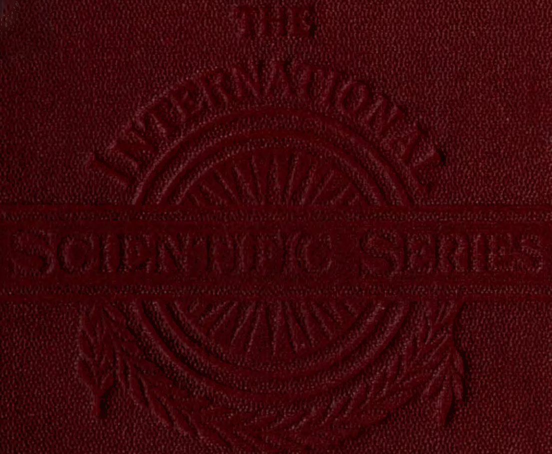

THE
INTERNATIONAL
SCIENTIFIC SERIES

740

SEEDLINGS

A
CONTRIBUTION TO OUR KNOWLEDGE
OF
SEEDLINGS

BY

[Lubbock, Sir John]

THE RIGHT HON. LORD AVEBURY

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WITH 282 FIGURES IN TEXT

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PREFACE

THE germination of plants is certainly not the least interesting portion of their life-history, but it has not as yet attracted the attention it deserves. The forms of cotyledons, and the fact that they differ so much from the subsequent leaves, had of course been alluded to more or less fully in botanical works, but no explanation had been offered, and KLEBS[1] in a recent memoir expressly states that the problem is still an enigma.

Under these circumstances it seemed to me that the subject was very promising, and it was evident that Kew would afford unrivalled opportunities for such an investigation. I applied, therefore, to Sir JOSEPH HOOKER, and I cannot too cordially thank him, as well as his successor, Mr. THISELTON DYER, and indeed the whole of the staff, for the facilities they have offered me, and for their valuable assistance in many ways.

I have also to thank Mr. CARRUTHERS and the Trustees of the British Museum, Mr. LYNCH and the

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[1] *Beitr. zur Morphologie u. Biologie der Keimung*: 'Im Allgemeinen sind uns diese Verschiedenheiten in den Blattformen hinsichtlich ihrer biologischen Bedeutung für die Pflanze ein Räthsel.' *Untersuch. Bot. Instit. zu Tübingen*, 1884.

authorities of the Cambridge Botanic Gardens, and other friends, especially Mr. HANBURY, for the gift or loan of many rare or interesting specimens. By degrees a large store of material accumulated, which I made use of for several papers which the Linnean Society has done me the honour of publishing in their Journal. I thought, however, that it would be well to publish descriptions and figures of the more interesting species, especially as many of them are not often grown from seed, and are therefore not easily procurable.

The full particulars are given in a larger work 'A Contribution to our knowledge of Seedlings,' published in two volumes by Messrs. Kegan Paul & Co. I have here given those parts which seemed of most general interest, and must refer those who wish for more detailed observations to the above-mentioned work.

The seedlings were drawn in most cases either by Mr. HENRY, or by my assistant, Mr. FRASER, to whose skill and ability I am greatly indebted. In the classification, &c., I have followed BENTHAM and HOOKER'S great work, the 'Genera Plantarum.' My time has latterly been so much occupied with other matters that Mr. RENDLE has been good enough to see the book through the press. Sir JOSEPH HOOKER has also most kindly looked through the proofs, and made many valuable suggestions, for which I beg to offer him my very warm thanks.

HIGH ELMS, DOWN, KENT.

A CONTRIBUTION
TO OUR
KNOWLEDGE OF SEEDLINGS

FORMS OF LEAVES.

I HAVE elsewhere[1] called attention to the forms of leaves, and discussed the causes to which we may ascribe the endless differences which they present. Vertical leaves, for instance, are generally long and narrow, horizontal ones have a tendency towards width, which brings the centre of gravity nearer to the point of support. Wide leaves, again, are sometimes heart-shaped, sometimes palmate. The former shape is obviously that which would arise if a linear leaf were gradually widened at the base; and I have pointed out that in many species with palmate leaves—for instance, species of Passiflora, Cephalandra, Hibiscus, &c.—the first, or few first, leaves are entire and more or less cordate.

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[1] *Flowers, Fruits, and Leaves* (Nature Series), Macmillan & Co. See also various papers in the *Journal of the Linnean Society*.

The cordate form, then, appears to be the early, the palmate a later form. But how has the palmate form arisen?

The origin is perhaps connected with the manner in which the leaves are folded up, more or less like a fan, into the bud, so as to save space.

Another advantage perhaps is that in cordate leaves with veins following the curvature of the leaf—as, for instance, in Tamus (fig. 1)—the vascular bundles pursue necessarily a curved course; while in palmate leaves, as in Acer (fig. 2), the veins are straight; and it is clearly an advantage that the main channels which convey the nutritive fluid should hold a direct course. In such cases the leaf naturally assumes the lobed form with the vein running to the point of each lobe. There has indeed been some question whether the path of the sap lies mainly in the cell-walls or in the cell-cavities; but

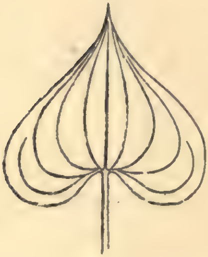

FIG. 1.—Leaf of *Tamus*, to show the curved course of the veins.

FIG. 2.—Leaf of Sycamore (*Acer*), to show the straight course of the veins

the evidence seems to point strongly to the latter view.[1] The tracheids of, say, the Yew 'are at least seventy or eighty times as long as they are broad, so that in travelling transversely the length of a single tracheid the water-current has to traverse seventy cell-walls instead of one.'[2]

In reply, then, to the question why some plants should have cordate leaves with curved veins, while others have palmate leaves with straight ones, I suggested that the first retains the old form of leaf, while the latter has assumed one which presents certain advantages.

We can also see a relation between the shape and size of the leaf and the length of the internode. For instance, in the common Lime the leaf-stalks are arranged at an angle of about 40° with the branch, and the upper surfaces of the leaves are in the same plane with it. The result is, they are admirably adapted to secure the maximum of light and air.

'In the Beech (fig. 3) the general plane of the leaves corresponds with that of the branch, but the leaves themselves are ovate in form, and smaller, being only from two to three inches in length. On the other hand, the distance between the nodes is also smaller, being, say, one and a quarter inch against something less than two inches. The diminution in length of the internode is

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[1] See, for instance, Darwin and Phillips, 'On the Transpiration Stream in Cut Branches,' *Proc. Cambridge Phil. Soc.* vol. v.

[2] *Loc. cit.* p. 364.

not, indeed, exactly in proportion to that of the leaf, but, on the other hand, the leaf does not make so wide an angle with the stem. To this position is probably due the difference of form. The outline of the basal half of the leaf fits neatly to the branch, that of the upper half follows the edge of the leaf beyond, and the form of the inner edge being thus determined, decides the outer one also.'[1]

FIG. 3.—Beech.

FIG. 4.—Spanish Chestnut.

In the Spanish Chestnut (fig. 4) the terminal branches are stouter in proportion, and can therefore carry a greater leaf-surface. The width of the leaf, however, being determined by the distance between the internodes, the leaf is, so to say, compelled to draw itself out, and hence the peculiar sword-like shape.

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[1] Lubbock, *Flowers, Fruits, and Leaves.*

We are so accustomed to the form of the oak leaf that it does not strike us as anything peculiar, and comparatively few of us, perhaps, have ever asked why it should be as it is. And yet it is peculiar, unlike that of any of our forest trees, and those of the evergreen oaks so abundant in hotter countries.

In botanical phraseology it is 'deciduous, oblong-oblanceolate, or oblong-elliptical, sinuated, with blunt lobes extending not more than halfway down to the mid-rib.' The sinus between the lobes is generally rounded off at the bottom.

Again, though I have not found this mentioned in the botanical works which I have consulted, they are rarely symmetrical, the lobes of the two sides not corresponding.

The three points, then, which give the oak leaf its peculiar form are :—

1. The deep rounded sinuses.
2. The want of symmetry of the two sides.
3. The obovate or oblanceolate outline.

The explanation which I would suggest is as follows. The leaves of the evergreen oak are entire, and small in comparison with those of the English oak. During the winter and early spring they are protected by a series of brown scales, inside which they lie, and with which they form the buds which are so familiar to us, and which are both small and short in proportion to the size of the leaves themselves.

In cooler and moister regions, on the contrary, there is, as we know, a tendency for leaves to become larger and deciduous. I will not now enter into the reasons for this, but the fact will not probably be denied. These influences do not, however, affect the outer scales, which remain as before without any increase of size. But as the leaves have increased in size, and the buds have not, the leaves can no longer retain their original arrangement in the bud. If, for instance, we compare the buds of the oak and of the beech we see that while the leaf of the oak is longer than that of the beech, the bud of the oak is, on the contrary, shorter than that of the beech.

