REVIEW OF LITERATURE

The stem is normally divided into node and internode regions. Blackmore and Tootill (1984) considered node as a point on the stem at which one or more leaves arise and internode as the part of stem lying between two adjacent nodes. A related subdivision of the stem is the phytomere, defined as a developmental unit consisting one or more leaves, the node to which the leaves are attached the internode below the node and one or more axillary buds (Taiz and Zeiger 2002). Node, internode and phytomere concept do not lend themselves well to analyse and intermediate region between the shoot apical meristem and the mature stem (Meicenheimer 1992).

The behaviour of protoxylem strands in the young stem may not correlate with node type (Beck 1962, Kumari 1963, Benzing 1967, Gibson 1994) and treating nodes of young and old axis parts in flowering plants sometimes may give an impression as if they had a modified siphonostele.

The vascular cylinder of the shoot axis shows different patterns at the nodes and internodes. This distinction is very difficult to study in monocotyledons because of the scattered nature of vascular bundles, but has been worked out in detail among dicotyledons, where the vascular bundles are arranged in a ring. The vascular cylinder is more complex at node than at internodes because of the presence of
lateral appendages, the leaves and branches. The vascular tissues form an almost continuous cylinder at nodes in dicotyledons. The vascular bundle that extends from stem to leaf is known as leaf trace.

Metcalfe and Chalk (1950) mentioned that the stem of *Lathyrus* and *Vicia* have special features, stems of *Lathyrus* species are flattened on one side providing two wings, each containing a vascular bundle. Rudall (2000) found that the vasculature of the internodal region of the stem is arranged in a cylinder of separate or fused collateral bundle in *Vicia faba* and some stems have cortical or medullary bundles which may be with leaf vasculature.

Metcalfe and Chalk (1979) and Hegde and Tilak (1982) described three trace trilacunar node as the third type. Minu and Murty (1991) studied nodal vasculature in *Leucaena leucocephala* and the first foliar node was three traced trilacunar with two intrapetiolar stipules and the axillary bud is supplied by the vascular tissue on either side of the median leaf gap.

Gupta and Murty (1986) recorded that there are two cortical bundles originating from the cotyledonary traces and traverse up to the third node and the cortical bundles formed from the vascular ring in the nodes above the third node traversing and supplying the stipules of leaves.
Leaf anatomical features have been proved to be useful for species grouping and identification (Ogundipe 2002, Nwachukwu and Mbagwu 2006) and it has been of great importance (Dehgan 1982, Ogundipe, and Olatunji 1991).

In nodal region where a leaf trace is bent away from the vascular cylinder in the stem toward the leaf base, a region of parenchyma occur in the cylinder. This is called a leaf gap which is defined as a parenchymatous region in the vascular cylinder of the stem located opposite to the upper part of a leaf trace approximately at the level of leaf insertion.

A comparative study of the anatomy of the node throughout the angiosperms has an evolutionary significance. In the primitive conditions, traces diverge radially from the outer surface of the protostelic column without leaving gaps. Comprehensive study reveals an unusually large array of nodal vascularization pattern which is of special anatomical and evolutionary interest. It provides a basis for interpretation of the stem-node-leaf vascular continuum (Howard 1974, Dickison 1980).

Sinnott (1914) made comprehensive study of a large number of taxa belonging to Ranales and on that basis recongnized three basic types of nodes in dicotyledons viz; unilacunar, trilacunar and multilacunar. In the unilacunar node, vascular traces or trace leave the
axis to supply each leaf and produce a single gap. In the trilacunar condition there is one median and two lateral gaps associated with the traces of each leaf. And in multilacunar node there are several gaps and traces associated with each leaf.

Unilacunar node has been reported in many families such as Solanaceae, Verbenaceae, Annonaceae, Ericaceae, Apocynaceae etc. One, two, three or many traces are associated with a unilacunar node and then nodes are known as unilacunar one trace, unilacunar two trace, unilacunar three trace and unilacunar multitrace respectively. According to Sinnott (1914) the trilacunar condition is the most primitive type of node and unilacunar and multilacunar types are derived from it by reduction and amplification.

Unilacunar two trace condition was observed by Marsden and Bailey (1955), Canright (1955) and Bailey (1956) and it was recognised as the fourth type of node and was considered to be the primitive nodal type for angiosperms. Unilacunar node with two distinct traces is characteristic not only of some gymnosperms and ferns but also occur in some dicotyledons such as Verbenaceae, Solanaceae, Labiateae and Laurales.

