Contributions towards a Knowledge of the Anatomy of the Genus Selaginella.

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With Plates XX and XXI.

PART IV. THE ROOT.

THE most important contribution to our knowledge of the anatomy of the root-system of *Selaginella* is that contained in Nägeli and Leitgeb's well-known monograph (2). Hofmeister, it is true, makes a brief reference to the subject (1), but confines his remarks to certain general points with regard to the origin and branching of the roots. He speaks of adventitious roots arising at the forkings of the stem in such species as *S. denticulata*, *helvetica*, *Martensii*, &c., either generally throughout its length or on the basal region of the stem only. The root, Hofmeister says, arises in the axil of the ventral leaf situated at the forking of the shoot axis, and from the outer side of the cross-band which unites the vascular systems of the two branches (e. g. in *S. denticulata*). The roots branch freely, the first forking being in the plane of the leaf in whose axil the root arises, and the second branching being at right angles to the first. Hofmeister also draws attention to the swelling

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that occurs at the end of the aërial portion previous to the first bifurcation. He gives no detailed account, however, of the anatomy of the root.

Nägeli and Leitgeb's researches lay the foundation of our knowledge of the anatomy of the roots, and as their observations and conclusions have been called in question by more recent investigators, it may be advisable to summarize their results at somewhat greater length. Their observations were apparently made on four species, viz. *S. Kraussiana*, *S. Martensii*, *S. cuspidata*, *and S. laevigata*. They commence by calling in question the accuracy of applying the term 'root' to the organs arising at the branchings of the stem, and point out that a root-cap is absent from the apices of such organs. They further express the belief that these bodies are in reality cauline in their homology, giving them the name of 'rhizophores' (*Wurzelträger*). Despite the fact that several authorities have brought forward evidence and arguments against this view, the name is still commonly employed in textbooks, &c., to designate the unbranched aërial portion of the root in such species as possess such organs. In the present paper the rhizophore is designated as the 'aërial part of the root,' and that portion which is embedded in the soil as the 'subterranean part.' The rhizophores, according to Nägeli and Leitgeb, originate on the upper side of the stem, near the base of the weaker branch, arching round towards the ground on that side. Following the system of bifurcation of the stem they arch alternately to right and to left, and occur at all the points of branching of the stem. In *S. Kraussiana* two rhizophores are occasionally given off, the accessory rhizophore arising close to the normal one from the upper side of the stem, but at a little distance from the branch, and bending round the stem on the other side. No root-cap is apparently developed at this stage. The rhizophore is at first circular in section, but later becomes elliptical, the long axis of the ellipse being parallel with the long axis of the stem. The apex of the rhizophore is occupied by a two-sided apical cell, giving off segments on the backwardly directed faces. Divisions of the apical cell cease when the rhizophore is about 1 mm. long, and by rapid divisions of the segments the apex swells and differentiation takes place within, so as to give rise to the true roots which at this stage do not exhibit further development. The cells of the swollen apex have their walls thickened, and they are filled with watery contents. Intercalary growth now becomes energetic, so as to bring the apex of the rhizophore into contact with the soil. The cells of the apex become disorganized, and the apices of the true roots enter the soil covered at first by a homogeneous slime derived from the disorganized apical cells.

In section the rhizophore exhibits a clearly marked cortex, whose cells are sclerotic save in the innermost layer, and a central vascular system. The first vascular elements arise centrally in *S. Kraussiana*; scalariform elements develop round these, and are surrounded in turn by three to five layers of small cells. The vascular cylinder of the rhizophore arises from the vascular strand of the stem of the same side at or near the conjunctive strand. The markedly centrifugal development of the vascular system in the rhizophore of *S. Kraussiana* is, according to Nägeli and Leitgeb, a unique feature.

In *S. Martensii* one rhizophore (the lower one) is alone developed, although occasionally the upper one is also. The latter is always represented by a swelling. The vascular bundles of the rhizophores unite in the stem and run parallel with its long axis to the point of bifurcation of the stem, and there unite with the cylinders of the branches. The air-space of the stem-cylinder is continued up through the rhizophore for a short distance. Nägeli and Leitgeb believe that the rhizophores are independent in origin. In the case of the true root the development of the protoxylem is lateral. Where the root branches the protoxylems face each other, hence the bundles undergo torsion to the extent of 90 degrees. Branching of the vascular cylinder takes place before the forking of the root itself, hence the end of the unbranched rhizophore contains two vascular cords. These authors compare the two cords with opposing protoxylems with the centroxylic condition of the rhizophore in *S. Kraussiana.* The planes of branching are always at right angles in *S. Martensii.* The root-cap is small, and is ultimately thrown off.

In *S. cuspidata*, Lk., and *S. laevigata*, Spr., there are no rhizophores, and the roots arise directly from the bifurcations of the stem. They differ from rhizophores in not arising at every bifurcation. The vascular system is a monarch strand with one lateral protoxylem. Pfeffer, in his paper on the development of the embryo of *Selaginella*, draws attention to the occasional development of the upper rhizophore into a leafy branch in *S. inaequalifolia* (3). Van Tieghem (4) describes the vascular bundle of the rhizophore as triangular in section, and so orientated that the protoxylem faces the ground if the stem be placed in an erect position. He also draws attention to the change in orientation of the bundles at the forkings. The so-called rhizophore Van Tieghem considers as a case of exaggerated intercalary growth of the aërial part of the root, and dissents from the view held by Nägeli and Leitgeb as to the cauline value of the organ. Russow (5) says that the so-called rhizophores and roots agree in anatomical structure, and holds the same view as Van Tieghem as to their morphological value. Division of the monarch bundle takes place in the aërial part before any appearance of external division. The xylem first of all broadens, and division takes place in the protoxylem first. The xylems suffer torsion through 90 degrees at the forkings both of the aërial and subterranean parts. In this relation it is interesting to note that Scott and Hill (10), in their paper on the anatomy of *Isoetes Hystrix*, remark that 'as the two strands (at the root-fork) separate from each other, they turn through an angle of 90 degrees so as to direct their protoxylems towards each other.'

Dangeard (6) describes and figures the central protoxylem of the rhizophore of *S. Kraussiana*, and says that a similar centroxylic condition occurs between the spore and the first two leaves, but he does not figure it. He gives no details of the anatomy of the root in any of the species which he discusses, but gives a short general summary, which, however, adds nothing to what had been previously known.