Under these circumstances, what must happen? The leaf grows and becomes longer than the bud; it is therefore necessarily bent into a curve. But an entire leaf, if thus thrown into a curve, would necessarily fall into folds, the number being determined by the number of ribs or veins. For such folds, however, there would be no room within the narrow limits of a bud, or rather, perhaps, they would be inconvenient because they would leave more or less empty spaces.

This may be rendered more clear by taking a piece of cloth or paper, folding it up, and then throwing it into a curve. It will then necessarily fall into one or more folds. If it were strengthened, as an oak leaf is, by three or four side ribs, there would be a fold between each two ribs. As a matter of fact, however, from the absence of space the membrane where the fold would be is not actually developed. We may imitate this by removing them. If this be done, the result will be the formation of sinuses, rounded at the base, closely resembling those so characteristic of the oak leaf. These sinuses are due, then, as I believe, to the curvature of the leaf, owing to the shortness of the bud in comparison with the length of the leaf.

The young leaf is not only curved, it is wrapped round the interior leaves. The result of this is that one side of the leaf is folded within the other; the one therefore has more space than the other. The two sides of the leaf are in fact differently situated, and this, I believe, accounts for the second point—namely, the want of symmetry.

The obovate form is an advantage in consequence of the way the leaves diverge from the stalk.

I think, then, that the explanation I have suggested accounts for all these points, and beautifully explains the peculiar form assumed by the leaf.

The leaves of the Tulip-tree (*Liriodendron*) have long attracted attention from the peculiarity of their form.

They are saddle-shaped, abruptly truncate at the end, or, in the words of Bentham and Hooker, 'sinuato-4-loba.' I have often wondered what could be the purpose or the advantage to the tree of this remarkable shape. One idea which occurred to me was that the difference of form might enable insects to perceive the tree at some distance, just as the colours of flowers are an advantage in rendering them more conspicuous. I then looked closely to see whether the peculiar forms could in any way be explained by the position of the leaves on the tree. I believe, however, that the cause is of a different nature, and has reference to the peculiar character of the bud.

Each young leaf is, as in the family Magnolieæ generally, originally enclosed in, and sheltered by, the stipules of its predecessor. These are in Liriodendron oval, or in form resembling a shallow dish or spoon, so that, when placed face to face, they form a hollow almond-shaped body. The first of these neat little boxes which I opened showed the young leaf in the stage shown in fig. 5, *p* being the petiole, *l* the lamina of the leaf, and *s* the stipule. This threw me off the scent, as it seemed to give no clue whatever to the peculiar form of the leaf. Eventually, however, on examining younger buds, I found what I believe to be the true

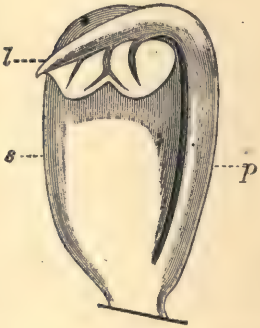

FIG. 5.—*Liriodendron.* Position of young leaf in bud. × 12.

FIG. 6.—*Liriodendron.* Very young leaf and stipule. × 20.

FIG. 7.—*Liriodendron.* Very young leaf and stipule. Second stage. × 20.

explanation. Within the stipules of such a bud as that represented in fig. 5 are contained several younger buds, one within the other. The youngest stage which need here be mentioned is represented in fig. 6. The petiole is short and thick, the lamina is widest in the middle, and tapers regularly towards both base and apex; the stipules are in the form of a hemisphere. Gradually the stipules become more oval (fig. 7), assuming an almond-like form, somewhat thicker in the middle, tapering away to the sides, and more gradually to the apex. The petiole has also elongated, and the lamina of the leaf is more abruptly turned downwards; so that the petiole passes up one side of the stipule, while the midrib passes round the tip of the stipule and down again on the other side. The lamina itself has considerably enlarged, is conduplicate

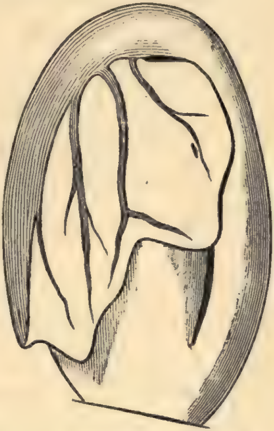

FIG. 8.—*Liriodendron.* Young leaf and stipule in a rather more advanced stage. × 20.

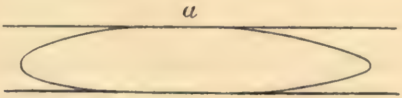

FIG. 9.—Almond-shaped body on and under a glass.

or folded on itself, and lies on one side of the stipule, between its own stipule and one of those by which it is enclosed. It has also considerably modified its form, and for the following reason. The young stipule at its central part touches the surrounding older stipule, so that the young leaf cannot find room between them; while, on the other hand, at the sides and towards the end of the young stipule there is plenty of space for growth. This, I would suggest, accounts for the particular shape it assumes. Suppose, for instance, we lay an almond on a table, and place a piece of glass over it, the glass will touch the almond on a surface, *a* (fig. 9). In the case of Liriodendron, from the form of the bud the surface of contact occupies not only the oval (fig. 10, *a*), but also the space lying below the line *b*. The young leaf therefore cannot retain its original form of lamina, because it is stopped by want of space along the line *a*, which it will therefore follow, as shown in fig. 10. Moreover, the thickened rib or vein (figs. 5 and 8) will be arrested sooner than the thin lamina. When stopped by meeting the stipule, it bifurcates; and this perhaps is one reason why the leaf permanently retains the form which it is thus compelled to assume. The lamina grows for a while

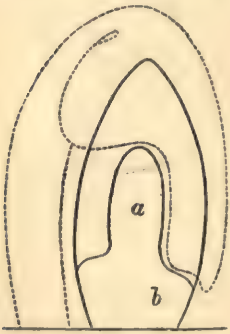

FIG. 10.—Diagram showing arrangement of the young leaf.

somewhat more rapidly than the stipule, then the stipule more rapidly than the lamina; and, lastly, the growth of the stipule is arrested while the leaf attains a considerable size. The terminal portion of the young leaf seems narrower in fig. 8 than it is in the leaf; but it must be remembered that it is to some extent curved round the inner stipule, so that in the figure it is somewhat foreshortened.

It might be suggested that the form of the leaf determines the bud. But in fact the form of the bud is not that of the leaf; the leaf follows, not the form of the bud, but that of the vacant space left in the bud.

In the Firs and Pines the leaves differ little in form, but some are much longer than others. Why is this? I puzzled over it for some time. The governing consideration is, I believe, to secure a suitable amount of leaf surface. They are all evergreen, but in some cases the leaves of one year fall soon after those of the next are developed. In others they are longer lived. In the Scotch Pine they last three or even four years; in the Norway Fir eight to ten; in the Pinsapo even as many as sixteen to eighteen. Now, speaking roughly, and having regard also to the stoutness of the terminal shoots, it will be found that the shorter leaves have longer lives, and *vice versa.*

In my book on 'Flowers, Fruits, and Leaves,' I have also given some account of the causes which have determined the form and structure of seeds and fruits.

FIG. 11.—Seedling of Mustard (*Brassica nigra*). × 3.

FIG. 12.—Seedling of Cress (*Lepidium sativum*). × 3.

FIG. 13.—Seedling of Pink (*Dianthus Caryophyllus*). Nat. size.

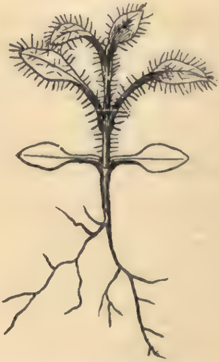

FIG. 14.—Seedling of Mouse-ear Chickweed (*Cerastium*). Half nat. size.

These considerations naturally led me to the study of cotyledons.

No one who has ever looked at seedlings can fail to have been struck by the contrast which the cotyledons afford, not only with the final leaves, but even with those by which they are immediately followed.

Let us then take certain plants (especially, as far as possible, the commonest and most familiar), and see what light can be thrown on the varied forms which their seedlings present. Look, for instance, at the familiar Mustard and Cress; the first (fig. 11) has kidney-shaped cotyledons, one of them rather larger than the other: while the Cress (*Lepidium sativum*) (fig. 12), on the other hand, has the cotyledons divided into three lobes. The Pink (fig. 13) has broad cotyledons, the Mouse-ear Chickweed (*Cerastium*) (fig. 14) narrow ones; those of the Beech (fig. 15) are fan-shaped in outline; those of the Sycamore (fig. 16) shaped almost like a knife-blade; those of Eschscholtzia (fig. 17) divided like a hay-fork; those of the Bean or Acorn thick and fleshy.

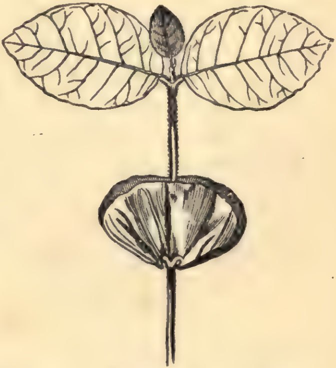
FIG. 15.—Seedling of Beech (*Fagus sylvatica*). Half nat. size.