Philipson and Philipson (1968) also mentioned that trilacunar node of *Rhododendron* is derived from unilacunar type.
Bailey (1956), Gamalei (1989), Hickey (1971, 1979) and Hickey and Doyle (1977) and Melville (1976) also considered the primitive node to be unilacunar type with two distinct leaf traces and Eames (1961), Carlquist (1961), Kull and Herbig (1994), Roth et al. (2001) strongly favoured the primitiveness of the unilacunar node with two traces.

Leaves with stipules usually have trilacunar nodes and often have blades with serrate margins. Cleastraceae with their unilacunar nodes, stipules and more or less serrate blades, seem to be an important exception, however their stipules can be the most evanescent of structures while both Perrottetia and Bhesa recently removed from Cleastraceae (now in Huerteales and Malighiales respectively) have complex nodes (Sinnott and Bailey, 1914).

In most Rubiaceae, a family characterized by its conspicuous interpetiolar stipules, unilacunar nodes are present but lateral bundles immediately split off and form a vascular ring around the stem.

In aquatic angiosperms, like Nymphaeales nodal anatomy is very complex, with a vascular plexus forming at the nodes and the internodal vascular tissue being very distinctive, even if ultimately the vasculature of leaves can be interpreted in conventional angiosperms (Schneider 1982, Moseley et al. 1987). Although many asterids especially Lamiales are commonly reported as having 1:1 nodes,
Neubauer (1977, 1978) emphasized that there is single trace often divided immediately into three or more in Lindeniaceae, Scrophulariaceae and also Cordia of Boraginaceae.

The node in seven species of umbellifers is multilacunar multitrace (Pillai and Kumar 1981). The number of traces increase from the lower foliar nodes reaching a maximum at the node bearing the largest foliage leaf and then gradually till the node bearing the inflorescence which is trilacunar three traces. In Bahuinia purpurea the distal, and proximal foliar nodes showed a trilacunar three trace condition (Dubey et al.1990).

The internodes of bamboo culms have been investigated. In contrast to the rather straightforward anatomy of the internodes, the composition and structural details of the more complex nodes have not been analysed as much (Zee 1974, Liese and Ding 1994, Ding and Liese 1995, 1997, Andre 1998). Nevertheless the nodes have special significance for culm function. Furthermore the nodal structure is important for liquid movement during drying and preservation as well as for physical and mechanical properties of culm. The functional role of nodal diaphragms is to act as braces to resist wall invagination or buckling (Nicklas 1997, 1998).

Anatomy of the foliar nodes in Euphorbiaceae has been studied by Sinnott (1914), Von Veh (1928), Reynolds (1942), Singh (1972),
Sehgal and Paliwal (1973), Bansal et al. (1982) and Thakur and Patil (2002, 2006). The nodal structure in Euphorbiaceae was unilacunar and trilacunar (Sinnott 1914, Singh 1972). Von Veh (1928) also mentioned the presence of trilacunar three trace nodes in the species of section *Anisophyllum* of the family.

Sehgal and Paliwal reported (1973) unilacunar one trace, and trilacunar three trace type of nodes in majority of species of *Euphorbia* while Sharma (1974) noted trilacunar, three trace and pentalacunar five trace condition in the node of the tribe Euphorbiaceae of the Euphorbiaceae. Thakur and Patil (2002, 2006) also reported trilacunar, three trace, unilacunar one trace and pentalacunar five trace condition in this family. Reynolds (1942) noted multilacunar multitrace nodes in *Ricinus* whereas unilacunar and trilacunar condition were observed by Bansal et al. (1982), while investigating foliar and cotyledonary nodes of *Emblica officinalis*.

Sinnott emphasized the significance of leaf trace and leaf gap in the systematics. But various anatomical and morphological features must be taken into consideration in order to understand angiosperm phylogeny. Nodal anatomy is one of the important features which have been used in the study of dicotyledonous affinity (Sinnott 1914, Ozenda 1949, Mardsen and Bailey 1955 and others). Sinnott found that nodal topography was exceedingly constant and stereo typed in the
taxa of higher rank and that most families and many others were characterized by only one of the three nodal types-uni, tri or multilacunar.

The latter observation has been confirmed by several others who have revealed considerable variation in nodal anatomy not only within different genera of one family but also within different individuals of a single species or even at different nodes of the same plant (Post 1958, Bisalputra 1962, Husson 1965, Kato 1966, 1967). These studies were primarily concerned with nodal diversity of the adult shoot but observations were extended to successive nodes of seedlings (Swamy 1949, Dickison 1969).

Takhtajan (1969,1980) postulated tri-or multilacunar type of nodal structure with double trace in median gap as the most primitive one, which has given rise to all the nodal types known presently. The trilacunar three trace node occurred in all the studied taxa except in *Phyllanthus urinaria*.