In a paper on *S. lepidophylla*, Wojinowić (8) says that there are no rhizophores in that species, that the roots arise directly from the stem, and without any relation to the branching of the axis. The root in this species shows in transverse section an epidermis with two or three layers of thin-walled hypodermis, followed by five or six layers of sclerenchyma, an endodermis, pericycle and normal-monarch vascular strand.

Bruchmann (9), in his monograph on *S. spinosa*, adds no new points beyond drawing attention to the occurrence of symbiotic fungal hyphae in the roots. He adds that this species and *S. Lyallii* are destitute of root-hairs.

In passing, it may be pointed out that Bruchmann, in describing the curious centroxylic condition of the vascular system in the creeping part of the stem, remarks: 'wie es bisher noch von keinem Stengel der Gattung *Selaginella* bekannt war.' Bruchmann's paper was published in 1897, but I may perhaps be permitted to point out that I described and figured that condition in this species in 1894 (11).

In the accounts of the root-system in the genus *Selaginella* given in the textbooks, it is customary to distinguish the unbranched aërial portion of the root as a 'rhizophore,' and to retain the term 'root' for that part which is underground and bears a root-cap and root-hairs. It would seem advisable at the outset to determine whether that nomenclature, and the views on which it is founded, can be maintained.

The chief arguments advanced in its favour are those of Nägeli and Leitgeb, who claim that the aërial part of the root is of cauline value on the ground that it has no root-cap, that it is occasionally transformed into a leafy branch, and that it arises exogenously whilst the true roots are developed from it later endogenously. This view is combated by Van Tieghem (4) and Russow (5).

In studying the comparative morphology of the root it is instructive to note that a complete series of transitions may be obtained in the different species, with *S. spinosa* at one end of the series and a typical 'rhizophore' bearing type such as *S. Martensii* or *S. Galeottei* at the other. In *S. spinosa* it will be seen that the roots arise directly from the base of the stem which is itself exceedingly delicate. Indeed the root-system in this species is out of all proportion to the comparatively massive and much branched aërial portion, and points to the important part which the lower prostrate branches play in absorption. *S. spinosa* is, indeed, largely saprophytic in habit. This characteristic is emphasized by the frequent occurrence of symbiotic fungal hyphae in the cortical cells of the root, as observed and figured by Bruchmann. On two or three occasions I have seen evidence of the presence of these symbiotic hyphae in the creeping part of the stem also. In *S. oregana* the roots spring not only from the base of the stem but also from the lower region generally, where the shoots are in contact with the tree on which this species is epiphytic. This basal origin of roots and absence of so-called rhizophores is characteristic of types where there is a short rhizomic part with numerous erect axes, e. g. *S. grandis*, *S. erythropus*, *S. Vogelii*, *S. Karsteniana*, *S. haematodes*, &c., and of those species which show a dense tuft of aërial erect axes arising from a short rhizomic basis, e. g. *S. involvens*, *S. pilifera*, &c. In *S. Braunii* and *S. Lyallii* the basal part of the stem is longer and more in the nature of a rhizome, and the roots arise from the under side of the rhizome, branching at once in the soil.

In forms like *S. Kraussiana*, *S. serpens*, *S. delicatissima*, &c., the stem is procumbent, grows parallel with the ground and a short distance from it. In these cases the aërial portions of the root are necessarily longer, and it is to this aërial part that the term 'rhizophore' is applied. In *S. Galeottei*, *S. caulescens*, *S. Martensii*, &c., the stem is at first procumbent and then becomes semi-erect. The roots have correspondingly short aërial regions below, but these become longer as the stems become more and more erect. From the point of view, therefore, of general external morphology there does not seem any stronger reason for distinguishing the aërial part of the root by a special name and ascribing to it stem-characteristics than there exists for differentiating the aërial part of the root of a *Pandanus* or a *Rhizophora* from that which is subterranean or subaquatic.

As a rule the root is intimately related to the branching of the stem, and normally one root arises from the stem at each fork. There is frequently an abortive root on the upper side of the stem, which scarcely appears above the surface, or is represented by a minute papilla, as in *S. Martensii*, *S. Willdenowii*, &c. Occasionally both roots are developed, e. g. *S. caulescens*. In *S. inaequalifolia*, as Pfeffer points out, the upper, usually abortive, root develops into a leafy shoot, and on that ground an argument is based for the cauline value of the aërial portion of the root. On the other hand, roots, as is well known, not infrequently bear both leaves and leaf-buds; and further, as Jones has pointed out in the allied genus *Lycopodium* (11), the differentiation between root and stem is far less marked in the vascular cryptogams than in higher plants, and consequently the organ in question may, without undue violence to morphological conceptions, be conceived as having a preponderance of cauline or radical characteristics according to circumstances. Pfeffer also draws attention to the neutral nature of the aërial part of the root. Another explanation is, however, possible, suggested by the condition of the roots in *S. Lobbii*. Normally, in this species, there is one aërial root developed at each forking of the stem, and that the lower one. The upper root is represented as usual by a papilla. Frequently, at all events in the material I possess, the upper root-papilla is replaced by a leafy branch; but at a short distance from its point of origin there is given off an aërial root which behaves exactly in the same manner as the lower aërial root. The question thus arises whether the leafy shoot of *S. inaequalifolia* and other species which possess this abnormality is not a genuine shoot, proliferating at the normal bifurcation, which is not robust enough to bear a root on its own account. In *S. Lobbii* the dorsal papilla may, apparently, either develop into a third proliferous shoot giving rise to a root, or the root may arise from the papilla directly, the intermediate shoot being suppressed.

Another argument advanced by those who uphold the stem-nature of the aërial root is that it is exogenous in origin and bears no root-cap. I have not as yet proceeded far enough with my own investigations into the origin of members in the genus to offer an independent opinion, but it has been shown by Van Tieghem (12) that no great weight can be laid on this argument, since neither in regard to exogenous origin nor absence of root-cap is *Selaginella* exceptional. Anatomically, it will be seen from the present paper that the aërial and subterranean parts of the root exhibit practically identical features. On all these grounds, therefore, I follow Van Tieghem in considering the root of *Selaginella* as in some cases subterranean only, in other cases partly subterranean and partly aërial, developed at the base of the stem only, and without relation to the branching of the stem, or at the bifurcations of the stem, sometimes singly and either from the dorsal or the ventral side, or both from the dorsal and ventral sides.

