down to the stalk, as in the Daisy; *subulate*, narrow and tapering like an awl; *acuminate*, or drawn out into a long point, as in Ficus religiosa; *mucronate*, with a hard stiff point or mucro at the apex. When the parenchyma is deficient at the *apex* so as to form two rounded lobes, the leaf is *obcordate* or inversely heart-shaped; when the deficiency is very slight the leaf is called *emarginate* (fig. 112), as having a portion taken out of the margin; when the apex is merely flattened or slightly depressed the leaf is *retuse*; and when the apex ends abruptly in a straight margin, as in the Tulip-tree, the leaf is *truncate*. When the veins at the base of the lamina are prolonged downwards at an obtuse angle with the midrib, and rounded lobes are formed, as in


Fig. 111.


Fig. 112.


Fig. 113.

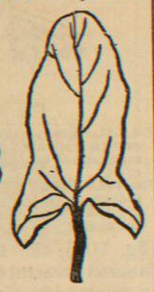
Fig. 114.

FIG. 111.—Oblong leaf of a species of Senna.
FIG. 112.—Emarginate leaf of a species of Senna. The leaf in its contour is somewhat obovate, or inversely egg-shaped, and its base is oblique.
FIG. 113.—Reniform leaf of *Nepete Glechoma*, margin crenate.
FIG. 114.—Sagittate leaf of Convolvulus.

Dog-violet, the leaf is *cordate* or heart-shaped; it is kidney-shaped or *reniform* (fig. 113), when the apex is rounded as in Asarum. When the lobes are prolonged downwards and are acute, the leaf is *sagittate* (fig. 114); when they proceed at right angles, as in Rumex Acetosella, the leaf is *hastate* or halbert-shaped. When a simple leaf is divided at the base into two leaf-like appendages, it is called *auriculate*. When the veins spread out in various planes, and there is a large development of cellular tissue, so as to produce a succulent leaf, such forms occur as *conical, prismatical, ensiform* or sword-like, *acinaciform* or scimitar-shaped, and *dolabriform* or axe-shaped. When the development of parenchyma is such that it more than fills up the spaces between the veins, the margins become *wavy, crisp*, or *undulated*, as in Rumex crispus and Rheum undulatum. By cultivation the cellular tissue is often much increased, giving rise to the *curled* leaves of Greens, Savoys, Cresses, Lettuce, &c. In Rushes the shoots which act as leaves are often *terete*. They are either barren or bear flowers. Their cellular tissue is often stellate, and the shoots sometimes exhibit a peculiar spiral twisting. Amongst parallel veined leaves the margins are usually entire, especially when the veins converge.

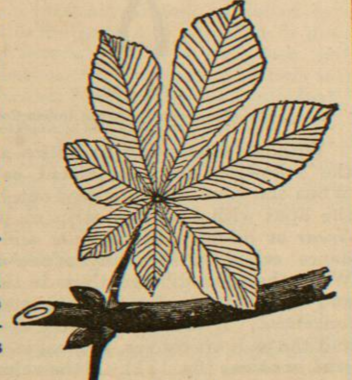
Fig. 115.
Septenate leaf of the Horse-chestnut (*Æsculus Hippocastanum*). Such leaves, especially when there are five leaflets, are called digitate.

Compound leaves are those in which the divisions extend to the midrib or petiole, and the separated portions become each articulated with it, and receive the name of *foliola* or *leaflets*. The midrib, or petiole, has thus the appearance of a branch with separate leaves attached to it, but it is considered properly as one leaf, because in its earliest state it arises from the axis as a single piece, and its subsequent divisions in the form of leaflets are all in one plane. The leaflets are either sessile (fig. 115), or have stalks, called *petiolules* (fig. 116), according as the vascular bundles of the veins spread out or divaricate at once, or remain united for a certain length. Compound leaves have been classified according to the nature of the venation and the development of parenchyma. If we suppose that in a simple feather-veined unicostate leaf the divisions extend to the midrib, and each of the primary veins spreads out or branches, and becomes surrounded with parenchyma, and the leaflets thus formed become articulated to the petiole or midrib (fig. 116), the leaf becomes compound and *pinnate*. If the midrib and primary veins are not covered with parenchyma, while the *secondary* (or those coming off in a feather-like manner from the primary veins) are, and separate leaflets are thus formed which are articulated with the veins, the leaf is *bipinnate*. In this case the secondary veins form as it were partial petioles. A farther subdivision, in which the *tertiary* veins only are covered with parenchyma and have separate leaflets, gives *tripinnate* or *decompound* forms, in which case the tertiary veins form the partial petioles. A leaf divided still more is called *supradecompound*. When a pinnate leaf has one pair of leaflets it is *unijugate*; with two pairs, it is *bijugate*; with many pairs, *multijugate* (fig. 116). When a pinnate leaf ends in a pair of pinnæ it is *equally* or *abruptly pinnate* (paripinnate); when there is a single terminal leaflet (fig. 116), the leaf is *unequally pinnate* (impari-pinnate); when the leaflets or pinnæ are placed alternately on either side of the midrib, and not directly opposite to each other, the leaf is *alternately pinnate*; and when the pinnæ are of different sizes, the leaf is *interruptedly pinnate*. In the case of a simple multicostate leaf with radiating venation, if we suppose the ribs to be covered with parenchyma, so as to form separate leaflets, each of which is articulated to the petiole, the *digitate* form of compound leaf is produced; if there are three leaflets the form is *ternate* or *trifoliate*; if four, *quaternate*; if five, *quinate*; if seven, *septenate*; and so on. If the three ribs of a ternate leaf subdivide each into three primary veins, which become covered with parenchyma so as to be separate articulated leaflets, the leaf is *biternate*; and if another threefold division takes place, it is *triternate*.