According to Larson and Isebrands (1978) a part of the nodal transition region may be referred to as the “constricted zone” because at this level each of the three traces appears to form a single, unified trace.

The vasculature of many unilacunar and trilacunar species are considered open system (Balfour and Philipson 1962, Devdas and
Beck 1971). The number of lateral traces is often variable among plants and among nodes on a plant in multilacunar species (Watari, 1934, 1939). They increase numerically in more vigorous leaves and the outermost laterals are often first to be either weakened or deleted as leaf vigor declines (Benzing 1967, Sehgal and Paliwal 1974, Hilger 1978, Neubauer 1978). These weak outermost traces often terminate blindly at some point in the stem, node or petiole. In contrast, the nodal vasculature of unilacunar and trilacunar species is remarkably stable, lateral trace in trilacunar species are rarely absent.

In eudicots and magnoliids nodal anatomy is characteristic of taxonomic groups particularly in terms of the number and arrangement of leaf traces and leaf gaps. Node may be uni, tri, or multilacunar depending on the number of leaf gaps in the stem, vascular cylinder. Sometimes the number of leaf gaps per node varies within a species or individual, usually increasing with plant size and age. The number of leaf traces departing from each gap is also generally characteristic of a species but may vary within a plant especially in species with unilacunar and trilacunar nodes. For example in *Clerodendrum* two traces typically depart from a single gap and in *Prunus* a single trace depart from each of three gaps in the central vascular cylinder. In *Quercus* upto five traces depart through a trilacunar node. Nodal vasculature is complicated by the axillary bud vascular traces; which
are connected with the main stem vasculature immediately above the leaf gaps (Rudall, 2000).

Many additional and significant taxonomic features have been derived from stem tissue. Leaf gaps and nodal anatomy are two of these useful features; they can be helpful in both herbaceous and woody plants (Dickison 1969, 1975, Keating 1970). Aspects of many different tissues in stems of rattan palms have been compared (Mathew and Bhatt 1997) as have patterns of primary vasculature in Chenopodiaceae (Al-Turki et al. 2003).

Howard (1962) stated that the petiolar anatomy is very useful in the generic level and in a few cases also at the specific level. Anatomical features of node and petioles are not correlated with any of the classification system as presented by Bentham and Hooker (1862-1883), Schumann (1891), Verdcourt (1958), Robberchet (1988, 1993a, 1993b) and Takhtajan (1997).

Howard (1974), Sharma and Pillai (1982), Larson (1984), Sharma and Pillai (1985), Dubey et al (1990) and others have emphasised the importance of study of vasculature through internode and leaf. Stem node - leaf - conitinnum in paripinnate leaves have been studied by Sharma and Pillai (1982), Pillai and Sharma (1984) and Dubey et al (1990) which indicated significant clues towards phylogenetic importance of petiolar vasculature.
Ingole and Patil (2003) studied the vasculature pattern of some Verbenaceae family members where they found petiolar anatomy to be taxon specific and useful in identification of different taxa.

Petiolar anatomy of *Cinnamomum* species has been used as an aid for taxonomic discussions (Baruah 2007).
OBSERVATIONS

The vasculature of stem, node and leaf was studied through internode, node, petiole and lamina in the following species belonging to six families of Gamopetalae.

1. *Adhatoda vasica*
2. *Helianthus annuus*
3. *Tagetes erecta*
4. *Xanthium strumarium*
5. *Zinnia elegans*
6. *Ipomoea purpurea*
7. *Nyctanthus arbor-tristis*
8. *Antirrhinum majus*
9. *Nicotiana tabacum*
10. *Petunia hybrida*

The four species of Asteraceae studied here showed three different patterns of arrangement of leaves on the stem. In *Xanthium* the arrangement of leaves is alterane (Fig. 18). Whereas in *Helianthus*, *Tagetes* and *Zinnia* the arrangement of leaves is both alternate and opposite (Fig. 8,13,24) or opposite and whorled (Fig. 23) on the stem. The upper part of plant shows alternate phyllotaxy and lower part
shows opposite decussate arrangement in *Helianthus* and *Tagetes*. In *Zinnia* the lower nodes have opposite decussate arrangement whereas the upper nodes bear whorls of three leaves. *Adhatoda vasica* of Acanthaceae shows opposite decussate type of arrangement of leaves (Fig.1,2). *Ipomoea* of Convolvulaceae shows alternate type of phyllotaxy (Fig. 30). *Nyctanthus* belongs to Oleaceae family and shows opposite superposed type of arrangement of leaves (Fig. 34). *Antirrhinum majus* of Plantaginaceae too shows opposite phyllotaxy (fig.41). *Petunia* and *Nicotiana* belong to Solanaceae family and both have alternate phyllotaxy (Figs. 45, 52).