Anatomically the root in *Selaginella* shows comparatively little variation, being, in the great majority of cases, composed of a more or less sclerotic cortex covered externally by two or more layers of thin-walled cells, the most external of which is piliferous. These superficial layers are absent from the aërial parts of the root. The vascular cylinder is enclosed by a usually well-marked endodermis and a two- or three-layered pericycle, and consists of one xylem and one phloem bundle. It will be most convenient to study the structure of the root in one species somewhat in detail, and thereafter add such further notes as may be necessary in explanation of the variations in anatomical structure seen in other species.

S. atroviridis, Spr., was found a convenient type for examination, as being fairly robust and possessing the morphological characters most commonly met with in the genus.

The roots arise singly at each forking of the stem, and are partly aërial, party subterranean. The root is at its origin about equal in thickness to the weaker branch, and at once bends downwards and backwards. On the upper side of the stem there also arises at each forking a papilla which represents an abortive root. The branching of the root is dichotomous, the first forking being in a plane at right angles to the long axis of the stem, the next at right angles to the first and so on for several divisions, until external conditions interfere with the regularity of the branching (Pl. XX, Fig. 2). The vascular cords of the root are inserted on those of the larger branch, apically to the point of origin of the minor branch (Fig. 1). The vascular cord of the dorsal abortive root arises behind the point of origin of that of the functional root, its xylem ending halfway through the cortex of the branch. The lacuna surrounding the vascular system of the stem is continued up the vascular cords of the roots, both dorsal and ventral, for a short distance. A transverse section of the root in its unbranched portion shows a crescentic vascular cord with the protoxylem in the concavity. The protoxylem is broken up into patches in the larger bundles and distributed round the concave side (Fig. 4). The outer cortex is strongly lignified, but becomes less so inwards, again becoming lignified as the endodermis is approached. In the younger roots the endodermis shows the usual radial markings, but as age advances the cuticularization becomes complete. The pericycle is from two to four layers thick. There is one row of sieve-tubes (or, more rarely, two) round the convex side of the cord ending at the tips of the horns of the xylem. Three to four layers of phloem-parenchyma completely envelop the xylem. In young roots the crescentic form of the xylem is not so well marked, and the horns approximate so that the protoxylem becomes almost enclosed.

The convex side of the bundle faces the apex of the stem, and the branching of the vascular cord of the root takes place before external branching. At the forking of the root the vascular bundles of the branch-roots undergo a change in orientation, so that the concave faces of the branch-bundles oppose each other. This alteration of the axis of the bundles has already been pointed out by several observers and seems to be a general rule for the genus. Unicellular root-hairs occur right up to the caps of the young roots.

Although there are some slight individual differences in the structure of the cortex, the development of the endodermis and in the amount of extension of the protoxylem, the structure just described for *S. atroviridis* holds good for the great majority of the species I have examined. There are, however, a few points of interest which may now be alluded to.

Approaching quite closely to the type are the roots of *S. plumosa*, Bak., *S. Martensii*, Spr., *S. Douglasii*, Spr., *S. serpens*, Spr., *S. apus*, Spr., *S. convoluta*, Spr., *S. albonitens*, Spr., *S. flabellata*, Spr., *S. producta*, Bak., *S. bisulcata*, Spr., *S. concinna*, Spr., *S. uncinata*, Spr., *S. molliceps*, Spr., *S. Vogelii*, Spr., *S. patula*, Spr., *S. haematodes*, Spr., *S. Karsteniana*, A. Br., *S. grandis*, Moore, *S. erythropus*, Spr., *S. Braunii*, Bak., *S. pilifera*, A. Br., *S. viticulosa*, Klotz., and *S. caulescens*, Spr. In this last-named species the cortex is very sclerotic, and the endodermis becomes greatly thickened towards the pericycle. Both pericycle and phloem-parenchyma may become sclerotic in very old roots.

In *S. involvens*, Spr., the roots arise from the bases of the closely growing stems and enter the ground at once. Anatomically the root is peculiar as regards its cortex. Superficially there is a layer of cubical cells, each of which gives off a root-hair. This layer is followed by a layer of large cells ovoid in section and very regularly placed, and that by a small-celled cortex, small-celled outwardly but becoming larger inwards, and bounded internally by a well-marked endodermis. The vascular cord is normally monarch. *S. cuspidata*, Lk., and *S. lepidophylla*, Spr., agree in all points of structure with *S. involvens* (Pl. XX, Fig. 5). All the above-mentioned species are monostelic so far as their stem-structure is concerned. There are two other species, both belonging to the monostelic type, which exhibit a somewhat peculiar anomaly. In *S. helvetica*, Lk., the cortex is similar to that of *S. involvens.* The vascular cylinder of the stem is ribbon-shaped with two marginal protoxylems, one situated at each margin of the stele. At the point of origin of the vascular cylinder of the root the protoxylem becomes internally placed so that the stele shows on one side a perixylic, on the other a centroxylic structure (Pl. XX, Fig. 19). The same peculiarity is shown by *S. denticulata*, Lk., a species which has otherwise a normal structure.

Turning now to the homophyllous species, *S. spinosa*, P. B., *S. oregana*, Eat., and *S. rupestris*, Spr., it will be found that in the case of the two last-mentioned species the root is normally monarch, save that, as in the case of the stem, the metaxylem consists chiefly of tracheae or vessels (i. e. cell-fusions). The root is covered externally by two layers of thin-walled cells with root-hairs, followed by four to eight layers of thick-walled cells with brown tannin-like contents, two to three layers of thin-walled cells, very liable to be torn through in the process of cutting, and a prominent and completely cuticularized endodermis. The vascular system is poorly developed (Pl. XX, Fig. 6). *S. rupestris*, Spr., agrees with *S. oregana* in all respects. The centroxylic condition of the creeping part of the stem of *S. spinosa*, P. B., has already been described by the present writer (10), and later by Bruchmann (8). It is worth while pointing out, however, that the stem, for some considerable distance before the point of origin of the roots, contains two vascular cylinders, both centroxylic. The root is normally monarch, as figured and described by Bruchmann, to whose description I have nothing to add.

