome gave rise to shoot axis and leaves of vascular plants by certain elementary processes like overtopping, planation, syngensis, reduction and recurving.
- The primitive pteridophytes like *Rhynia* possessed the simplest type of stele – the protostele which is also found in all living pteridophytes in the sporeling stage and is retained in some parts till maturity. Later in evolutionary sequence appeared siphonostele from which probably evolved a variety of stele when vascular cylinder diverged into a leaf or branch. As a consequence solenostele and dictyostele are present in advanced pteridophytes.
- Heterospory is the production of two types of spores. Smaller spores form male gametophytes and larger ones develop into female gametophytes. *Selaginella*, *Isoetes* and *Azolla* and some others forms are heterosporous.
- Heterospory appeared about 370 million years ago. Heterospory ultimately led to seed habit. In addition to heterospory, reduction in the number of megaspores to one, retention of megasporophyte within the megaspore (which is present inside the megasporangium) and envelopment of megasporangium by integument were responsible for seed habit.
- Pteridophytes have considerable importance in horticulture, as food plants, as delicacies, in medicine and as biological fertilizer. It serves as substitute for green manure and as indicator to mineral content of soil.
- Ferns are very good indicators of their environment. They provide a valuable ecological tool to measure micro-level environment. Ferns help in studying the ecology of the region.

18.7 TERMINAL QUESTIONS

1. Define following terms:
i) Telome ii) Overtopping iii) Planation iv) Syngeneses
v) Reduction vi) Recurving.
2. Differentiate between the terms: haplostele, actinostele, plectostele, siphonostele, dictyostele.
3. What is heterospory? Mention its biological significance.
4. Write a note on "Pteridophytes as biofertilizer".
5. List any five pteridophytes used for landscape and floral industry.

18.8 ANSWERS

Self-Assessment Questions

1. a) i) T ii) T iii) F iv) T v) T vi) F
b) i) sporophytic; ii) actinostele; iii) plectostele; iv) haplostele; v) phloem; vi) primitive.
2. i) heterospory; ii) incipient heterospory; iii) *Equisetum*; iv) seed habit; v) integument.

Terminal Questions

1. i) It is simple, ultimate terminal portion of dichotomously branched plant
ii) It refers to unequal growth of two sister branches of a dichotomy.
iii) It is process by which branching in more than one plane got replaced by dichotomy in a single plant.
iv) A process by which development of connections between telomes and mesomes occurred.
v) A process where simplification of telome trusses lead to the formation of needle-like microphyllous leaf.
vi) During this process fertile telomes reflexed resulting in an inverted position of sporangia.
2. See Section 18.3
3. Refer Section 18.4, Subsection 18.4.3
4. Refer Subsection 18.5.4
5. Any five; Subsection 18.5.1

GLOSSARY

Actinostele	:	A protostele with star-shaped configuration.
Dichotomous	:	A system of equally forked dichotomies in plant successively at right angles to each other.
Dictyostele	:	Scattered series of vascular bundles in transaction where each stele is a meristele. When a solenostele gets dissected due to overlapping of leaf gaps it forms dictyostele.
Enation	:	Bulges from the surface of the stem with or without vascular supply.
Haplostele	:	A protostele circular in outline.
Leaf gap	:	A discontinuity in the vascular system.
Leaf trace	:	A part of the vascular system that traverse through cortex to a leaf.
Mesomes	:	The parts of the plant body that connects the telome (i.e. the internodes between two forkings).
Monopodial	:	A branching pattern where the stronger branch of a dichotomy grows vertical and pushes the other less developed axis sideways.
Plectostele	:	A protostele where central cone of xylem is broken into plates, each of which is surrounded by phloem.
Protostele	:	A central core of xylem cylinder surrounded by phloem.
Siphonostele	:	A medullated protostele.
Solenostele	:	A stele with two endodermal layers. One delimits it from cortex and the other from pith; possesses two phloem zone on either side of xylem: amphiphloic siphonosele.
Syntelomes	:	Grouping of many telomes into a complex body.
Telome	:	Single-nerved extreme portions (base to apex) of the plant body from tip to next point of branching. It is also described as the distal branches of a dichotomously branched axis.

FEEDBACK FORM

Dear Student,

We look forward to your feedback regarding the **design, contents, time for study language, presentation style, and delivery** of the course. Your feedback on any other aspect is also welcome. The mailing address is given at the back of this page.

Thank you,

Yours sincerely
Course Coordinator
Biodiversity (Microbes, Algae, Fungi and Archegoniates)
Course Code: BBYCT-131

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To,

The Course Coordinator
Biodiversity (Microbes, Algae, Fungi and Archegoniates)
Course Code: BBYCT-131
School of Sciences
Indira Gandhi National Open University
Maidan Garhi,
New Delhi-110068

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