Mustard and Cress were the delight and wonder of our childhood; but at that time it never occurred, to me at least, to ask why they were formed as they are, and why they differed so much. So they grew, and beyond that it did not occur to me, nor I think to most, that it was possible to inquire.

Fig. 16.—Seedling of *Acer Pseudo-Platanus*. Half nat. size. In this and some other figures, one (or more) of the leaves is given in outline only.

Fig. 17.—Seedling of *Eschscholtzia californica*. Nat. size.

I now propose, however, to suggest reasons which may account for some, at any rate, of these differences.

In previous memoirs I have discussed the causes which regulate the forms of seeds, and will not now, therefore, enter into them. I may, however, observe that the shape of the cotyledons seems to have little, if any, influence on that of the seed.

OVULE AND SEED.

The seed of a flowering-plant contains a more or less highly developed embryo, which, after a certain time, will, under favourable conditions, resume growth, emerging from the seed-coat to produce the young plant or seedling. In the section of flowering-plants known as Gymnosperms, and including the Conifers and Cycads, the seeds are borne naked on an open scale, while in the far larger section of the Angiosperms they are protected till ready for dispersion in the closed cavity of the *Fruit*.

The seed is the result of the fertilisation of the ovule by the pollen. The effect of fertilisation, however, extends in the Angiosperms beyond the ovules to the ovary in which they are contained, causing often a great increase in size, as well as important structural changes. The ovary thus becomes the fruit as the ovule has become the seed.

Sometimes the effect extends still further to other parts of the flower, which thus persist, usually with increased size or change of structure, and form part of what is then termed a *pseudocarp* or false fruit. In the apple, for instance, the edible portion consists of the greatly developed floral-receptacle, which includes the ovary as its core. The ovules are borne usually on some definite part of the ovary wall or walls known as the placenta. They consist of an internal portion, the *nucellus*, one cell of which grows at the expense of the rest to form an *embryo-sac*, which again contains the egg-cell or *oosphere*, and one or two integuments entirely surrounding the nucellus except at the apex, where a small aperture, known as the *micropyle*, is left. In the process of fertilisation the pollen-tube passes down the micropyle to the oosphere which, enclosed in the embryo-sac, approaches very close to the outer wall of the ovule at this point. After fertilisation the oosphere develops into the embryo, the rest of the embryo-sac becoming filled with a cellular tissue, the *endosperm*, containing a store of food for the young plant. This is, however, sometimes reabsorbed before germination, so that the embryo occupies the whole interior of the mature seed. The original substance of the ovule, the nucellus, is often completely displaced by the embryo-sac, and the subsequent development of endosperm in its interior. One or two layers, however, may persist and share with the integuments in the formation of the seed-coats. Occasionally, as occurs in the Nymphæaceæ, Piperaceæ, and some of the Scitamineæ, a considerable portion of the nucellus remains in the mature seed, sharing with the endosperm the function of storing reserve material, or it may quite take the place of the endosperm. It is known as *perisperm*.

There is considerable variety in the position and arrangement of the ovule and subsequently of the seed. They are attached to the placenta by a stalk or *funicle*, the point of connection with the funicle being called the *hilum*. Vascular tissue supplying nutriment runs up the funicle into the integuments, and the point reached in the latter before the nutritive vessels ramify is the *chalaza*.

In some cases, usually where there is only one ovule in the ovary or ovary-cell, as *e.g.* in Buckwheat or Nettle, the ovule stands erect, and the micropyle is opposite the hilum, which in this case coincides with the chalaza. The ovule is then said to be *orthotropous*[1] or straight. But this, though the simplest, is the least common form. More often, as in the Bean, Chickweed, and many others, the ovule during its growth is curved on itself, so that the apex and the micropyle are brought down very near to the base. Such ovules are known as *campylotropous* or curved.

In a third category the ovule itself is straight, but it stands as it were at right angles to the base of attachment. These are called *half-anatropous* or half-reversed.

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[1] Figures of the various positions of the ovule are given in most text-books; see, for instance, Vines' *Students' Text-book of Botany*, p. 437, fig. 284; or Asa Gray's *Structural Botany*, p. 278.

Lastly, in a very large number—in fact the largest—the ovule is quite inverted on its base; the funicle, or stalk, growing with its curvature, and forming a sort of ridge or *raphe*, which is very conspicuous in the ovule, but gradually becomes less and less apparent, finally becoming merged in the seed-coat. The chalaza is thus carried right away from the hilum to the opposite end, and the whole ovule or seed is reversed, so that the true base is removed from, and the true apex brought close to, the point of union with the ovary. Such are called *anatropous* or reversed.

Now this seems a very curious and roundabout arrangement. It is described in all works on general Botany, but those which I have seen do not give any explanation of its object or purpose. I will for the moment omit any consideration of campylotropous and half-anatropous seeds, and confine myself to orthotropous and anatropous forms.

In most orthotropous species, as, for instance, in the Buckwheat, the ovule is straight, upright, and attached by its base to the funicle and base of the ovary. At the free end is the micropyle, and immediately below it the egg-cell, which, when fertilised by the pollen, becomes the rudiment or embryo of the future plant. When the pollen falls on the stigma it soon pushes out a little tube which rapidly elongates, passes into the cavity of the ovary, and entering the micropyle of the ovule fertilises it.

But ovules thus constituted are, as I have already mentioned, exceptional. In a great many plants the ovule, instead of being upright and attached to the base of the ovary, is, on the contrary, attached to the summit and pendent. Now in a pendent orthotropous ovule the micropyle is turned away from the pollen-tube, and the object and effect of the ovule being reversed or anatropous seems to be to bring it back into a convenient position for fertilisation. So also, when there are many ovules, the result of the anatropous arrangement is again to bring the micropyle into a suitable position.

The structure and arrangement of the ovule have been the subject of various important memoirs, which, however, have been almost exclusively descriptive. Dalmer[1] indeed quotes Schleiden, who, speaking of Berberis, pointed out that among the normal anatropous ovules here and there one occurs which is orthotropous, and that these never develop into seeds. The pollen-tubes, however, would naturally follow the regular course; and we could not, I think, deduce a general conclusion from such rare and abnormal cases. Dalmer himself does not seem to have done so; for, after referring to the different forms of ovules, he observes that '*sometimes* the form of the ovule appears to be adapted so as to facilitate the entrance of the pollen-tube.' Even here, then, the explanation I venture to suggest seems referred to rather as an exceptional occurrence than as a general explanation of this remarkable arrangement.

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[1] 'Ueber die Leitung der Pollenschläuche bei den Angiospermen,' *Jenaisch Zeits.* 1880, p. 530.

It must be admitted that there are some cases in which the anatropy of the ovule appears at first sight rather disadvantageous than otherwise. Most of these can, I believe, be explained, while in some it is possible that some plants retain, even perhaps to their present disadvantage, an arrangement inherited from an ancestral condition in which it was beneficial. I hope, however, to enter into this question more fully on a future occasion.

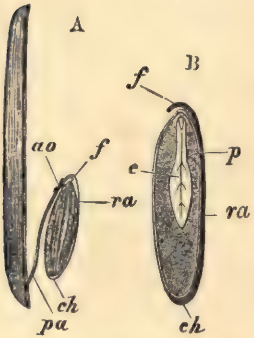

Fig. 18.—*Fraxinus excelsior.* A, samara with half removed and the seed pulled out, nat. size: *pa*, placental axis; *ao*, aborted ovules; *f*, funiculus; *ra*, raphe; *ch*, chalaza. B, longitudinal section of seed, × 2: *f*, funiculus; *p*, endosperm; *e*, embryo; *ra*, raphe; *ch*, chalaza.

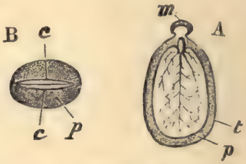

Fig. 19.—*Ricinus sanguineus.* A, longitudinal section of seed, nat. size. B, transverse section of seed, nat. size. *c*, cotyledon; *m*, caruncle; others as in fig. 18.

The mature seed contains the more or less differentiated embryo, in some cases, as in Larkspur (*Delphinium*) (fig. 23), very small, consisting only of a small basal portion, the radicle, which on germination gives rise to the primary root, and one (Monocotyledons), two (Dicotyledons), or several (Conifers) seed-leaves or cotyledons, sheathing a microscopic bud, the *plumule*—from which the future stem is developed. The rest of the space is occupied by the mealy, oily, fleshy, or horny endosperm. In other cases, as in the Ash (*Fraxinus*) (fig. 18) or Castor Oil (*Ricinus*) (fig. 19), the embryo is much larger, and we find a little miniature plant, generally white, sometimes green, but still embedded in endosperm. In others, again, the endosperm is reduced almost to a film, as in Hippophaë (fig. 20), and finally, as in the Bean (fig. 21), the embryo occupies the whole seed, and the nourishment intended for the young plant is stored up in the cotyledons themselves. Similarly, in a Walnut, the two halves of the seed are filled by the two cotyledons, and attached to them may be found the little plantlet with a delicate white radicle, and a little plumule bearing five or six minute rudiments of leaves, often just tipped with green.