With regard to the bistelic species it may be said generally that the root-structure is, in most respects, similar to that already described for the monostelic species. In *S. Galeottei*, Spr., the aërial part of the root is very long, and one root arises at each fork of the stem on the upper side and bends over behind the lesser branch downwards to the soil. The vascular cylinder of the root arises just in front of the origin of the lateral branch and far behind the point of fusion of the steles of the main axis. The aërial and subterranean parts of the roots both contain normal-monarch cords. Root-hairs are abundant. *S. rubella*, Moore, agrees in all essential respects with *S. Galeottei*.

In *S. Kraussiana*, A. Br., the roots arise singly at each forking of the stem on the upper side and arch over to the side of the stronger branch. Since the branches are alternately right and left, the roots are alternately left and right. Each is unbranched until it reaches the soil and then it branches profusely. Anatomically the vascular cylinder of the aërial part arises from the vascular system of the stem at the junction of the stem-cords. The aërial portion, as has been already pointed out by several authors, is centroxylic (Pl. XX, Fig. 17), and remains so until the subterranean parts are reached when the root becomes normally monarch. *S. Kraussiana* has hitherto been regarded as the solitary exception in this respect. *S. Poulteri*, Veitch, and *S. delicatissima*, A. Br., however, show precisely the same centroxylic condition in the aërial roots, like *S. Kraussiana* becoming monarch in the subterranean portions.

Turning now to the species usually designated as tristelic, it may be said that they agree in almost all respects with the majority of the species already described in the monarch character of their root-cylinders.

The root of *S. canaliculata*, Bak., in its aërial part shows a slightly crescentic xylem and a protoxylem situated in the middle of the crescent. The mode of origin of the steles of the root is as follows :—From the upper and lower steles of the stem vascular strands are isolated (Pl. XXI, Fig. 24, 1), then one from the middle strand, and at the same time one for the ventral leaf (2) ; the middle stele then broadens and forks and a strand is given off the lower stele (3); the upper stele then bends down and unites with the upper branch of the fork of the middle stele, the lower branch uniting with the offset of the lower stele (4). The middle stele is now isolated and the fork portion is still united with the upper stele (5) ; the three steles of the lateral branch are thus distinct. The vertical strand divides into an upper part which goes to the upper root and a lower part which goes to the lower and functional root (6, 7). As in *S. helvetica*, the upper and middle steles of the stem, before giving off the strands to the vertical band which supplies the roots, become centroxylic on that side, again becoming perixylic when the root-strands are isolated.

In *S. Wallichii*, Spr., the roots are very short and not related in all cases to the branching of the stem, but generally arise from the under side of the rhizome just at the junction of the minor and major branches, but from the latter. The stele of the aërial root in section is similar to that of *S. atro-viridis*, save that the protoxylem is almost isolated from the xylem. The endodermis is well defined, the pericycle is two or three layers thick, and there are abundant root-hairs right up to the margin of the root-cap.

In the general anatomy of the root similar features to those exhibited by *S. Wallichii* are shown by *S. chilensis*, Spr., *S. viridangula*, Spr., *S. Victoriae*, Moore, *S. inaequali-folia*, Spr., and *S. gracilis*, Moore. In *S. Willdenowii*, Bak., the root arises as in *S. Wallichii.* There is an abortive root on the upper side of the stem, which has a small prominence of vascular tissue arising from the strand of the functional root near its junction with the stele of the stem. The lateral branch is isolated farther back. The abortive root, as in *S. inaequalifolia*, is sometimes functional. The xylem of the root-stele is slightly crescentic, with the protoxylem almost isolated from the xylem but accompanied by some meta-xylem. The subterranean part of the root is normally monarch with a sclerotic cortex and plentiful root-hairs. *S. laevigata*, Baker, var., *Lyallii*, Spr., which exhibits so many anomalies in its stem-structure, is normal in its root-structure. The roots arise singly at the bases of the erect shoots, and their vascular strands are inserted on the cylindrical stele of the rhizome.

In *S. Lobbii*, Moore, the only other species which I have examined in detail, the roots arise at the forkings of the stem, but not at all of them. The roots are developed at each fork, the ventral one becomes functional but the other develops into a leaf-bearing shoot. The functional root forks at a variable distance from the stem in a plane at right angles to the long axis of the stem, the next forking taking place at right angles to the previous one, and so on. The dorsal papilla develops in most cases into a leafy shoot from which at its base a functional root arises (Pl. XX, Fig. 11). A section taken between the origin of the root and the main axis shows a central cylinder with an extended protoxylem and a slight lacuna. Just before the origin of the root the protoxylem breaks up and is distributed round the metaxylem. Beyond the point of origin of the root the stele differentiates into the usual three steles of the ordinary branch. A transverse section of an old aërial root shows a well-marked epidermis, a slightly sclerotic external cortex, followed by a thick cortex of large elongated cells. The stele has an endodermis with radial cuticularization, a pericycle three or four cells deep, then one or two rows of sieve-tubes followed by three or four layers of phloem-parenchyma. The xylem forms a crescentic band of scalariform and sometimes reticulate fibres, the largest elements being on the convex side, viz. that towards the apex of the shoot from which the root arose. The phloem-parenchyma turns the horns of the crescent and is continuous with the parenchyma, which entirely lines the concave side and separates the proto- and metaxylem by three or four layers of cells. The protoxylem is thus aggregated in a strap-like mass in the hollow of the crescent. The sieve-tubes stop abruptly at the horns of the crescent, but the pericycle is continuous round the horns and outside the protoxylem. In sections of smaller roots taken close to the stem the endodermis is not so well marked, the pericycle is thinner and the sieve-tubes are more numerous. The xylem is horse-shoe shaped with a break at the convexity and with an isolated protoxylem. Previous to the forking of the root the protoxylem-band also divides, and the two protoxylems take up positions one-third and two-thirds of the way along the concave margin of the xylem. The isolation of the protoxylem in this species is a peculiar feature which I can find no parallel for amongst other members of the genus, although the condition is led up to by the semi-isolation of the protoxylems in such species as *S. Wallichii.*

General Conclusions.