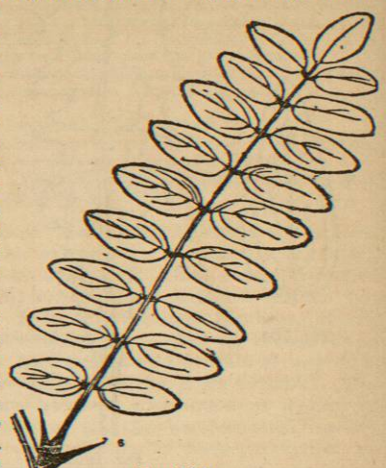
Fig. 116.
Impari-pinnate (unequally pinnate) leaf of Robinia. There are nine pairs of shortly-stalked leaflets (foliola, pinnæ), and an odd one at the extremity. At the base of the leaf stipules *s* are seen.

The *petiole* or leaf-stalk is the part which unites the limb or blade of the leaf to the stem (fig. 99, *p*). It is absent in *sessile* leaves, and this is also frequently the case when the vagina is present, as in Grasses. It consists of a mass of fibro-vascular bundles with a varying amount of cellular

tissue. The vessels are enclosed in an epidermal covering, with few stomata, and are more or less compressed. When the vascular bundles reach the base of the lamina they separate and spread out in various ways, as already described under venation. At the place where the petiole joins the stem there is frequently an articulation, or a constriction with a tendency to disunion, and at the same time there exists a swelling (fig. 117, *p*), called *pulvinus*, formed of cellular tissue, the cells of which exhibit the phenomenon

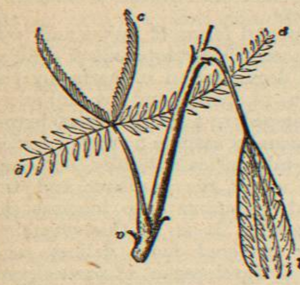
Fig. 117.

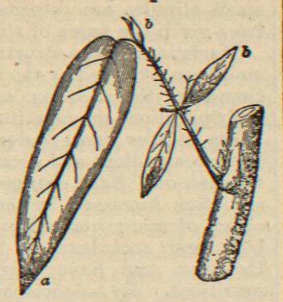
Fig. 118.

FIG. 117.—Branch and leaves of the Sensitive plant (*Mimosa pudica*), showing the petiole in its erect state, *a*, and in its depressed state, *b*; also the leaflets closed, *c*, and the leaflets expanded, *d*. Irritability resides in the pulvinus *p*, and in the struma.
FIG. 118.—A portion of the branch and leaf of the Moving plant of India (*Hedysarum* or *Desmodium gyrans*). The leaf is impari-pinnate, and often pinnately-trifoliate. The large leaflet or pinna, *a*; the smaller leaflets, *b*, of which there are either one or two pairs. The leaflets are in constant motion.

of irritability (figs. 117, 118). At the point where the petiole passes into the lamina, or where the midrib joins the leaflets of a compound leaf, there is occasionally a cellular dilatation called *struma*, and an articulation. In Mimosa pudica a sensitiveness is located in the pulvinus (fig. 117, *p*), which upon irritation induces a depression of the whole bipinnate leaf; a similar property exists in the struma at the base of the leaflets which fold upwards. In Desmodium gyrans (fig. 118) the pulvinus and struma have a similar power of causing movements of the large terminal leaflet and the two smaller lateral ones. In other cases the petiole is not articulated, but is continuous either with the stem, or with the sheath (vagina). The articulation or joint is by many considered as indicating a compound leaf, and hence the leaf of the Orange is considered as such, although it has an undivided lamina (fig. 119, *l*). In articulated leaves, the pulvinus may be attached either to the petiole or to the axis, and may fall with the leaf, or remain attached to the stem. When articulated leaves drop, their place is marked by a cicatrix or scar, seen below the bud in fig. 63. In this scar the remains of the vascular bundles *c* are seen; and its form furnishes characters by which particular kinds of trees may be known when not in leaf. In the case of many Palms and Tree-ferns the scars or cicatrices of the leaves are very conspicuous. In fossil plants important characters are founded on them.