**Adhatoda vasica**

*Adhatoda vasica* is a perennial shrub with erect stem bearing large petiolate, leaves with pointed tips. The arrangement of leaves is opposite decussate (Figs. 1,2).

**The Internode**

The internode is round to oval in shape (Fig. 55). The outermost layer as seen in transverse section is made of quadrangular thick walled cells bearing uniseriate multicellular hairs. Vascular bundles are present in a ring-like structure with about 8 large bundles interconnected with procambium and arranged almost in a quadrangle. Two large bundles closely associated with each other are seen at each angle of the quadrangle (Figs. 55-57). Cortex is broad and made of 10
– 12 cells layers. The outer 3 - 4 layers are thick walled. These cells also have chlorophyll in young stems. The cells of pith are hexagonal and broader than the cortical cells and are parenchymatous.

**The Node**

The vasculature of the axis approaching the node is represented by four large vascular groups interconnected with procambial tissue (Figs. 57,58). The axis then becomes oval and the vasculature is also drawn in the similar shape (Fig. 58). The two diagonally opposite placed bundles become two opposite bundles in the nodal plane in which the axis has broadened. Each bundle on either side in this plane leaves the axis as a leaf trace bundle (Figs. 59-62). The node is of unilacunar, one trace type (Figs. 63-66). The leaf traces enter the petiole through an arch forming a single gap. Each trace enters into the base of petiole as a large vascular arch (Fig. 64).

**The Petiole**

The outline of the petiole is semilunar with a large arch of vascular bundles (Figs. 67, 68). Small branches of vasculature from the vascular bundle of the petiole separate on either side and become small adaxial bundles (Figs. 69-70). The two vascular groups continue to enlarge and these two vascular groups merge in the lamina as lateral veins. More vascular groups separate at higher levels and supply the lamina (Figs. 70-76).
**Helianthus annuus**

The erect, herbaceous and branched plants bear simple leaves which are arranged in alternate phyllotaxy at upper nodes and in opposite decussate manner at lower few nodes. Leaves are petiolate with reticulate venation (Fig. 8).

**The Internode**

Outline of the internode is oval to spherical in transverse sections (Figs. 77, 80). Tightly packed isodiametric cells constitute the single layered epidermis which bears unicellular and multicellular hairs (Fig. 79). Inner walls of these cells are conspicuously thicker than the outer and radial walls. The 3-4 layered hypodermis constitutes collenchymatous cells which are thick walled and without intercellular spaces. Cortex is parenchymatous and 4-5 cell layered. Pericycle is present in the form of sclerenchymatous patches outside the vascular bundles. Vasculature of the internode consists of 16-18 vascular bundles which are joined together with procambial tissue and form a ring (Figs. 77-80).

**The Node**

Two bundles placed opposite to each other in the axis stele become larger than the remaining bundles of the stele (Fig. 80). These bundles prepare themselves to leave the stele, meanwhile four
bundles, two on either sides of the larger bundles, also prepare to leave (Fig. 81). The larger bundles leave the stele as two medians of the two opposite leaves. Simultaneously the four smaller bundles also leave the stele as two laterals to each leaf. Out of the two laterals to one leaf, one leave slightly at lower level than the second. The node is of trilacunar three trace type (Figs. 82-84). The alternately placed leaves also are supplied in similar manner at different nodes.

**The petiole**

The three traces to a leaf enter the petiole as separate bundles (Figs. 85, 86). Small branch from the lateral side of each lateral separate and get housed below the adaxio- lateral margins of the petiole (Figs. 87, 88). The three bundles at higher levels supply the midrib and lamina of the leaf (Figs. 89,90).

**Tagetes erecta**

The erect herbaceous stem bears pinnately compound leaves. The oblong leaflets with dentate or toothed margins are arranged in pinnately compound arrangement. The leaves are alternate in lower part of plant and opposite in upper part of plant (Figs. 12-14).

**The Internode**

The shape of internode is cylindrical with six ridges and as many alternate furrows (Fig. 91). Epidermis is present with dark
stained thick walled cells. Uniseriate multicellular hairs are occasionally seen. A ring of six large vascular bundles are present below the ridges. The interfascicular regions showed smaller bundles of patches of procambial tissue joining the larger bundles. Cortex and pith are parenchymatous. Pith cells are larger and broader. Outer 2 - 3 layers of cortex are collenchymatous with filled in intercellular spaces.