1. The root of *Selaginella* is either subterranean only, or partly aërial and partly subterranean.

2. The view held by some authors that the aërial part of the root is of cauline value, and should be distinguished from the underground portion as a 'rhizophore,' is not supported by sufficient morphological, anatomical, or developmental evidence.

3. The root anatomically is monarch, both in its aërial and underground regions, with well-defined endodermis.

The branching of the root is dichotomous, and the first dichotomy is at right angles to the long axis of the stem.

4. In several species the vascular cord of the stem at the origin of the root is centroxylic.

5. A centroxylic condition of the aërial part of the root occurs in *S. Kraussiana*, *S. delicatissima*, and *S. Poulteri.*

6. At every forking of the root the protoxylems of the two branch roots face each other, having revolved through an angle of 90 degrees.

7. Certain exceptional positions of the protoxylems are also referred to.

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EXPLANATION OF FIGURES IN PLATES XX AND XXI.

Illustrating Professor Harvey-Gibson's paper on the Anatomy of the genus *Selaginella.*

PLATE XX.

Fig. 1. Origin of the vascular cords of the roots of *Selaginella atroviridis*, Spr. × 2. *a.* lateral branch ; *b.* dorsal abortive root; *c.* main stem ; *d.* ventral root.

Fig. 2. Root-system of *S. atroviridis.* Nat. size.

Fig. 3. Transverse section of the root of *S. atroviridis* just previous to the third forking. × 350. Lettering as in Fig. 4.

Fig. 4. Transverse section of the aërial part of the root of *S. atroviridis.* × 350. *a.* endodermis ; *b.* pericycle ; *c.* sieve-tubes ; *d.* phloem-parenchyma ; *e.* metaxylem (see Fig. 3).

Fig. 5. Transverse section of the cortex of *S. involvens*, Spr. × 350. *a* endodermis ; *b.* cortex ; *c.* hypodermis ; *d.* piliferous layer.

Fig. 6. Transverse section of the root of *S. oregana*, Eat., showing piliferous layer and hypodermis, sclerotic outer and thin-walled inner cortical cells, endodermis and monarch vascular cylinder. × 350.

Fig. 7. Portion of the axis of *S. Galeottei*, Spr., showing the alternate origin of roots to right and left. Nat. size.

Fig. 8. Vascular cords of *S. Galeottei.* Nat. size. *a.* vascular cords of the lateral branch ; *b.* of the root ; *c.* of the main axis. The arrow points towards the apex of the stem.

Fig. 9. Root-system of *S. caulescens*, Spr. Nat. size.

Fig. 10. Successive positions taken by the protoxylems at the bifurcation of the root of *S. molliceps*, Spr. Diagr.

Fig. 11. Origin of the roots in *S. Lobbii*, Moore. Nat. size. *a.* adventitious shoot in the position of the dorsal root; *b.* root arising from the adventitious shoot ; *d* and *c.* right and left branches of the shoot axis.

Fig. 12. Transverse section of the root of *S. Vogelii*, Spr. × 350.

Fig. 13. Root-system of *S. Vogelii.* Nat. size.

Fig. 14. Transverse section of the root of *S. grandis*, Moore, taken just before the forking. × 350.

Fig. 15. Origin of the normal root of *S. Lobbii.* Nat. size.

Fig. 16. Transverse section of the root (aërial) of *S. Lobbii* at the point of forking. The metaxylem has divided but not the protoxylem. × 350.

Fig. 17. Transverse section of the aërial part of the root of *S. Kraussiana*, A. Br. × 550. *a.* metaxylem ; *b.* phloem-parenchyma ; *c.* sieve-tubes ; *d.* pericycle ; *e.* endodermis ; *f.* protoxylem.

Fig. 18. Origin of the root in *S. Wallichii*, Spr., in transverse and longitudinal view. Diagr.

Fig. 19. Centroxylic condition of one of the marginal bundles of the stele of the shoot at the origin of a root of *S. helvetica.* × 350.

Fig. 20. Transverse section of one of the smaller roots of *S. Wildenowii*, Baker. × 550.

PLATE XXI.

Fig. 21. Root-system of *S. Lyallii*, Spr. Nat. size.

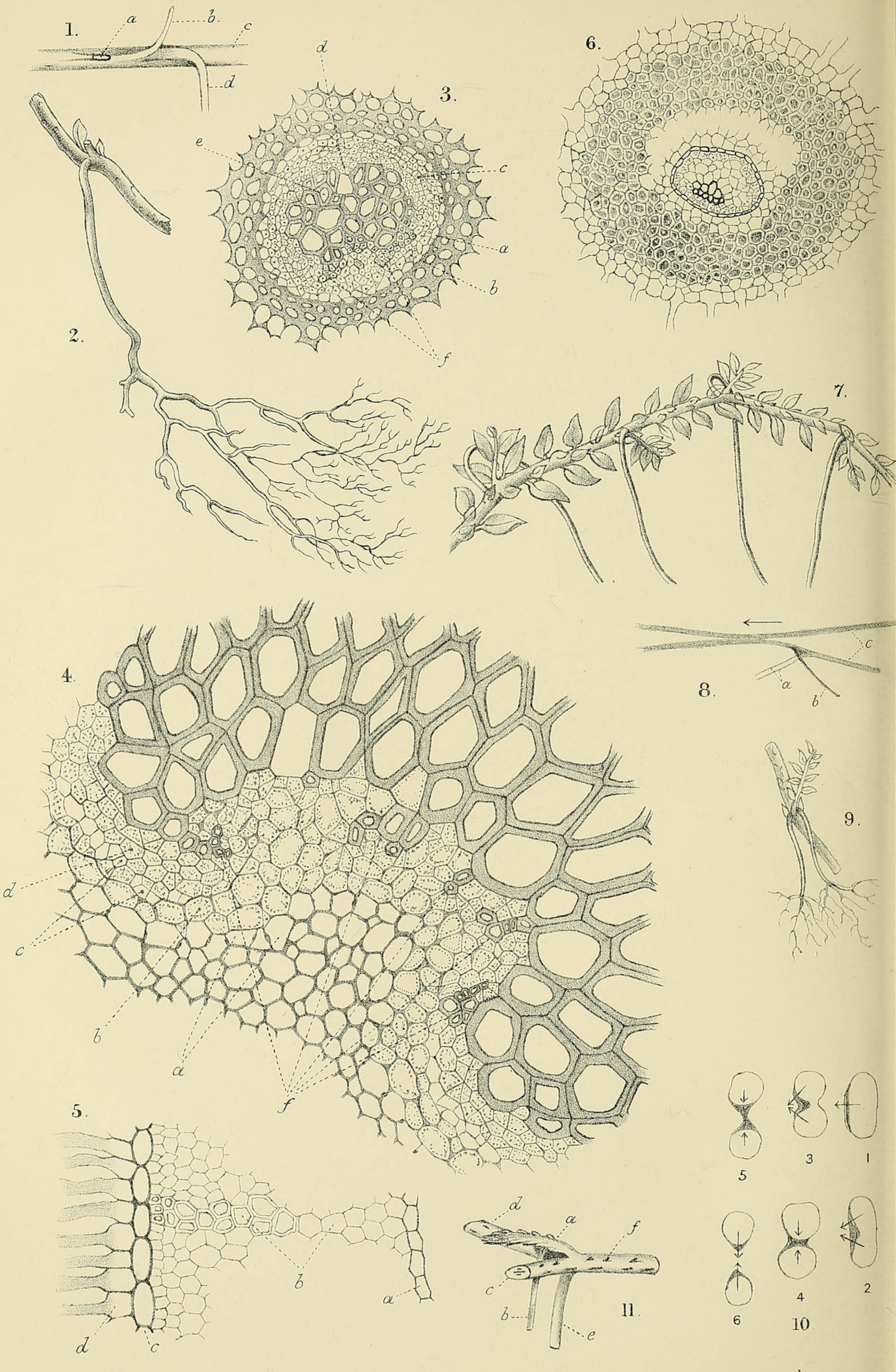
Fig. 22. Forking of the root-stele in *S. Lyallii.* × 350.