When there is no articulation between the petiole and the stem, as is the case with many Monocotyledons, the leaf is continuous with the axis, and is not deciduous, but withers on the stalk. In many Liliaceous plants the leaves during their decay continue attached to the plants. The petiole varies in length, being usually shorter than the lamina, but sometimes much longer. In some Palms it is 15 or 20 feet long, and is so firm as to be used for poles or walking-sticks. In general, the petiole is more or less rounded in its form, the upper surface being flattened or grooved. Sometimes it is compressed laterally, as in the Aspen, and to this peculiarity the trembling of the leaves of this tree is attributed. In aquatic plants the leaf-stalk is sometimes distended with air, as in Pontederia and Trapa, so as to float the leaf. At other times it is *winged*, and is either leafy, as in the Orange (fig. 119, *p*), Lemon, and Dionæa (fig. 46, *p*), or pitcher-like, as in the Pitcher-plant

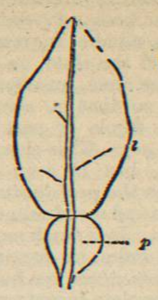
Fig. 119.


Fig. 120.

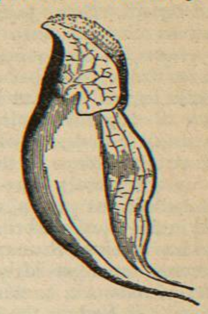
Fig. 121.

FIG. 119.—Leaf of Orange (*Citrus Aurantium*), showing a winged leafy petiole *p*, which is articulated to the lamina *l*. It is considered a compound leaf, having only one leaflet.
FIG. 120.—Pitcher of a species of Pitcher-plant (*Nepenthes distillatoria*). It is supposed to be formed by a folded petiole *p*, the edges of which are united. The lid *l* at the top is supposed to represent the lamina, united by articulation to the pitcher.
FIG. 121.—Pitcher (*ascidium*) of a species of Side-saddle plant (*Sarracenia purpurea*). The pitcher is supposed to be formed by the folded petiole, which is prolonged.

(fig. 120, *p*) and Sarracenia (fig. 121). Leafy petioles are occasionally united to the axis for some extent, and thus become *decurrent*. In some Australian Acacias, and in some species of Oxalis and Bupleurum, the petiole is flattened in a vertical direction, the vascular bundles separating immediately after quitting the stem, and running nearly parallel from base to apex. This kind of petiole (fig. 122, *p*) has been called *phyllodium*. In these plants the laminæ or blades of the leaves are pinnate, bipinnate, or ternate, and are produced at the extremities of the phyllodia in a horizontal direction; but in many instances they are not developed, and the phyllodium serves the purpose of a leaf. Hence some Acacias are called leafless. These phyllodia, by their vertical position and their peculiar


Fig. 122.


Fig. 123.

FIG. 122.—Leaf of an Acacia (*Acacia heterophylla*), showing a flattened leaf-like petiole *p*, called a phyllodium, with straight venation, and a bipinnate lamina *l*.
FIG. 123.—Leaf of Pansy, *l*, separated from the stem; the lyrate-pinnatifid stipules *s* are distinctly visible, and their lateral position is seen.

form, give a remarkable aspect to vegetation. On the same Acacia there occur leaves with the petiole and lamina perfect; others having the petiole slightly expanded or winged, and the lamina imperfectly developed; and others in which there is no lamina, and the petiole becomes large and broad. Some petioles, in place of ending in a lamina become changed into a delicate filiform body, a *tendril* or *cirrus*, so as to enable the plant to climb. In many leaves interposed betwixt the petiole and the stem, or, in sessile leaves, betwixt the lamina and the stem, an expansion of the foliar tissue takes place, so that a *sheath* (*vagina*) is formed, which embraces the whole or part of the circumference of the stem (fig. 102, *gv*). This sheath is comparatively rare in Dicotyledons, but is seen in Umbelliferous plants, where it constitutes the *pericladium*, and in the Rhubarb order, where it is large and membranous, and has received the name of *ochrea* or boot. It is much more common amongst Monocotyledons. In Palms it forms a kind of network, to which the name of *reticulum* has been given. In Sedges the sheath forms a complete investment of the stem, whilst in Grasses (fig. 102) it is split on one side. In the latter plants there is also a membranous outgrowth at right angles to the median plane of the leaf from the point where the sheath passes into the lamina (there being no petiole). To this structure the name of *ligule* (fig. 102, *gl*) has been given. It is of various dimensions, and thus gives a character to the plants.