**The Node**

Six leaf traces in nodes with oppositely placed leaves depart almost at same level, three on one side and three on the other side (Figs. 92-94). In nodes bearing alternate leaves only three traces are seen at each node (Figs. 97-99). Out of the six traces of the node with opposite phyllotaxy, two laterals on one side (for the two opposite leaves) depart at almost the same level followed by the two laterals on the other side. This is followed by the median traces of the two leaves which also depart at almost same level. The median gap is filled after supplying the axillary bud whereas lateral gaps are immediately filled (Figs. 95-96).

**The Lamina**

The two laterals of each leaf travel in the cortex and enter the base of leaf separately along with the median of the leaf. The outline of the base of leaf is semilunar with two flaps on the adaxial sides (Figs. 98-102). The flaps continue to enlarge on either sides of the
lamina (Figs. 103-104). The three traces remain separate and represent the two lateral veins and midrib of the leaf lamina. Branches arise from lateral bundles to supply the lamina (Figs. 105, 106).

**Xanthium strumarium**

The branched, erect and rough stem covered with short hairs bears ovate to sub-orbicular leaves having toothed margins (Figs. 18, 19). The leaves are alternatively arranged on stem with long petioles. Leaf base is generally 3-veined.

**The Internode**

The shape of internode is wavy with three pronounced ridges alternating with as many grooves (Fig. 107). Single layered epidermis is present with thick walled cells bearing large number of unicellular and multicellular uniseriate hairs. The outer 3–4 layers are collenchymatous and remaining inner cell layers are parenchymatous. The vasculature is represented by bundles interconnected with smaller procambial tissue groups. The bundles becoming traces to a leaf are larger than the other axis bundles. Pith is very large and have broad parenchymatous cells.

**The Node**

The node is trilacunar three trace type with two laterals and one median trace. The two laterals (LT₁ and LT₂) depart one by one
followed by the median trace (MT) (Figs. 108-111). The lateral gaps are immediately filled with procambial tissue. The median gap is filled after axillary bud supply. The vasculature of each lateral trace along with the median enters the base of petiole separately (Figs. 111, 112).

**The Petiole**

The outline of petiole is semilunar (Figs. 113-116). Two small vascular groups (one from each lateral) separate on the adaxial side and get housed below the small adaxial ridge on either side. At higher levels two small bundles from abaxial sides of laterals separate and become part of the petiolar vasculature. Adaxially differentiating vascular tissue is seen at higher levels and as the petiole approaches the lamina, its vasculature is represented by one adaxial, one abaxial and two lateral large bundles (Figs. 117-120). These four bundles are alternated by small interfascicular vascular groups. The branches from abaxial and lateral bundles along with from ridges bundles supply the lamina on either sides (Figs. 121-124).

**Zinnia elegans**

The stem is erect, branching and hairy (Figs. 22,25). Two types of phyllotaxy are seen on the same branch. The upper few nodes showed whorls of three leaves each whereas lower ones had opposite decussate arrangement. The three veined simple lanceolate leaves are sessile and exstipulate.
The Internode

The cylindrical internode is almost circular to oval in outline (Fig. 125). About 20–21 conjoint, collateral open vascular bundles interconnected with procambial tissue constitute the axis vasculature. Epidermal cells are quadrangular to rectangular and thick walled. Unicellular and Multicellular uniseriate epidermal hairs are present on the axis surface. 2–3 layered (outer) collenchymatous and 3–6 layered (inner) parenchymatous cells constitute the cortex. Pith is very broad and have larger parenchymatous cells with intercellular spaces.

The Node

The nodes with opposite and whorled leaves are of trilacunar three trace type. The laterals are first to depart from the axis followed by the medians. Laterals (4 in case of opposite leaves and six in case of whorled leaves) depart almost at the same level. Similarly medians (two in opposite leaves and three in whorled ones) depart simultaneously. In Some cases a minor difference in levels of departure of laterals of 2 or three leaves and medians of 2 or 3 leaves (as the case may be) is also noticed. However, this difference is negligible (Figs. 126-136). The three traces (one median and two laterals) of each leaf travel for some distance in the cortex and enter into the base of lamina directly (as petioles are absent). The traces remain separate. The laterals supply the lamina while the median becomes part of the mid vein (Figs. 137-141).
Ipomoea purpurea

It is an annual and herbaceous climber. Simple leaves are ovate in shape with long petioles and cordate lamina bases. They are alternatively arranged on stem (Fig. 30).

The Internode

The shape of internode in T.S. is round to oval (Figs. 142, 143). The single layered epidermal cells are thick walled and darker stained. The cortex is collenchymatous (outer 2-3 layers) and parenchymatous (inner 6-7 layers). Single layered endodermis and pericycle are well developed. Pith is large and broad constituting parenchymatous cells.