Fig. 23. Root-system of *S. Kraussiana*, A. Br. Nat. size.

Fig. 24. Successive sections showing the mode of origin of the steles of the lateral branch and root in *S. canaliculata*, Baker. Diagr.

Fig. 25. Transverse section of the root of *S. Willdenowii*, Baker, showing the almost isolated protoxylem. × 350.

Fig. 26. Successive sections of the stem of *S. Willdenowii*, Baker, showing the mode of origin of the vascular systems of the root and lateral branch. Diagr.



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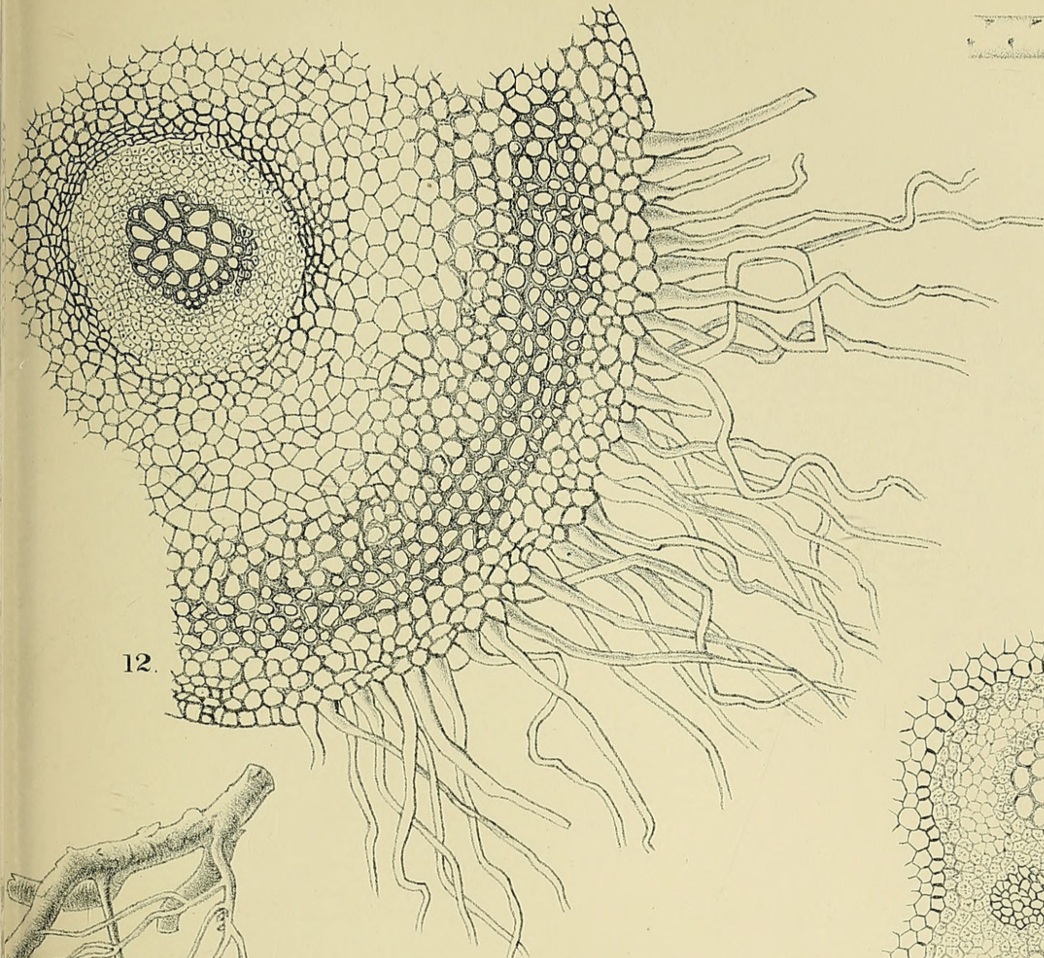