In leaves in which no sheath is produced we not unfrequently find small foliar organs at the base of the petiole. These have been denominated *stipules* (fig. 123, *s*). The stipules are often two in number, and they are important as supplying characters in certain natural orders. Thus they occur in the Pea and Bean family, in Rosaceous plants, and the Cinchona bark family. They are not common in Dicotyledons with opposite leaves. Plants having stipules are called *stipulate*; those having none are *exstipulate*. Stipules are formed by some of the vascular bundles diverging as they leave the stem, and becoming covered with parenchyma, so as to resemble true leaves. Like leaves they are large or small, entire or divided, deciduous or persistent, articulated or non-articulated. They are not usually of the same form as the ordinary foliage leaves of the plant, from which they are distinguished by their lateral position at the base of the petiole. In the Pansy (fig. 123) the true leaves *l* are stalked and crenate, while the stipules *s* are large, sessile, and pinnatifid. In Lathyrus Aphaca, and some other plants, the true pinnate leaves are abortive, the petiole forms a tendril, and the stipules alone are developed, performing the office of leaves. When stipules are attached separately to the stem at the base of the leaf, they are called *caulinary*, as in Salix aurita. When stipulate leaves are opposite to each other, at the same height on the stem, it occasionally happens that the stipules on the two sides unite wholly or partially, so as to form an *interpetiolary* or *interfoliar* stipule, as in Cinchona and in Ipecacuan. In the case of alternate leaves, the stipules at the base of each leaf are sometimes united to the petiole and to each other, so as to form an *adnate*, *adherent*, or *petiolary* stipule, as in the Rose, or an *axillary* stipule, as in Houttuynia cordata. In other instances the stipules unite together on the side of the stem opposite the leaf, and become *synochreate*, as in Astragalus. This so-called union or adhesion of stipules is not an accidental adhesion taking place after they have been developed. In these cases the parts never were separate; from the first they are developed as one portion. In the development of the leaf the stipules frequently play a most important part. They begin to be formed after the origin of the leaves, but grow much more rapidly than the leaves, and in this way they arch over the young leaves and form protective chambers wherein the parts of the leaf may develop. In Ficus, Magnolia, and Potamogeton they are very large and completely envelop the young leaf-bud. The stipules are sometimes so minute as to be scarcely distinguishable without the aid of a lens, and so fugacious as to be visible only in the very young state of the leaf. They may assume a hard and spiny character, as in Robinia Pseudacacia, or may be cirrose, as in Smilax, where each stipule is represented by a tendril; while in Cucurbitaceæ there is only one cirrose stipule. At the base of the leaflets or foliola of a compound leaf, small stipules are occasionally produced, to which some have given the name of *stipels*.

Variations in the structure and forms of leaves and leaf-stalks are produced by the increased development of cellular tissue, by the abortion or degeneration of parts, by the multiplication or repetition of parts, and by adhesion. When cellular tissue is developed to a great extent, leaves become succulent and occasionally assume a crisp or curled appearance. Such changes take place naturally, but they are often increased by the art of the gardener, and the object of many horticultural operations is to increase the bulk and succulence of leaves. It is in this way that Cabbages and Savoys are rendered more delicate and nutritious. By a deficiency in development of parenchyma and an increase in the fibro-vascular tissue, leaves are liable to become hardened and spinescent. The leaves of Barberry and of some species of Astragalus, and the stipules of the False Acacia (Robinia) are spiny. To the same cause is attributed the spiny margin of the Holly-leaf. In the Gooseberry, the swelling (pulvinus) at the base of the petiole, and below the leaf, assumes a spinose character. Changes in the appearances of leaves are produced by adhesions and foldings of various kinds. When two lobes at the base of a leaf are prolonged beyond the stem and unite (fig. 124), the leaf is *perfoliate*, the stem appearing to pass through it, as in Bupleurum perfoliatum and Chlora perfoliata; when two leaves unite by their bases they become *connate* (fig. 125), as in Lonicera Caprifolium;

Fig. 124.

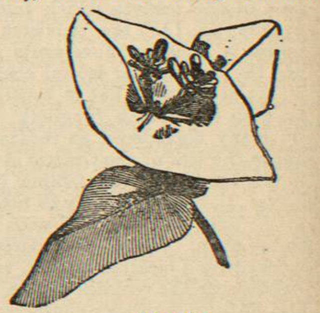

Fig. 125.

FIG. 124.—Perfoliate leaf of a species of Hare's-ear (*Bupleurum rotundifolium*). The two lobes at the base of the leaf are united, so that the stalk appears to come through the leaf.
FIG. 125.—Connate leaves of a species of Honeysuckle (*Lonicera Caprifolium*). Two leaves are united by their bases.

and when leaves adhere to the stem, forming a sort of winged or leafy appendage, they are *decurrent*, as in Thistles. The formation of peltate and orbicular leaves has been traced to the union of the lobes of a cleft leaf. In the leaf of the Victoria regia the transformation may be traced during germination. The first leaves produced by the young plant are linear, the second are sagittate and hastate, the third are rounded-cordate, and the next are orbicular. The cleft indicating the union of the lobes remains in the large leaves. The parts of the leaf are frequently transformed into *tendrils* (*cirri*), with the view of enabling the plants to twine round others for support. In Leguminous plants (the Pea tribe) the pinnæ are frequently cirrose. When tendrils occupy the place of leaves, and

appear as a continuation of the leaf-stalk, they are called *petiolary*, as in Lathyrus Aphaca, in which the stipules perform the function of true leaves. In Flagellaria Indica, Gloriosa superba, Anthericum cirrhatum, and Albuca cirrhata, the midrib of the leaf ends in a tendril. In Smilax there are two stipulary tendrils, while in the Cucumber tribe there is a single one at the base of each leaf. In the Passion-flower the lateral leaf-buds, and in the Vine the terminal ones, become tendrils. In the Vanille plant (*Vanilla aromatica*) the tendrils are produced opposite the leaves, until the plant gains the top of the trees by which it is supported,—the upper tendrils being then developed as leaves. The midrib is sometimes prolonged in a cup-like or funnel-shaped form; this is occasionally seen in the common Cabbage, and seems to depend on the vascular bundles of the midrib spreading out at their extremity in a radiating manner, and becoming covered with parenchyma in such a way as to form a hollow cavity in the centre.