The Node

Two large adjoining vascular bundles of the axis leave for a leaf forming a single gap. The two traces after running for distances in the cortex separately enter into the petiole (Figs. 144-146).

The Petiole

The two traces send two branches from their adaxio-lateral sides which get housed below the two small adaxial ridges (Figs. 148-155). Branches from the lateral sides of the large petiolar bundles supply the lamina at higher levels.
Nyctanthus arbor-tristis

It is a large shrub growing up to 3 to 3.6 m tall. The hairy and rough leaves are opposite superposed. They are simple, broad, having entire margins (Fig. 34).

The Internode

The outline of internode is quadrangular with four ridges and two furrows in the internodal plane (Fig. 156). The epidermis is single layered showing uniseriate hairs (Figs. 156, 157). Four inversely oriented (xylem towards periphery and phloem towards centre) cortical bundles are present below the four ridges. Two larger vascular bundles placed opposite to each other in the nodal plane prepare themselves to leave the axis for the leaves. The outline of axis in T.S. is seen like a dumble (Fig. 158, 159). Cortex is 6–8 layered collenchymatous and parenchymatous. 3-4 cell layers below the ridges are thick walled sclerenchymatous present against the primary xylem of the cortical bundles. Pith is broad and parenchymatous. The two opposite larger vascular bundles leave the axis vasculature to supply the two leaves.

The Node

For supplying the two opposite leaves two traces depart from the axis vasculature and the node is seen to be unilacunar one trace type. The two gaps (one on either side) such formed are filled after
supplying the axillary buds on either sides. When the two leaf traces are traversing in the cortex, branches from the cortical bundles (two on either side) are also seen moving towards these bundles. So each leaf receives three traces forming one gap in the nodal area. The node is of unilacunar three trace type (Figs. 159-167). The gaps are filled after bud supply have separated from the axis (Fig. 168).

**The Petiole**

The leaf trace from the axis flanked by two branches of cortical bundles on either side enter into the bases of petioles of leaves placed opposite to each other. The outline of the base of the petiole is semilunar with two adaxial flaps (Figs. 169-172). The three traces fuse at higher level and the vasculature of the petiole forms an arch (Fig. 173). Branches, separating out in the form of small bundles from the lateral sides of the arch, supply the leaf lamina (Figs. 174-176).

*Antirrhinum majus*

It is an erect, herbaceous and perennial plant. Stem is green and glabrous. The arrangement of lens shaped simple leaves on the stem is opposite (Fig. 40,41).

**The Internode**

The shape of internode is rounded to oval (Fig. 177). Epidermis is single layered. 3-4 layered cortex is present, which is parenchymatous.
Vascular bundles are arranged in a ring-like structure with longitudinal furrows which are occupied by procambial tissues. Pith is small and parenchymatous.

**The Node**

The axis becomes oval prior to nodal region (Fig. 178). Three large adjoining vascular groups on either sides of the nodal plate and placed opposite to each other come closer and start preparing to depart from the axis as vasculature of the two opposite leaves at the node (Figs. 179-180). These become two composite large bundles (one on either side) and leave the axis in the nodal region (Figs. 181-184). They leave two gaps (one on either side) and the node is of unilacunar one trace (originated from 3 vascular groups) type. The axis vasculature supplies the axillary buds on either sides before the leaf gaps are filled in by differentiation of procambial tissue.

**The petiole**

The leaf trace enters the base of petiole in the form of a large arch (Fig. 185). The base of rachis is semilunar and the vasculature fits in to this shape. From either sides of the vascular arch branches separate and supply the lamina (Figs. 186-188).

*Nicotiana tabacum*

It is an annual and little branched herb with erect and hairy stem bearing rounded and oval shaped leaves which are arranged in alternate phyllotaxy (Fig. 45).
The Internode

The shape of internode is oval to circular (Fig. 189). The single layered epidermis is present which bears unicellular and uniseriate multicellular hairs. The cortex is collenchymatous but outer 2-3 layers are collenchymatous. The vasculature is represented by continuous rings of xylem and phloem separated by 2–3 layered cambium.

The Node

Two vascular groups of the axis prepare themselves as a large arch below the nodal region. This large arcuate vascular group leaves the axis in the nodal region forming a large leaf trace and leave a single leaf gap which is filled in after supplying the axillary bud (Figs. 191, 198). So the node is of unilacunar one trace type. The semilunar base of petiole with large arcuate vascular bundle separates from the axis and remain in the similar structure at higher levels also (Figs. 199-204). Branches from the lateral sides of the midrib bundle (the arcuate bundle from the petiole continues as midrib vasculature) separate and supply the lamina at higher levels.