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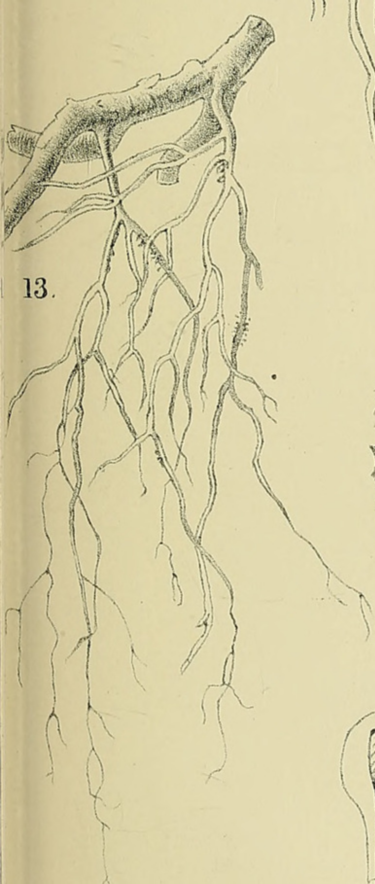

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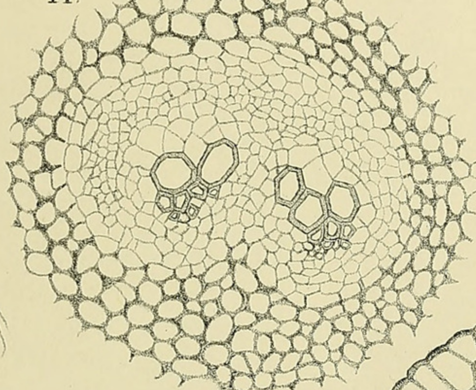

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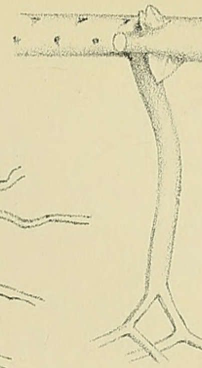

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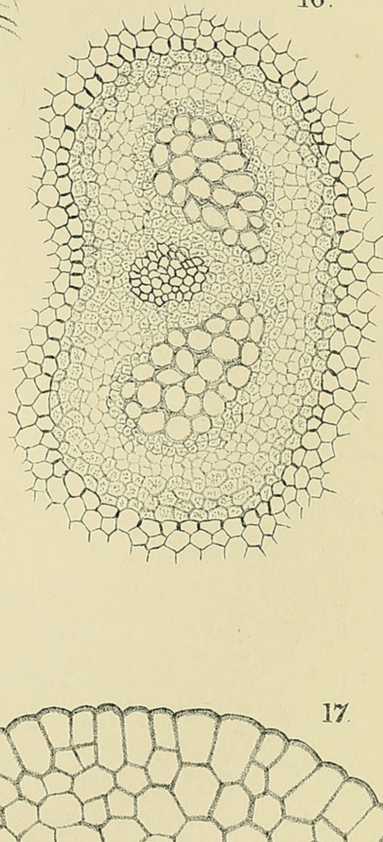

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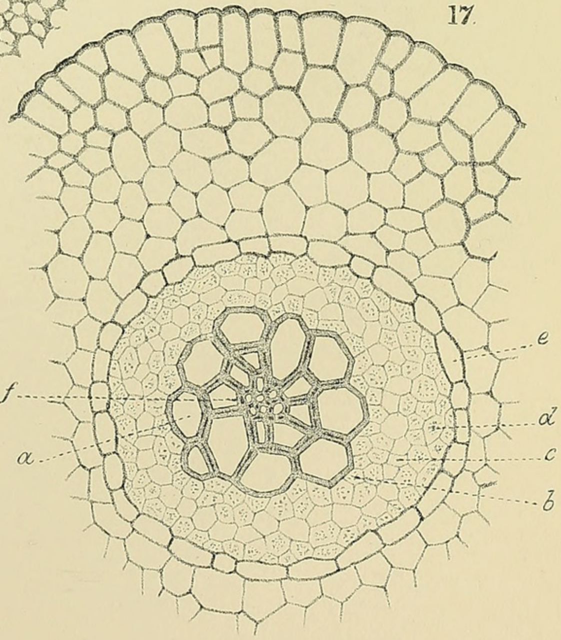

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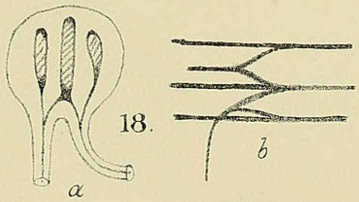

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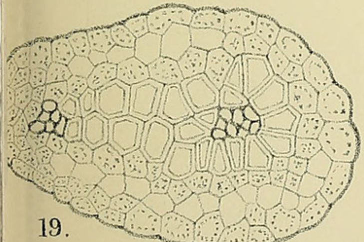

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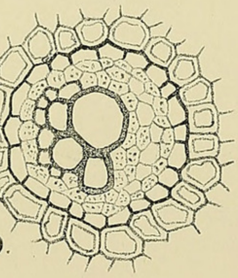