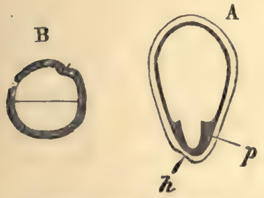

FIG. 20.—*Hippophaë rhamnoides.* A, longitudinal section of seed, × 4. B, transverse section of seed, × 4.

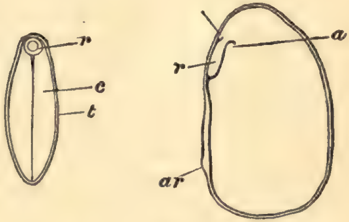

FIG. 21.—*Phaseolus multiflorus.* Section of seed parallel and vertical to cotyledons, three-fourths nat. size: *a*, *a*, auricles; *ar*, arillode; *r*, radicle.

The Bean and Walnut are instances of *exalbuminous* or non-endospermic seeds, while those containing endosperm (or perisperm) are termed *albuminous.* The seed-coat is double in cases where the ovule was provided with two integuments, the outer coat, or *testa,* developed from the outer integument, being the stronger and often crustaceous in texture. The inner coat or *tegmen* is thin or soft and delicate, conforming closely to the surface of the endosperm or embryo. It is developed chiefly from the inner integument of the ovule, and is therefore wanting in ovules with only one coat.

The testa is often provided with appendages or outgrowths of very diverse form and nature, but generally having reference to dissemination of the seed, as in the case of wings or tufts of hair. A more or less incomplete accessory seed-coat is sometimes formed between the time of fertilisation and ripening of the seed. This is known as an *aril.* Good instances are seen in the Water Lily (*Nymphæa*) and the Yew. Crest-like or wart-shaped appendages developed during the same period are known as *strophioles* or *caruncles.* The Castor Oil (*Ricinus*) supplies a good instance of the latter (*m,* fig. 19).

NUMBER AND SIZE OF SEEDS.

As regards the size of seeds, if we could imagine a state of things in which every seed grew and attained maturity, it would be sufficient to keep up the number of any given species existing at any time if each plant produced but one or two seeds during its whole life. There is, however, an enormous destruction of seeds. The great majority are eaten by animals, or fail to secure a suitable site for germination; of those which do germinate, again, many are crowded out by their fellows. Darwin observed that out of 357 seedlings which came up in a space of 3 feet by 2, no less than 295 were destroyed by slugs and insects. Now the greater the chance against any given seed reaching a suitable locality and attaining maturity, the larger number of seeds must the plant produce in order to maintain its numbers, and, as a general rule, the smaller will the individual seeds be. On the contrary, the greater the chance that each seed enjoys of arriving at maturity, the smaller the number of seeds that is necessary, and in such cases it is an advantage that the seeds should be large.

Hence parasitic plants generally produce a large number of very small seeds, though there are exceptions due to other considerations, as, for instance, in the Mistletoe (I believe, indeed, in all the Loranthaceæ), where the seeds are carried by birds.

An interesting illustration is afforded by certain species which produce two kinds of pods, as, for instance, Cardamine chenopodifolia of Brazil. Besides ordinary pods, which resemble those of any other Cardamine, and contain several seeds, this plant produces a second sort of pod underground. Now in the ordinary pods the number of seeds increases, of course, the chance that some one will find a suitable place. On the other hand, the subterranean pods are sown, as it were, by the plant itself. In this case, if there were a number of seeds they would only get in one another's way, and hence, perhaps, the fact that the subterranean pods only produce one or two seeds.

In most species the seeds vary somewhat in size; but in such cases we cannot contrast the produce of large seeds with that of smaller ones, because it might fairly be said that the former were better nourished, and inherently, perhaps, more vigorous. In Cardamine chenopodifolia, however, the seeds from the underground pods are larger than the others, and Grisebach found that they produced more vigorous seedlings.[1]

Some species of Vetch also have two kinds of pods.

The seeds of Atriplex hortensis are of two sizes, the small ones being black, with a rather thick, crustaceous, smooth and shining seed-coat, while the larger ones are brown and more orbicular, with a thin, membranous, smooth but not shining coat. The large brown ones germinate much more quickly than the small black ones, which would seem, under natural conditions, to be more adapted to remain in a resting condition in the ground during the winter, and germinate in spring. If such is the case they would enable the plant to exist in a colder climate than the large ones would. Of a sowing made on October 29, one black seed germinated

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[1] 'Der Dimorphismus der Fortpfl. v. Cardamine chenopodifolia,' *Göttinger Nachrichtungen*, 1878.

in four days, and three days later no more had come up, whereas thirty-two of the large brown seeds germinated in the seven days. On November 16, a sowing was made of thirty-five each of the black and brown seeds. In the course of six days, five of the brown seeds germinated, and only one black seed in the course of thirteen days, whereas by that time twenty-three of the brown seeds had germinated. Twenty-three days after being sown, ten of the black seeds had germinated, and twenty-six of the large brown ones.

There are, on the contrary, other considerations which may make it an advantage that the number of seeds produced by a flower should be reduced, as, for instance, in the case of the Compositæ, where the agglomeration of a number of flowers into a single head, as in the Daisy, and their consequent diminution in size, renders it an advantage that each floret should produce but one seed.

HETEROCARPISM.

The production of more than one kind of fruit by a plant, as in the Brazilian Cardamine just mentioned, I have proposed to call Heterocarpism.

A species of Corydalis supplies another example. Some fruits are slightly flattened, short and broad, with rounded angles, while others are elongated, hooked, and shaped like a shepherd's crook with a thickened staff.

The hook perhaps serves for dispersion. It is possible that the alveolate surface of the seed may serve the same purpose—the depressions imprisoning, as it were, a certain quantity of air, and thus lowering the specific gravity. Again, in Caucalis nodosa (Umbelliferæ) the fruits are remarkable for their dimorphic character. Those on the circumference of the umbel have the outer or most exposed mericarp furnished with a double row of spreading, curved, and hooked bristles on each of the secondary ridges, while the corresponding more protected and centripetal carpel as well as all the rest of the fruits are only muricate on the secondary ridges.

FIG. 22. *Calendula officinalis*, × 8.

The polymorphic forms of the fruits of Calendula even on the same receptacle are very remarkable. In the Marigold (*C. officinalis*) at least three very distinct and salient types may be noted. Two or three rows round the periphery or margin of the receptacle consist of greatly elongated curiously constructed, curved achenes, muricate on the back, often beaked at the apex and produced into a foot-like process near the base on the inner face. The middle set of fruits is furnished with broad wings involute at the margin, but neither beaked at the apex nor produced into a foot at the base. Those about the centre of the receptacle are greatly incurved, often forming a complete ring, and have narrow wings involute at the margin. The seeds at first sight closely resemble a small curled grub or caterpillar. The embryo is cylindrical in all three cases, curved, gradually tapered into the radicle, and otherwise similar except that in the middle series it is not so strongly curved.

It would seem, then, as if we have here three devices for promoting dispersion—one by means of a wing, one by the presence of a hook, and one by resemblance to an insect.

During germination all three kinds behave in a similar manner, except that in the broadly winged fruits of the middle series (fig. 22) the radicle runs along the groove formed by the strongly involute wings till it reaches the apex of the fruit when it turns downwards and enters the soil, firmly fixing the fruit to the ground while the elongating hypocotyl extricates the cotyledons. In all three cases the radicle emerges at the base of the fruit which splits longitudinally by three valves, thus facilitating the exit of the embryo. The splitting of the fruit is brought about by the energy or force of the rapidly swelling cotyledons.

The fruits of C. pluvialis are dimorphic. Those at the periphery of the receptacle are broadly obovate or suborbicular, flattened, and smooth with broad flat wings. The embryo is straight in conformity with the fruit. The other fruits are obovoid, not flattened, and muricate all over the surface. In C. hybrida the fruits are also dimorphic. The outer ones of the receptacle are obovate, much flattened with broad flat wings. Those of the centre of the receptacle are obovoid, slightly curved or straight, trigonous and toothed on all the three angles. The embryo is straight or nearly so in both cases. The fruits of C. gracilis are also somewhat dimorphic, judging from the specimens observed. One kind is curved so as to form a complete annulus, and it is muricate in transverse wavy ridges. In the other case the annulus is not complete and the muricate ridges on the back are nearly obsolete.

There are three or four different forms of fruit in C. algarviensis. Those on the periphery of the receptacle are oblong, straight or slightly curved, not winged but prolonged at the apex into a slender beak. The next series consists of fruits with narrow, strongly involute wings, muricate along the back with three rows of teeth, and coiled so as to form a complete annulus. In a third set of fruits the annulus is less complete, the wings are absent, and the back is merely rugose in transverse obtuse ridges. In the fourth or central series the fruits are very small, apparently imperfect, and not completely annular.

SIZE OF EMBRYO.