*Petunia hybrida*

It is an annual, erect and hairy stem bearing simple leaves which are ovate to oval and arranged in an alternate phyllotaxy (Fig. 52).
The Internode

The outline of internode is round (Fig. 205, 206). Single layered epidermis consisting of isodiametric thick walled cells is present. It is covered with large number of unicellular and multicellular uniseriate hairs. Cortex is both collenchymatous (outer 2–3 layers) and parenchymatous (inner 5-6 layers). Pith is broad with broader parenchymatous cells having larger intercellular spaces. Axis vasculature is represented by a ring of conjoint, collateral and open cylinder which showed 3 vascular bundles becoming larger below the nodal region.

The Node

The axis becomes almost oval. The vasculature of the alternate leaves start departing and leaves single gap at the node (Figs. 207-212). The gap is filled by the procambium after supplying the axillary bud (Fig. 211-212). The axis outline becomes oval at this stage (Fig. 213). The leaf trace enters the base of petiole in the form of a large arch. The outline of petiole is semilunar. The large arcuate petiolar vascular bundle becomes the vasculature of midrib and supplies the lamina through lateral branches (Figs. 214-216).
DISCUSSION

The course of vasculature from internode through node and leaf was studied in all the ten species of the gamopetalae belonging to six families.

1. *Adhatoda vasica* Acanthaceae
2. *Helianthus annuus* Asteraceae
3. *Tagetus erecta* Asteraceae
4. *Xanthium strumarium* Asteraceae
5. *Zinnia elegans* Asteraceae
6. *Ipomoea purpurea* Convolvulaceae
7. *Nyctanthus arbor-tristis* Oleaceae
8. *Antirrhinum majus* Plantaginaceae
9. *Nicotiana tabacum* Solanaceae
10. *Petunia hybrida* Solanaceae

The ten species of six families studied here showed various kinds of phyllotaxy. An alternate pattern of leaf arrangement was shown by *Ipomoea* (convolvulaceae), *Nicotiana and Petunia* (Solanaceae) and *Xanthium* (Asteraceae). Remaining six species showed different kinds of opposite phyllotaxy. An opposite decussate pattern is present in *Adhatoda* and *Antirrhinum*. While opposite superposed arrangement is seen in *Nyctanthus*. In *Helianthus, Tagetus* and *Zinnia* lower few
nodes showed opposite decussate phyllotaxy while upper nodes showed alternate in the former two species and whorled arrangement in *Zinnia*. All the four species of Asteraceae showed the trilacunar three trace nodal condition irrespective of the type of phyllotaxy. Whereas remaining six species of the five families showed unilacunar types of nodes.

However the unilacunar node is with one trace in *Adhatoda vasica*, and *Petunia hybrida*; with a compound bundle of two vascular groups in *Antirrhinum majus* and *Nicotiana tabacum*; with two traces in *Ipomoea purpurea* and accompanied by two cortical bundles from the axis in *Nyctanthus arbor-tristis*. On the basis of number of traces to a leaf and formation of leaf gaps in the axis the studied species may be arranged in a tentative forked line key as described on last page of this chapter.

*Nyctanthus arbor-tristis* showed cortical bundles which have been treated as leaf traces by earlier workers. In *N. arbor-tristis* each leaf is vascularised by three traces, but they have two different origins. The median originates from the same nodal area whereas the cortical bundles enter as laterals to the leaf. Narang (1978) studied nodal anatomy of *Crotalaria burhia* and stated that the vascular supply of the leaf was interesting in that the leaf traces after their separation from the central cylinder at a node traverse two successive internodes before entering the nodal leaf. Due to this, in transverse sections of
internode, extrastelar bundles are seen. Earlier Pillai et al. (1970) also reported *C. burhia* that the lateral and median traces are derived from two vascular systems, the median from the central vascular system and laterals from the outer vascular system which consists of a few concentric bundles. The nodal vasculature studied in *Nyctanthus*, however broadly confirms with these observations. However, the outer vascular system here consists of four inverted collateral bundles. Narang (1978) studied the successive nodes and found that the outer vascular system is due to the leaf traces originated at the previous nodes. She observed that both median and laterals were contributed by the lateral traces constituting the outer vascular system. In *Nyctanthus* the median comes from the central vascular system and laterals are contributed by the outer vascular system, the cortical bundles. *Nyctanthus* showed quadrangular stem with four cortical bundles which are inversely oriented. Narang (1978) observed 6-9 vascular bundles outside the central cylinder. She however, did not treat these leaf traces bundles as cortical as they remained enclosed within the endodermis till they separated into their respective leaves in the nodal region. Metcalfe and Chalk (1950) who stated that cortical vascular bundles occured in a few species of Papilionaceae which had winged or grooved stems. Narang (1978) observed presence of meristematic activity below the protoxylem of cortical bundles making it appear surrounded by secondary tracheidal cells on the inner and lateral sides.
However Pillai et al. (1970) found the cortical bundles, which were treated as leaf traces, became concentric during secondary growth. No such meristematic activity was observed in the cortical bundles *Nyctanthus* studied here.