The vascular bundles and cellular tissue are sometimes developed in such a way as to form a circle, with a hollow in the centre, and thus give rise to what are called *fistular* or hollow leaves, as in the Onion, and to *ascidia* or *pitchers*. Pitchers are formed either by petioles or by laminæ, and they are composed of one or more leaves. In Sarracenia (fig. 121) and Heliamphora, the pitcher is composed apparently of the petiole of the leaf. In Nepenthes (fig. 120) and perhaps in Cephalotus, while the folding of a winged petiole *p* forms the pitcher, the lid *l*, which is united by an articulation, corresponds to the lamina. This kind of ascidium is called *calyptrimorphous*, and may be considered as formed by a leaf, such as that of the Orange (fig. 119); the lamina *l* being articulated to the petiole *p*, which, when folded, forms the pitcher. In Dischidia Rafflesiana, a climbing plant of India, the pitchers are formed by the lamina of the leaf, and have an open orifice into which the rootlets at the upper part of the plant enter. These pitchers would seem, therefore, to contain a supply of fluid for the nourishment of the upper branches of the plant. In Utricularia the leaves form sacs called *ampullæ*. Some suppose that pitchers are not due to folding and adhesion, but that they are produced by a hollowing-out of the extremity of the stalk. In some cases the leaves are reduced to mere *scales*; they are then frequently called *cataphyllary* leaves. They are produced abundantly upon underground shoots. In parasites (Lathræa, Orobanche), and in plants growing on decaying vegetable matter (*Saprophytes*), in which no chlorophyll is formed, these scales are the only leaves produced. In Pinus the only leaves produced on the main stem and the lateral shoots are scales, the acicular leaves of the tree growing from axillary shoots. In Cycas whorls of scales alternate with large pinnate leaves. In many plants, as already noticed, phyllodia or stipules perform the function of leaves. The production of leaf-buds from leaves has already been noticed. Such leaves are termed *proliferous*. In Bryophyllum (fig. 67) this is a common occurrence, and it is met with in many plants of the order Gesneraceæ. The leaf of Venus's Fly-trap (Dionæa muscipula, fig. 46), when cut off and placed in damp moss, with a pan of water underneath and a bell-glass for a cover, has produced buds from which young plants were obtained. Some species of Saxifrage and of Ferns also produce buds on their leaves and fronds. In Nymphæa micrantha buds appear at the upper part of the petiole.

Amongst Dicotyledons we have leaves which present the greatest amount of variation in structure and form. The venation is reticulated. They are frequently articulated, exhibit divisions at their margin, and become truly compound. There are, no doubt, instances in which the veins proceed in a parallel manner, but this will be found to occur chiefly in cases where the petiole may be considered as occupying the place of the leaf. Examples of this kind are seen in Acacias (fig. 122). Dicotyledons rarely have a sheath developed, but stipules are very commonly present.

In Monocotyledons the leaves do not present an angular network of vessels, nor do they, as a rule, exhibit divisions on their margin. Exceptions to this occur in some plants, as Tamus and Dioscorea, which have been called Dictyogens by Lindley, on account of their somewhat netted venation; and in Palms, in which, although the leaves are entire at first, they afterwards become split into various lobes. They are rarely stipulate, and very frequently have a sheath at their base. The petiole is often absent, and a sheathing ligule takes its place. The leaves are often continuous with the stem. In some aquatic Monocotyledons the submerged and floating leaves are narrow, like petioles, while those growing erect above the water expand. This is seen in Sagittaria sagittifolia, in which the erect leaves assume an arrow-like shape.

In Acotyledons the leaves vary much, being entire or divided, stalked or sessile, often feather-veined, occasionally with radiating venation, the extremities of the veins being forked. In Ferns the leaf (frond) is usually stalked, with frequently a much-divided lamina, remarkable for the prolonged growth at the apex, and in the young state usually covered with curious flattened hairs (*paleæ*). In Equisetaceæ the leaves are sheathing cylinders embracing successive internodes of the stem, and subsequently splitting at the top into few or many teeth. In Lycopodiaceæ the leaves vary from mere rudimentary scales, as in Psilotum, to the flattened acuminate leaf of Selaginella, with only a single fibro-vascular bundle, and then to the more complicated form in Isoetes, in which the longest leaves in the order occur, and these have a sheathing basal part and an upper lamina. On the face of the sheathing part is a depression or *fovea*, in which rests the sporangium, the margin of it rising as a thin membranous outgrowth, the *velum*. Above the fovea, and separated from it by a saddle-like ridge, lies a smaller depression the *foveola*, the lower margin of which forms a lip, the *labium*, and from its bottom is prolonged beyond the foveola an apiculate membranous structure, which is termed the *ligule*. In Mosses we have the simplest form of leaf, composed of one or more layers of cells, sometimes the central ones being more or less compacted and forming a median vein.