As already mentioned, there are many cases, in fact many whole orders, in which the ripe seed is entirely occupied by the embryo; in other cases, again, as in

Delphinium (fig. 23), the embryo is very small, and examples of every intermediate stage might be given.

Where it is an advantage to the plant that germination should be rapid, this of course can be more readily secured if the embryo is large. In fact, we find that species with large embryos, such, for instance, as the Cabbage or Pea, germinate much more rapidly than those, such as Umbellifers, Ranunculaceæ, &c., in which the embryos are small.

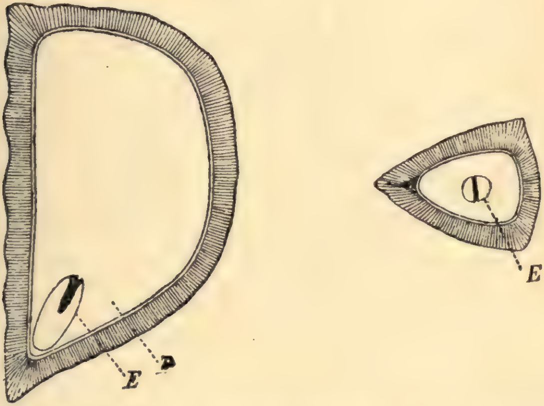


FIG. 23.—Longitudinal and transverse sections of seed of *Delphinium Staphysagria*, × 12: *E*, embryo; *P*, endosperm.

On the other hand, in some cases, time is less important, and here other considerations come into play. The protection of the embryo is mainly effected by the outer coverings; but the endosperm itself contributes also, especially where it is hard, as in the Date and

Vegetable Ivory (*Phytelephas*), and hence a small embryo is less liable to injury.

ARRANGEMENT OF THE EMBRYO.

In albuminous seeds the arrangement of the embryo presents no special difficulties, as the endosperm simply fills up all vacant spaces. In exalbuminous, on the contrary, Nature has to exercise much ingenuity, and adopts various devices to fill up the whole space.

One plan is to arrange the cotyledons face to face, and then roll them up in a ball. This is adopted, amongst other cases, in the Sycamore (fig. 16) and hence the long strap-like form of the cotyledons. Another is to arrange the cotyledons face to face, and then double them up, as in the Cabbage, Mustard, and Radish (fig. 135, B–D).

FIG. 24.—*Cordia subcordata.* Half nat. size.

In a third the cotyledons are convolute edgeways, as in Calycanthus.

In Lepidium sativum the cotyledons are trifid (fig. 12); in Cordia they are thrown into plaits (fig. 24). In others we have still more complex folds, as in the Beech.

In such cases as the Lupine the cotyledons become so fleshy and thickened that they almost lose the appearance of leaves; in this instance they are set free by the splitting of the testa.

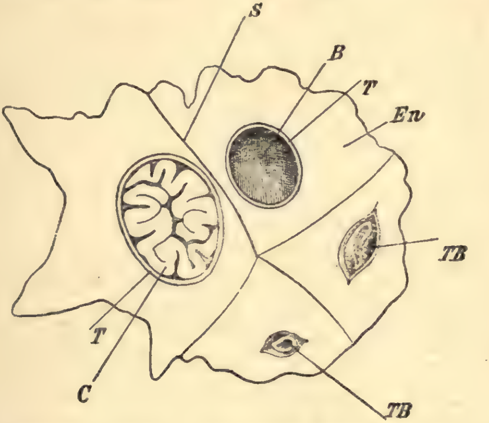


FIG. 25.—*Cordia subcordata.* Transverse section of nut, × 4: *T*, testa; *C*, cotyledon; *TB*, *TB*, testa of barren seeds in empty cells; *En*, endocarp; *B*, barren cell with testa, *T*; *S*, sutural line.

In the arrangement of a large embryo in a seed there are two ways in which the radicle may be bent over the cotyledons.

Sometimes it is turned up over the back of one of the cotyledons, as in figs. 26 and 27, and is said to be incumbent; while sometimes it is turned along the edge of the cotyledons, as in figs. 28 and 29, which are then termed accumbent. The divisions of the Cruciferæ are based to some extent on this character, some groups being accumbent and some incumbent. I puzzled for some time over the reasons which could account for this difference, though the explanation which I would suggest is very simple when once stated.

Fig. 26.

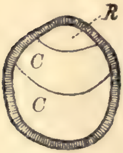
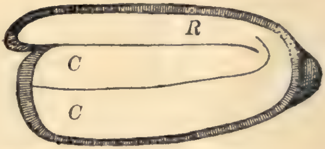


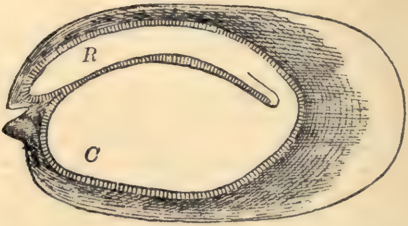
Fig. 27.



Figs. 26 and 27.—Sections of seed of *Hesperis matronalis*, × 10: *R*, radicle; *C*, cotyledons.

Fig. 28.

Fig. 29.



Figs. 28 and 29.—Sections of seed of Wallflower (*Cheiranthus Cheiri*), × 10.

I scarcely feel justified, however, in doing more than throwing it out as a suggestion.

Seen in section the two forms would be as shown in figs. 26 and 28. Now if from the form of the pods, or for any other reason, it is an advantage that the seed should be compressed, as in fig. 28, then, the thickness of the cotyledons remaining the same, it is better that the radicle should be accumbent; while, on the other hand, in a thicker or globular seed, as in fig. 26, the incumbent arrangement is most convenient. In fact we find that in groups, such as the Arabideæ, where the seeds are as a rule compressed, the radicle is almost always accumbent; while in incumbent groups, such as the Sisymbrieæ, the seeds are, on the contrary, more or less turgid. As an actual example of an incumbent form I give Hesperis matronalis (figs. 26 and 27), and of an accumbent, Cheiranthus Cheiri (figs. 28 and 29).

POSITION OF THE EMBRYO IN THE SEED.

As a general rule, the arrangement and position of the embryo in the seed is approximately the same within the limits of any one genus. There are, however, many exceptions.

In Carum Carvi (fig. 30), for instance, the seed is five-angled, and closely conforms to the interior of the mericarp which it fills.

The straight embryo, which is comparatively large for the size of the fruit and also for the Order, is embedded in a copious fleshy endosperm. The cotyledons are oblong, obtuse, entire, plano-convex, and slightly longer than the radicle, lying with their backs or their edges to the axis of the fruit, or obliquely. All these positions seem to be taken indifferently, and two of them frequently in the same cremocarp. In another species of the same genus, C. Ajowan (fig. 31), where the conditions

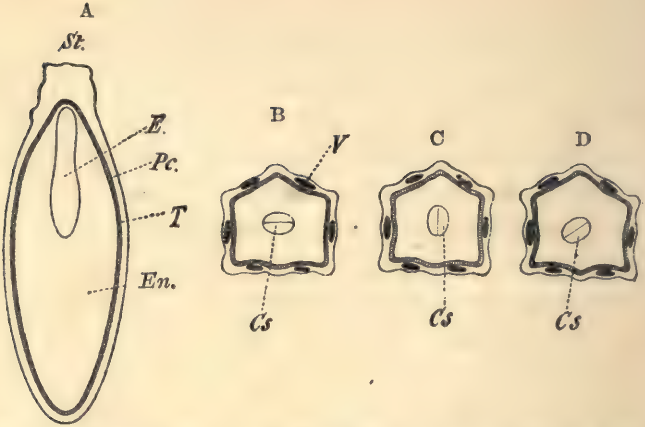


Fig. 30.—*Carum Carvi*, × 10. A, longitudinal section of fruit: *St*, stylopodium; *E*, embryo; *Pc*, pericarp; *T*, testa; *En*, endosperm. B, C, and D, transverse sections of the mericarp showing the cotyledons (*Cs*) in three different positions, transverse at right angles, and oblique in relation to the axis of the fruit: *V*, vitta or oil canal.

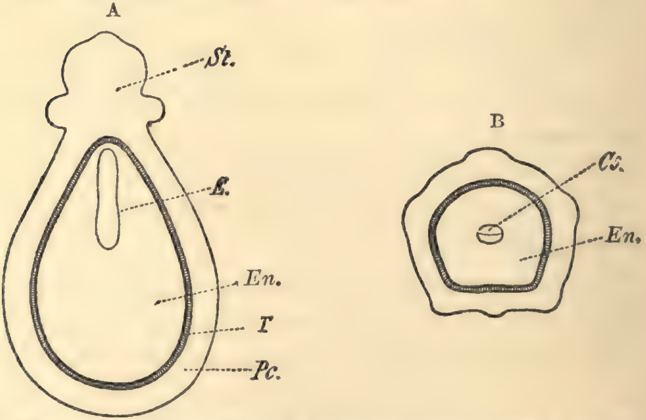


Fig. 31.—*Carum Ajowan*, × 24. A, longitudinal section of fruit *Pc*, pericarp; *T*, testa; *En*, endosperm; *E*, embryo *St*, stylopodium. B, transverse section of fruit: *Cs*, cotyledons.

in the seed are very similar, the position of the cotyledons with their backs to the axis seems to be constant.