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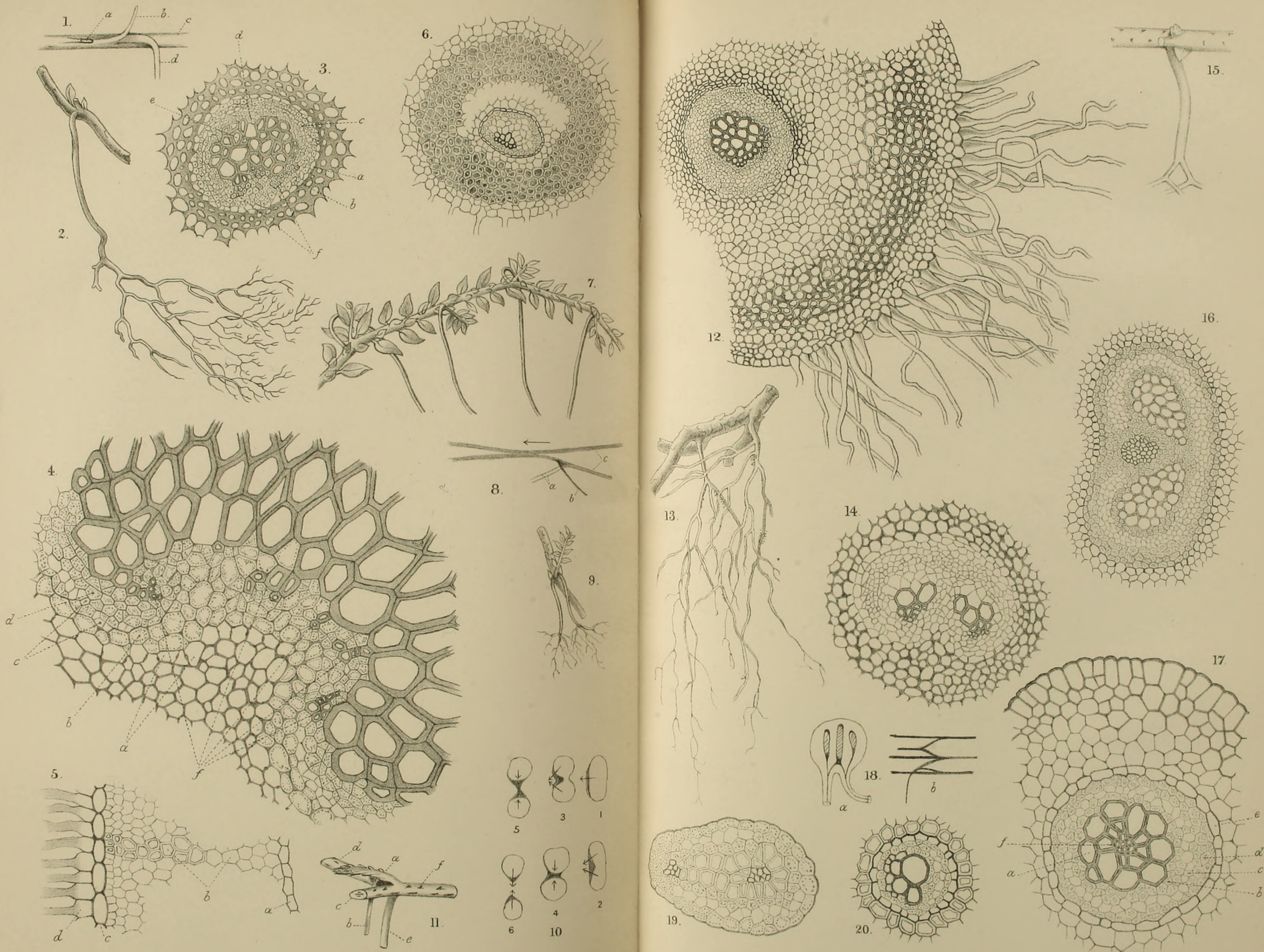

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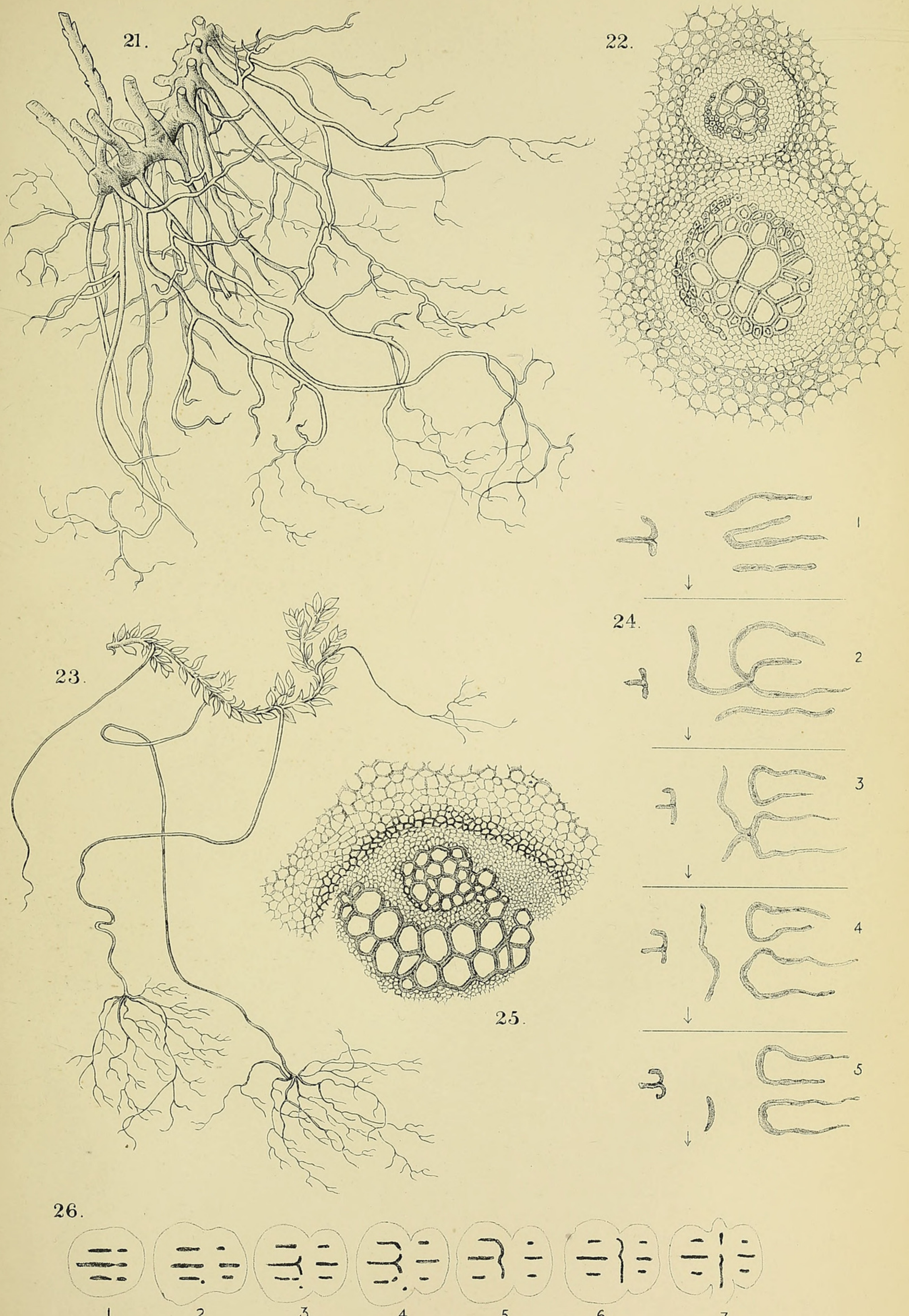

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