Leaves occupy various positions on the stem and branches, and have received different names according to their situation. Thus leaves arising from the crown of the root, as in the Primrose, are called *radical*; those on the stem are *cauline*; on the branches, *ramal*; on flower-stalks, *floral* leaves. The first leaves developed are denominated *seminal* leaves or *cotyledons*, and those which succeed are *primordial*. The arrangement of the leaves on the axis and its appendages is called *phyllotaxis*. In their arrangement leaves follow a definite order. It has been stated already that there are regular *nodes* or points on the stem at which leaves appear, and that the part of the stem between the nodes is the *internode*. Each node is capable of giving origin to a leaf. Occasionally several nodes are approximated so as to form as it were one, and then several leaves may be produced at the same height on the stem. When two leaves are thus produced, one on each side of the stem or axis, and at the same level, they are called *opposite* (fig. 126); when more than two are produced (fig. 127), they are *verticillate*, and the circle of leaves is then called a *verticil* or *whorl*. When the zone of the axis which produces the circle of leaves is transverse from its origin, the whorl is a *true* one; but when the zone is the result of unequal development or of displacement the whorl is *spurious*. Again, in each whorl the leaves may be all formed together, and a *simultaneous* whorl results; or they may be formed one after the other, as in Characeæ, when a *successive* whorl is formed. When leaves are opposite, each successive pair may be placed at right angles to the pair immediately preceding. They are then said to *decussate*, following thus a law of alternation. The same occurs

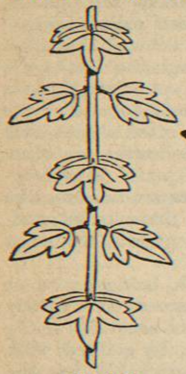

Fig. 126.

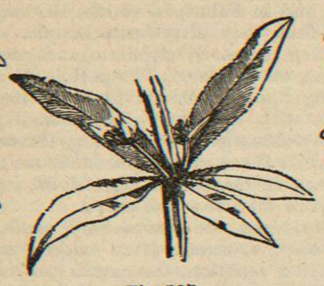

Fig. 127.

Fig. 128.

FIG. 126.—A stem with opposite leaves. The pairs are placed at right angles alternately, or in what is called a decussate manner. In the lowest pair one leaf is in front, and the other at the back; in the second pair the leaves are placed laterally, and so on.

FIG. 127.—Verticillate or whorled leaves of a species of Madder. There are five leaves in the verticil or whorl.

FIG. 128.—A stem with alternate leaves, arranged in a pentastichous or quincuncial manner. The sixth leaf is directly above the first, and commences the second cycle. The fraction of the circumference of the stem expressing the divergence of the leaves is two-fifths.

in the verticillate arrangement, the leaves of each whorl rarely being *superposed* on those of the whorl next it, as on the branches of Chara, but usually alternating so that each leaf in a whorl occupies the space between two leaves of the whorl next to it. There are considerable irregularities, however, in this respect, and the number of leaves in different whorls is not always uniform, as may be seen in Lysimachia vulgaris. When a single leaf is produced at a node, and the nodes are separated so that each leaf is placed at a different height on the stem, the leaves are *alternate* (fig. 128). A plane passing through the point of insertion of the leaf in the node, dividing the leaf into two similar halves, is the median plane of the leaf; and when the leaves are arranged alternately on an axis so that their median planes coincide they form a straight row or *orthostichy* On every axis there are usually two or more orthostichies. The leaves in such a case are said to be rectiserial. In fig. 129, leaf 1 arises from a node n; leaf 2 is separated by

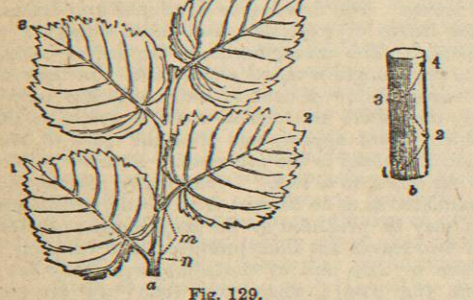

Fig. 129.

Portion of a branch of a Lime tree, with four leaves arranged in a distichous manner, or in two rows. a, the branch with the leaves numbered in their order n being the node, and m the internode or merithal; b is a magnified representation of the branch, showing the cicatrices of the leaves and their spiral arrangement, which is expressed by the fraction $\frac{1}{2}$, or one turn of the spiral for two internodes.