In the genus Plantago the cotyledons sometimes have their faces and sometimes their edges to the placenta. This difference is not indeed mentioned either by Barnéoud or Decaisne in their respective monographs of the family. Bentham and Hooker, however, say ('Genera Plantarum,' vol. ii. p. 1223):—'Embryo rectus v. rarius hippocrepicus, hilo parallelus v. in fructu monospermo erectus v. transversus.'

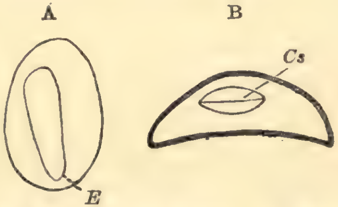


FIG. 32.—*Plantago media*. A, longitudinal section of seed, × 8: *E*, embryo. B, transverse section of seed, × 8: *Cs*, cotyledons.

In P. media the fruit is capsular, dry, membranous, 2-celled and 2–4-seeded. The seeds (fig. 32) are plano-convex or sub-concavo-convex, peltate, small, with equal obtuse ends; or with the basal end slightly the broader; the testa is thin, pale brown; the hilum a little below the middle on the ventral aspect, round, and deeper brown than the rest of the testa; the raphe tapers from the hilum obliquely towards the upper end of the testa. The endosperm is copious, fleshy, and white. The embryo is straight, narrow, white, a little shorter than the endosperm, and embedded in it, a little nearer the dorsal aspect of the seed and somewhat oblique to the median axis; the cotyledons are linear-spathulate, tapering towards the base, obtuse, entire, and with their faces towards the placenta; the radicle is inferior, obtuse, and shorter than the cotyledons.

In P. lanceolata (fig. 33) the capsule is also 2-celled, with one seed in each cell. The seed is concave on the ventral side, at first pale green, at length becoming yellow. The hilum is oval, forming a white or pale spot about or a little below the middle on the ventral aspect. The endosperm is abundant, fleshy, or almost horny when dry, and semitransparent. The embryo is straight, white, embedded in the endosperm, and a little shorter than the seed. The cotyledons are narrowly oblong or linear, obtuse, plano-convex, closely applied face to face, and with their edges to the placenta. The radicle is narrower than the cotyledons, inferior, and tapering downwards.

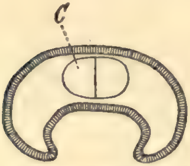


Fig. 33.—*Plantago lanceolata.* Transverse section of seed, × 12: *C*, cotyledons.

In P. Coronopus the capsule is many-seeded. The seeds are oblong-oval, suddenly tapering to an obtuse point at the lower end, small, in transverse section somewhat diamond-shaped, with the angles rounded off, and attached to the placenta considerably below the middle. They are much smaller than those of P. media, and differ much among themselves. The embryo is comparatively large, straight, central, nearly equalling the endosperm in length; the cotyledons are linear, obtuse, entire, plano-convex, thick, closely applied face to face, and with their edges to the placenta.

In P. maritima the fruit is narrowly ovoid, 2-celled, 2-seeded. The seed is oblong-lanceolate, biconvex or flattened on the ventral side. The embryo is straight, large, and nearly fills the seed; the cotyledons have their edges to the placenta.

In P. Cynops the fruit is green, with a pale line where the two carpels come together, and a darker one along the middle of the carpel, giving it in a young state the appearance of consisting of four carpels, 2-celled, 2-seeded. The seed is ovate, obtuse, peltate, compressed dorsally, concave on the ventral side, smooth, shining, deep green when young, and sufficiently transparent to show the embryo by transmitted light. The embryo is straight; the cotyledons linear, obtuse, entire, closely applied face to face, with their edges to the placenta.

In P. arenaria and P. major the cotyledons are also placed with their edges to the placenta.

I was for some time much puzzled as to why the cotyledons in P. media should be placed differently from those of the other species examined; though the reason seems in reality very simple. At first I thought it might have reference to the mode in which the embryo emerges from the seed; but this does not seem to have any bearing on it. In P. lanceolata, however, and its allies the cotyledons are narrow and thick; and the seed being somewhat compressed, it will be seen from fig. 33 that if the embryo had been placed with the faces of the cotyledons to the placenta, it would not have had room to develop.

On the other hand, in P. media (fig. 32) the reverse is the case: the cotyledons are thin and comparatively wide; their width, in fact, is greater than their thickness. It follows that, if they had been arranged as in the other species, they would not have had room to develop. The difference of position is therefore explained by the fact that in P. media the width of the cotyledons is greater than the thickness; while in P. lanceolata &c., on the contrary, the thickness of the two cotyledons, taken together, is greater than their breadth.

The normal arrangement of an embryo in the seed is to have the faces of the cotyledons turned to the placenta. There are, however, not a few cases in which, as in these species of Plantago, the cotyledons have their edges to the placenta. When this is the case, it may be suggested as possible that the position is due to the fact of the seeds being more or less, in some cases very much, flattened; and that the embryo is twisted round at right angles to its normal position, so that the cotyledons may lie in the broad way of the seed, as in Ailanthus, Euonymus, Passiflora, Linum, Fraxinus, Diospyros, Heliotropium, and many Crucifers, Leguminosæ, and Rosaceæ.

On the other hand, in the case of Claytonia (fig. 34) this explanation will not apply. There would appear no reason, so far as the seed is concerned, why the cotyledons should not lie in the usual position.

It has occurred to me that perhaps the arrangement of the cotyledons may have reference to their exit from the seed. If we examine a germinating seedling of Claytonia we shall see that the testa splits vertically from the micropyle, and the cotyledons from their position, when they separate, act with greater advantage in enlarging the orifice, and thus securing their exit, than they would if they occupied the more usual position. This, however, I only throw out as a suggestion which requires further investigation.

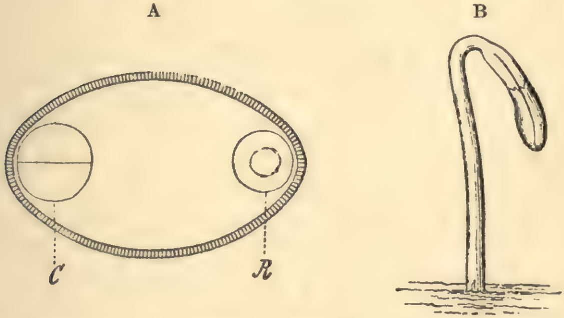


Fig. 34.—*Claytonia perfoliata.* A, transverse section of seed, × 15: *C*, cotyledons; *R*, radicle. B, seedling, × 6.

When the seed is flattened laterally, the embryo must either be narrow or lie with the edges of its cotyledons to the placenta.

For instance, in Heliophila pilosa the seeds (fig. 35) agree closely in form with those of the Wallflower (*Cheiranthus Cheiri*) (figs. 28 and 29); they are oblong-obtuse at each end, compressed dorsally, with a notch at one end, and in section are narrow elliptic; but while the cotyledons of Cheiranthus are broad, in Heliophila they are long and linear. The reason of this may be that while in Cheiranthus and other Arabideæ the pods are flattened dorsally and the cotyledons are accumbent in the broad way of the seed (figs. 28 and 29), those of the Sisymbrieæ, to which Heliophila belongs, have (fig. 35, A and B) the cotyledons incumbent, so that they lie across the seed, and it is consequently an advantage that they should be linear.

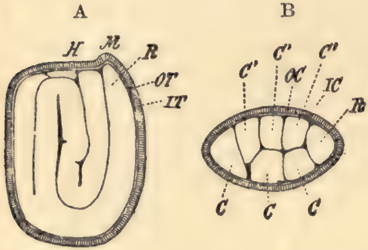


FIG. 35.—*Heliophila pilosa.* A, longitudinal section of seed, × 12. B, transverse section of seed, × 12.

Similar cases occur in other Orders, as, for instance, in Caryophyllaceæ and Solanaceæ.

GERMINATION.

In the great majority of cases the cotyledons escape from the seed and are carried above the ground, becoming green and taking part in the processes of assimilation like foliage leaves.

When, however, the testa does not readily split, and where in large seeds there is no endosperm, the difficulty of unfolding the cotyledons and extricating them from the seed becomes great, and we arrive at cases where Nature seems to have abandoned the attempt, and, as in the Oak and Horse Chestnut, the cotyledons never quit the seed. Thus, among the Juglandeæ, Pterocarya has leaf-like cotyledons, while those of the Walnut never quit the shell. Everyone, however, must have observed the elaborate folds into which the two cotyledons are thrown—folds which seem to have no significance or importance now, and which carry us back to a time when the Walnut, like Pterocarya, had foliaceous cotyledons.