Anatomical characters have been employed for systematic purposes well over a hundred years (Dickison, 1975). Earlier Metcalfe (1968) stated that anatomy of the vegetative organs of flowering plants could be taxonomically useful. Depending upon whether one, three or five or more leaf gaps are left in the stele by the departure of leaf traces to the leaf, nodes are described as unilacunar, trilacunar, or multilacunar. The nodal pattern is often expressed in terms of the number of traces and gaps. Accordingly different types of nodal patterns are seen in the nine species of gamopetalae studied here.

Sinnott (1914) observed that trilacunar nodes occurred in majority of dicotyledons. Howard (1970) stated that multilacunar nodes were relatively uncommon in dicotyledonous families, but were found in members of primitive orders such as Magnoliales, Piperales and Trochodendrales, and advanced orders such as Umbellales and Asterales. The unilacunar node had an interesting distribution, namely, the Laurales, Caryophyllales, Ericales, Diapensiales, Ebenales, Primulales, Myrtales and a majority of the families in the Asteridae. The data presented here are in agreement with this as different variations of unilacunar nodal pattern are also observed in the species
of five families studied here. But all Asteraceae members studied here are not in accord with Howard's observation as the four Asteraceae species exhibited trilacunar three trace nodal pattern.

Nodal anatomy had assumed much importance in discussion relating to angiosperm phylogeny. Sinnott (1914), Ozenda (1949), and Marsden and Bailey (1955) and Canright (1955) considered trilacunar, multilacunar and unilacunar two trace nodes respectively as primitive. Takhtajan described trilacunar or multilacunar with two traces diverging from the median gap as primitive. Dickison (1975) stated that primary evidence used to support the primitive nature of the unilacunar two trace node as its occurrence (or modifications thereof) in members of the Magnoliideae, (Calycanthaceae, Lactoridaceae, Illiciaceae, Amborellaceae, Lauraceae, Chloranthaceae, Monimiaceae, Austrobaileyaceae, Schisandraceae and Trimeniaceae), the distribution of this type in vascular plants other than angiosperms, and its presence in the cotyledonary node of many dicots even though the mature foliar nodes of the same plants may be tri or multilacunar. But the nine species of gamopetalae studied here showed trilacunar and unilacunar (including unilacunar double trace) nodes in the mature foliar branches. The gamopetalae are generally considered at higher position in the evolutionary ladder (particularly based on external morphological characters). The data present interesting trends and indicate the need of wider investigation on these lines.
A. Only one trace to each leaf
   \[A_1\] Single large vascular group forming one trace; node
   is of unilacunar one trace type
   \[A_2\] Leaves alternate........................................... *Petunia*
   \[A_3\] Leaves opposite decussate................................... *Adhatoda*
   \[A^1_1\] Two large vascular groups forming one trace; node
   is of unilacunar one trace type
   \[A^1_2\] Leaves alternate........................................... *Nicotiana*
   \[A^1_3\] Leaves opposite........................................... *Antirrhinum*

B. More than one trace to a leaf
   \[B_1\] Two traces to a leaf; node is of unilacunar double
   trace type.......................................................... *Ipomoea*
   \[B^1_1\] Three traces to a leaf forming one or three gaps in
   one nodal area of the axis vasculature
   \[B^1_2\] One leaf trace forming one gap in the axis whereas
   two traces coming from the cortex superposed
   leaves arranged in opposite phyllotaxy........... *Nyctanthus*
   \[B^1_3\] Three traces forming three gaps in one nodal
   area of the axis vasculature
   \[B^1_4\] Leaves arranged in alternate phyllotaxy...... *Xanthium*
   \[B^1_5\] Leaves arranged in both alternate and
   opposite phyllotaxy on the same plant.
   \[B^1_6\] Lower nodes have opposite while upper
   nodes have whorled arrangement....... *Zinnia*
   \[B^1_7\] Lower nodes have opposite while upper
   nodes have alternate arrangement
   \[B^1_8\] Leaves simple ....................... *Helianthus*
   \[B^1_9\] Leaves compound................. *Tagetes*