an internode m, and is placed to the right or left; while leaf 3 is situated directly above leaf 1. In this case, then. there are two orthostichies, and the arrangement is said to be *distichous*. When the fourth leaf is directly above the first, the arrangement is *tristichous*. The same arrangement continues throughout the branch, so that in the latter case the 7th leaf is above the 4th, the 10th above the 7th; also the 5th above the 2d, the 6th above the 3d, and so on. The size of the angle between the median planes of two consecutive leaves in an alternate arrangement is their *divergence;* and it is expressed in fractions of the circumference of the axis which is supposed to be a circle. In a regularly-formed straight branch covered with leaves, if a thread is passed from one to the other, turning always in the same direction, a spiral is described, and a certain number of leaves and of complete turns occur before reaching the leaf directly above that from which the enumeration commenced. If this arrangement is expressed by a fraction, the numerator of which indicates the number of turns, and the denominator the number of internodes in the spiral cycle, the fraction will be found to represent the angle of divergence of the consecutive leaves on the axis. Thus, in fig. 130, a, b, the cycle consists of five leaves, the 6th leaf being placed vertically over the 1st, the 7th over the 2d, and so on; while the number of turns between the 1st and 6th leaf is two; hence this arrangement is indicated by the fraction $\frac{2}{5}$. In other words, the distance or divergence between the first and second leaf, expressed in parts of a circle, is $\frac{2}{5}$ of a circle, or $360° \div \frac{2}{5} = 144°$. In fig. 129, a, b, the spiral is $\frac{1}{2}$, *i.e.*, one turn and two leaves; the third leaf being placed vertically over the first, and the divergence between the first and second leaf being one-half the circumference of a circle, $360° \div \frac{1}{2} = 180°$. Again, in a tristichous arrangement the number is $\frac{1}{3}$, or one turn and three leaves, the angular divergence being 120°.

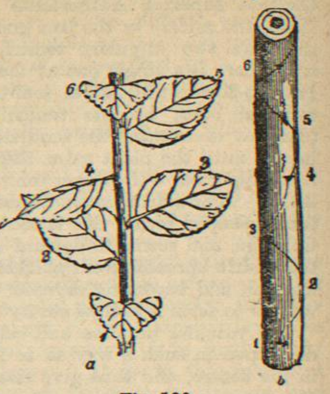

Fig. 130.

Part of a branch of a Cherry with six leaves, the sixth being placed vertically over the first, after two turns of the spiral. This is expressed by two-fifths, or the quincunx. a, the branch, with the leaves numbered in order; b, a magnified representation of the branch, showing the cicatrices of the leaves or their points of insertion, and their spiral arrangement.

By this means we have a convenient mode of expressing on paper the exact position of the leaves upon an axis. And in many cases such a mode of expression is of excellent service in enabling us readily to understand the relations of the leaves. The divergences may also be represented diagrammatically on a horizontal projection of the vertical axis, as in fig. 131. Here the outermost circle represents a section of that portion of the axis bearing the lowest leaf, the innermost represents the highest. The broad dark lines represent the leaves, and they are numbered according to their age and position. It will

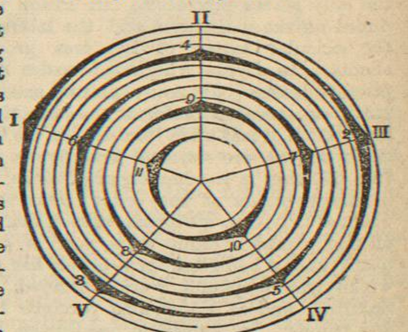

Fig. 131.

Diagram of a phyllotaxis represented by the fraction 2-5ths. (*Sachs.*)

be seen at once that the leaves are arranged in orthostichies marked I.–V., and that these divide the circumference into five equal portions. But the divergence between leaf 1 and leaf 2 is equal to $\frac{2}{5}$ths of the circumference, and the same is the case between 2 and 3, 3 and 4, &c. The divergence, then, is $\frac{2}{5}$, and from this we learn that, starting from any leaf on the axis, we must pass twice round the stem in a spiral through five leaves before reaching one directly over that with which we started. When the leaves or scales are alternate, and run in a single series, they are *unijugate;* when the leaves are opposite, and there are two series, the arrangement is *bijugate;* while in the case of whorled leaves the arrangement may be *trijugate* or *quadrijugate*. The line which, winding round an axis either to the right or to the left, passes through the points of insertion of all the leaves on the axis is termed the *genetic* or *generating spiral;* and that margin of each leaf which is towards the direction from which the spiral proceeds is the *kathodic* side, the other margin facing the point whither the spiral passes being the *anodic* side.

In cases where the internodes are very short, and the leaves are closely applied to each other, as in the House-leek, it is difficult to trace the *generating spiral*. Thus, in fig. 132 there are thirteen leaves which are numbered in their order, and five turns of the spiral marked by circles in the centre

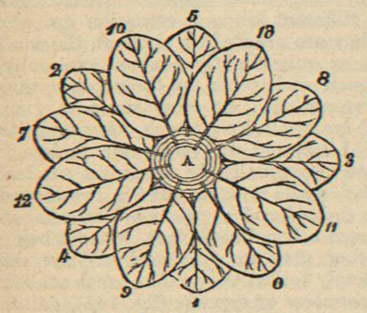

Fig. 132.

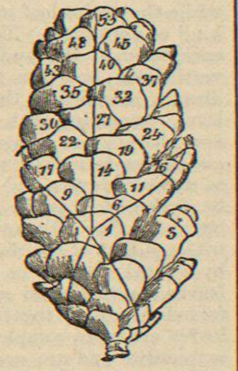

Fig. 133.

FIG. 132.—Cycle of thirteen leaves placed closely together so as to form a rosette, as in Sempervivum. A is the very short axis to which the leaves are attached. The leaves are numbered in their order, from below upwards. The circles in the centre indicate the five turns of the spiral, and show the insertion of each of the leaves. The divergence is expressed by the fraction 5-13ths.