If these suggestions be correct, we should expect that species with non-emerging cotyledons would generally have large seeds and be exalbuminous. This certainly appears to be the rule; among the species with reference to which I have notes, there are 37 genera in which the cotyledons are subterranean or remain in the seed. The seeds themselves are notably large, and all but three are exalbuminous. Some Lupines and Beans present us with an intermediate stage, the cotyledons being aerial, and more or less green, but fleshy and by no means leaf-like. For other cases see pp. 60–90.

Cotyledons which appear above the surface of the soil are said to be *epigeal*, those which remain beneath the surface and never leave the seed, *hypogeal*.

In cases where the seed is well covered, or the primary root has secured a good hold in the soil, the growth of the *hypocotyl* or portion of the axis below the cotyledons, is sufficient to draw the latter out of the seed. Our native hedge-plant, Galium Aparine (fig. 36), will serve as an example.

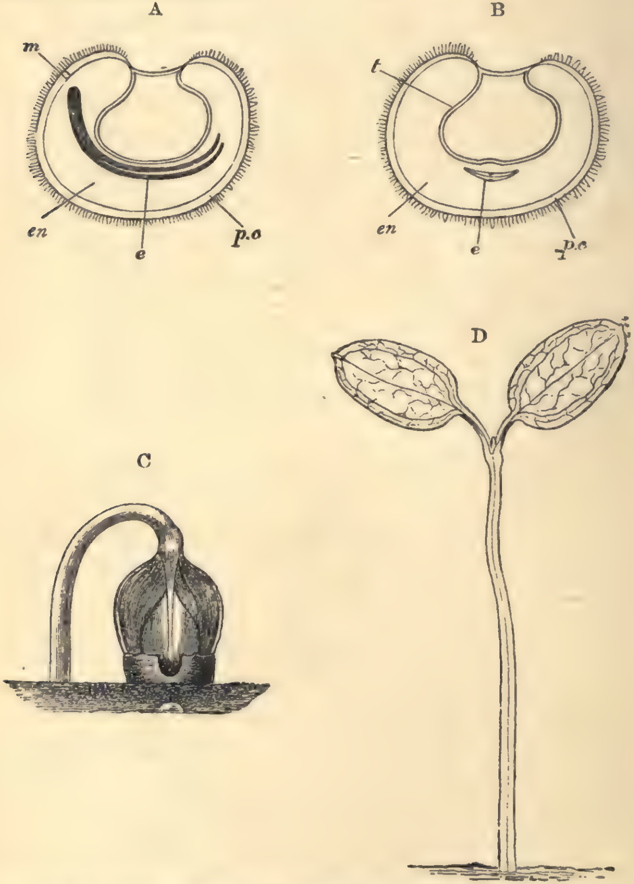


Fig. 36.—*Galium Aparine.* A, longitudinal; B, transverse section of seed, × 8: *e*, embryo; *pc*, pericarp; *t*, testa; *en*, endosperm; *m*, micropyle. C, germinating seedling, × 4. D, seedling, × 2.

During germination the endosperm is gradually absorbed, and the cotyledons increasing at the same time fill the internal cavity of the seed. The radicle pushes its way into the soil where it throws out lateral rootlets and gets a firm hold. The hypocotyl is the first to appear above ground, and if the seed is buried sufficiently deep is able to pull the now largely developed cotyledons out of the soil without the testa; if this is not the case, the testa is carried up on their tips.

In the Water Plantain (*Alisma Plantago*), where the radicle does not at once elongate, the peculiarly thickened hypocotyl produces numerous root-hairs by which the seedling is fixed in the soil or mud. The single awl-shaped cotyledon frees itself by its own growth.

Seeds sown in a greenhouse, in soil sunk in water, germinated in three days.

The hypocotyl first emerges, ending bluntly or even truncately in the very short radicle, with a thickened margin around the tip (fig. 37, A).

Three days after germination (fig. 37, B) the thickened margin at the base of the hypocotyl gives out numerous root-hairs which fix the plantlet in the soil. The place whence the plumule presently emerges is dimly visible at the base of the slender cotyledon. The carpel or achene is now suspended at the tip of the cotyledon. The hypocotyl is very short. The radicle has not yet elongated.

Four days after germination (fig. 37, C) the coty-

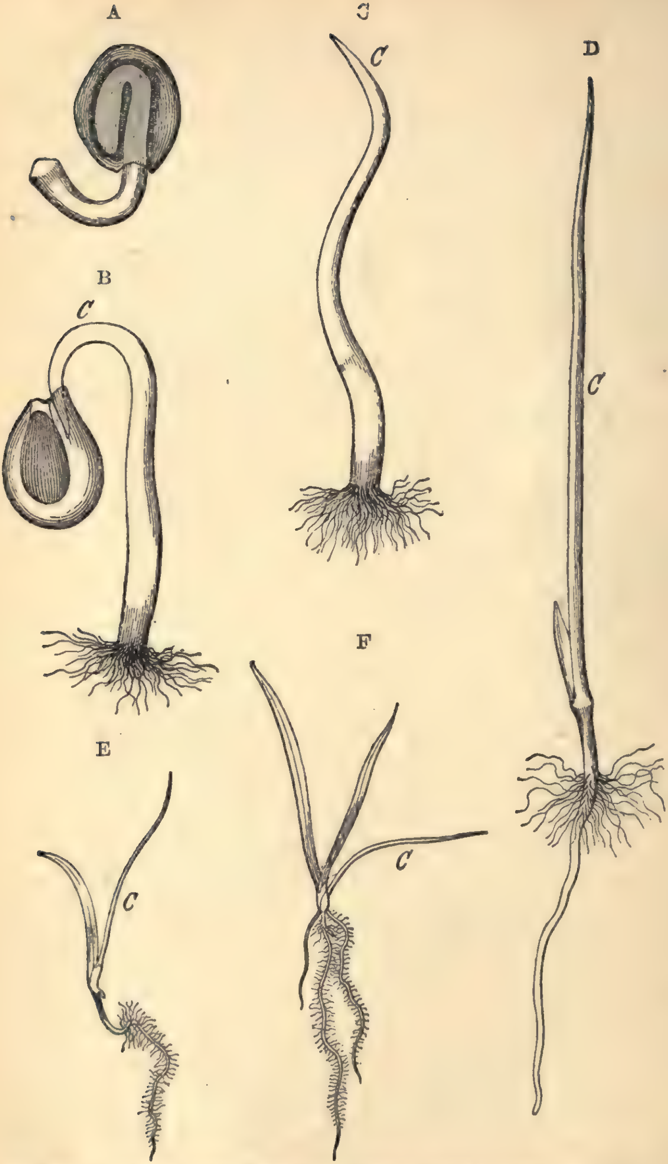


FIG. 37.—*Alisma Plantago*, showing various stages in germination and growth of the young seedling. A, B, and C, × 8; D, × 4; E and F, nat. size. *C*, cotyledon.

ledon rises up, freed from the achene, but is still slightly twisted at the end.

Seven days after germination (fig. 37, D) the cotyledon becomes much elongated, narrowly subulate or filiform, tapering slightly upwards and straight. The root-hairs are still copious at the base of the short hypocotyl, and the radicle has become considerably elongated. The plumule is also considerably advanced, having broken through the sheathing base of the cotyledon by which it has been hitherto protected.

Twelve days after germination (fig. 37, E) the cotyledon has not altered; but the first leaf has appeared. It is linear, acuminate, thin, membranous, and shows a distinct midrib. An adventitious rootlet is seen just pushing from the first node above the hypocotyl. The radicle is elongated and furnished with root-hairs nearly to the tip.

Nineteen days after germination (fig. 37, F) the cotyledon is still unaltered. A second leaf similar to the first has been developed and is also sheathed at the base by the cotyledon. The radicle is elongated and furnished with root-hairs. Adventitious roots well furnished with root-hairs have also sprung from the first node.

The escape of the cotyledons is often facilitated by their being narrow, as probably in the species of Claytonia to which I have already referred; or divided as in Eschscholtzia (fig. 17) and Schizopetalon (fig. 185). Where the seed is enclosed in a stony endocarp which does not burst in germination, their escape is rendered possible by their narrow shape. Symplocos paniculata (fig. 38), a member of the tropical family Styraceæ, may serve as another illustration.

The endocarp of the fruit is obovoid, woody, and does not burst during germination. The radicle emerges by a small hole at the narrow end, the hypocotyl elongates, becoming curved and finally straightening, carrying up with it the endocarp containing the seed. As the cotyledons elongate they push out at the small hole in the endocarp, finally free themselves and spread out to the light.

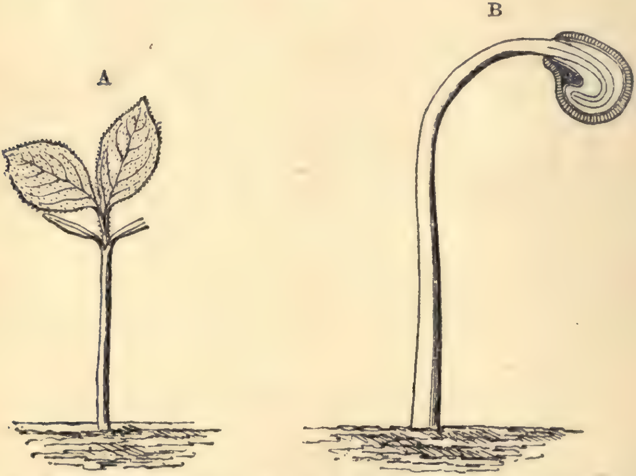


Fig. 38.—*Symplocos paniculata.* A, seedling, nat. size. B, germinating seedling with vertical section of endocarp and seed, showing mode of exit of embryo, × 2.