FIG. 133.—Cone of *Abies alba* with the scales or modified leaves numbered in the order of their arrangement on the axis of the cone. The lines indicate a rectilinear series of scales, and two lateral secondary spirals, one turning from left to right, the other from right to left.

($\frac{5}{13}$ indicating the arrangement); but this could not be detected at once. So also in Fir cones (fig. 133), which are composed of scales or modified leaves, the generating spiral cannot be determined easily. But in such cases a series of *secondary spirals* or *parastichies* are seen running parallel with each other both right and left, which to a certain extent conceal the genetic spiral. Thus, in fig. 133, it will be found that there are five secondary spirals running towards the right and parallel to each other, the first passing through the scales 1, 6, 11, 16, &c.; the second through 9, 14, 19, 24, &c.; the third through 17, 22, 27, 32, 37, &c.; the fourth through 30, 35, 40, 45, &c.; the fifth through 43, 48, 53, &c. The number of these secondary spirals indicates the number of scales intervening between every two scales in each of these spirals, the common difference being five. Again, it will be found on examination that there are secondary spirals running to the left, in which the common difference between every two scales is eight, and that this corresponds to the number of secondary spirals, the first of which passes through the scales 1, 9, 17, &c.; the second through 6, 14, 22, 30, &c.; the third through 3, 11, 19, 27, 35, 43, and so on. Thus it is that, by counting the secondary spirals, all the scales may be numbered, and by this means the generating spiral may be discovered. From the number of secondary spirals the angle of divergence may be easily calculated, the sum of those which wind in both directions giving the denominator of the fraction, while the smaller of the two numbers representing those winding in each direction is the numerator. Thus in the instance last mentioned the angular divergence is $\frac{5}{13}$. In the cone of the American larch (fig. 134) there is a quincuncial arrangement of scales marked by the fraction $\frac{2}{5}$. There are five vertical ranks, as marked in the tabular numerical view at the side of the cone, which represents the unwound surface of the cone, viz., 2, 7, 12; 4, 9, 14; 1, 6, 11; 3, 8, 13; 5, 10, 15,—the common difference in each row being 5. On looking at the cone we find also parallel oblique ranks, two of which, ascending to the left, are marked by the numbers 1, 3, 5, which, if the diagram is coiled round a cylinder, continue in the numbers 7, 9, 11, 13, 15; and 2, 4, 6, 8, 10, continued into 12, 14. There are thus two left-handed spirals, with 2 as the common difference in the numbering of the scales. Again, three oblique parallel spirals ascend to the right, marked by the numbers 1, 4, 7, running into 10, 13; 3, 6, 9, 12, going on to 15; and 5, 8, 11, 14; here the common difference in the numbering of the scales is 3, corresponding with the oblique right-handed spirals.

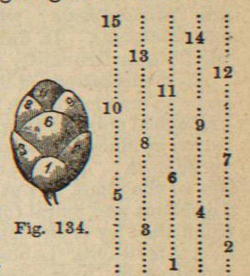

Fig. 134.

Cone of a species of Larch (*Larix microcarpa*). The surface of the cone is supposed to be unwound and the scales numbered so far as seen. The arrangement is 2-5ths, in the five-ranked series.

All the constant divergences found in phyllotaxis may be represented as successive convergents of the continued fraction

$$\frac{1}{a+1} + 1 + 1 + 1, \text{ \&c.},$$

where a may have the values 1, 2, 3, 4, &c.

The actual fractions thus resulting are—

when $a = 1, \ldots \frac{1}{2}, \frac{2}{3}, \frac{3}{5}, \frac{5}{8}, \frac{8}{13}$, &c.
$a = 2, \ldots \frac{1}{2}, \frac{1}{3}, \frac{2}{5}, \frac{3}{8}, \frac{5}{13}$, &c.
$a = 3, \ldots \frac{1}{3}, \frac{1}{4}, \frac{2}{7}, \frac{3}{11}, \frac{5}{18}$, &c.
$a = 4, \ldots \frac{1}{4}, \frac{1}{5}, \frac{2}{9}, \frac{3}{14}, \frac{5}{23}$, &c.

The spiral is not always constant throughout the whole length of an axis. The angle of divergence may alter either abruptly or gradually, and the phyllotaxis thus becomes very complicated. This change may be brought about by arrest of development, by increased development of parts, or by a torsion of the axis. The former are exemplified in many Crassulaceæ and Aloes. The latter is seen well in the Screw pine (Pandanus). In the bud of the screw pine the leaves are arranged in three orthostichies with the phyllotaxis $\frac{1}{3}$, but by torsion the developed leaves become arranged in three strong spiral rows running round the stem. These causes of change in phyllotaxis are also well exemplified in the alteration of an opposite or verticillate arrangement to an alternate, and *vice versa;* thus the effect of interruption of growth, in causing alternate leaves to become opposite and verticillate, can be distinctly shown in Rhododendron ponticum. Again, parts which are usually opposite or verticillate become alternate by the vigorous development of the axis, as in Hippuris, and also in Lysimachia vulgaris, where on different parts of the same stem there may be seen alternate, opposite, and