The cotyledons owe their shape to that of the seed which is reniform or curved, and contains a large quantity of fleshy endosperm. If a seed is cut open during germination the cotyledons are found to be linear, obtuse, and together with the apex of the hypocotyl

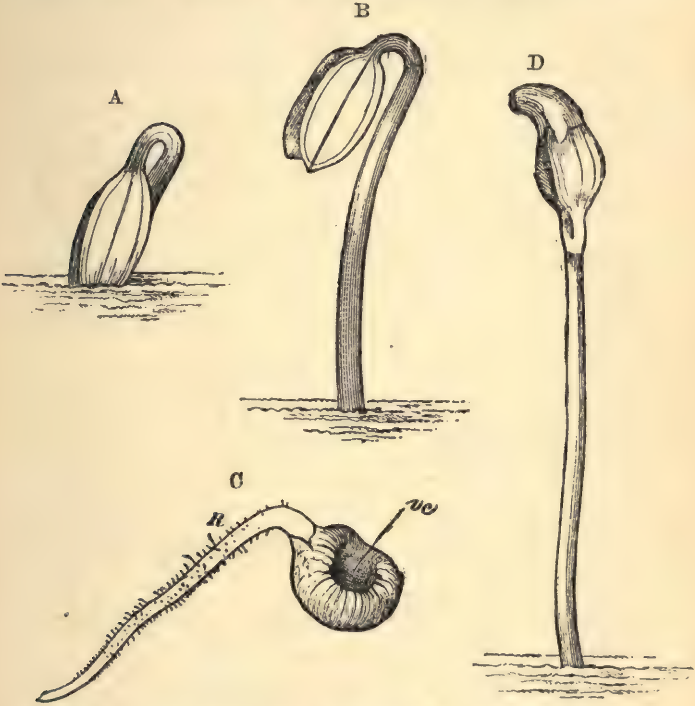


FIG. 39.—*Veronica hederæfolia.* A, seedling, × 4, showing mode of germination when the seed is buried. B, another stage of A, × 4. C, seed germinating when insufficiently buried: *R*, radicle; *vc*, ventral cavity of seed, × 4. D, another seedling, × 4.

curved like the head of a shepherd's staff. Their shape then might be accounted for by the shape of the seed, the quantity of endosperm originally surrounding them, and, thirdly, by the difficulty that broad cotyledons would experience in getting out of the indehiscent endocarp.

As the figures of Alisma and Symplocos show, the seed or one-seeded fruit may be carried up on the hypocotyl or tip of the cotyledons in germination. This is generally due to an insufficient covering of soil. For instance, in the Corn Speedwell (*Veronica hederæfolia*), when the seed is well buried the radicle pushes out first and fixes the plant in the soil, then the hypocotyl arches and in straightening pulls the cotyledons out of the seed.

Two days later the cotyledons get quite clear, an easy process when the seed is properly covered with soil. The hypocotyl elongates greatly meanwhile (fig. 39, A, B).

When the seed has been insufficiently buried, it is carried up with the cotyledons, which have then, as it were, to wriggle their way out (see fig. 39, C and D).

Dipsacus ferox (fig. 40) supplies another instance. The ovary of the Dipsaceæ is simple, being inferior and one-celled, with a solitary pendulous anatropous ovule; but in addition to the true calyx with which it is surmounted, each flower of the capitulum is surrounded by an involucel which completely encloses it, and appears like a second or double calyx. The fruit is an achene surmounted by the persistent rarely deciduous (as in D. ferox) calyx, and is completely enclosed by the involucel, which is also persistent and either surmounted by a lamina varying greatly in size, or truncate at the apex. The seed is solitary and suspended from the apex of the loculus, is covered by a thin membranous testa, and contains a layer of fleshy endosperm. The embryo is straight with a superior radicle and oblong or ovate cotyledons.

In D. ferox the radicle emerges at the apex of the fruit through the mouth of the truncate involucel. Numerous root-hairs are produced on the radicle and the base of the hypocotyl.

The fruit enclosed in the involucel is usually carried up with the cotyledons (fig. 40, about the second day after their first appearance above ground), which by widening have split the involucel along one side.

FIG. 40.—*Dipsacus ferox.* The fruit enclosed in the involucel carried up by the cotyledons in germination. Second day after first appearance above ground. × 3.

Nearly all the seedlings carry up the fruit during germination, but eventually the energy of the expanding cotyledons generally, if not always, suffices to extricate them from their investments and they spread out to the light. They are oblong in shape, and entire with a slightly prominent, apical, colourless tooth; narrowed into a short petiole, with a few obscure lateral nerves; at first pale green in colour, but soon becoming darker.

The fruit and involucel of Scabiosa australis are closely similar to those of Dipsacus ferox, but the behaviour in germination is different.

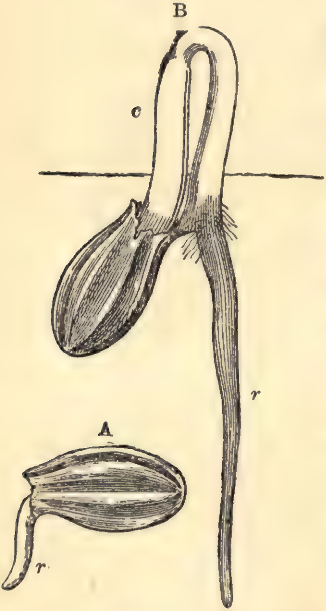


FIG. 41.—*Scabiosa australis*, × 6. Commencement of germination. In A the radicle (*r*) only has protruded; in B the cotyledons (*c*) are nearly free.

The achene closely occupies the interior of the involucel, so that on germination the radicle gets outside immediately and pushes down straight into the soil for a considerable depth, at the same time giving off numerous root-hairs (fig. 41).

If the involucel is fairly well covered with soil the cotyledons, after the long radicle has established itself, are easily and readily pulled out clear of the seed and its investments. The cotyledons in this species are not very broad, because the seed itself is not very thick.

The base of the hypocotyl has a thickened projecting ledge which presses against the rim of the involucel and pins it to the earth while the arching upper part grows upwards and extricates the cotyledons (fig. 41, B).

A third type is represented by Scabiosa Grammuntia (fig. 42). The involucel is furnished with a well-developed cup-like lamina, and the radicle on germinating pierces it, and holds it firmly to the soil by means of a thickening at the base of the hypocotyl while the latter on lengthening draws out the cotyledons. This thickening is symmetrical or equal all round, not unilateral as in S. australis. The fruit of S. Columbaria is rather thicker and shorter, while the cotyledons are also shorter, but in other respects the seedlings agree with those of S. Grammuntia.

In a fourth type the radicle of the germinating seedling pushes through the sides of the involucel, beneath the thickened rim at the base of the lamina. The base of the hypocotyl also has a symmetrical, annular thickening as in the third group. The involucel of Scabiosa palæstina (fig. 44) is salver-shaped and attains a much greater size than that of the other species which I have examined. The lamina is large, membranous and traversed by straight radiating nerves excurrent at the margin, forming a deeply fringed border.

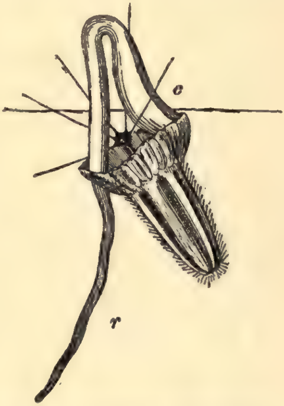


Fig. 42.—*Scabiosa Grammuntia*, × 4. Commencement of germination. *r*, radicle; *c*, cotyledons.

Beneath the thickened rim at the base of the lamina are numerous perforations, through one of which the radicle finds its way, fixing the fruit to the ground.

The radicle in germinating emerges through the opening at the apex of the involucel, easily rupturing the thin membranous pericarp. If the involucel with the fruit is placed mouth downward in the earth (an unnatural position), and but lightly buried or lying on the surface of the soil, the whole may be carried up with the cotyledons. If, on the other hand, the involucel is lying on its side or with its mouth upwards, the radicle proceeds freely a short distance, and then turning down-

Fig. 43.—*Scabiosa palæstina.* Germination, × 2.

Fig. 44.—*Scabiosa palæstina.* Involucel, containing fruit, × 3.

wards passes through one of the openings, and grows deep down into the earth. Some seedlings in the course of germination showed a radicle measuring 20–40 mm. in length, seven days from the time of sowing. This conduct of the radicle is of great importance in a country with the dry climate of Syria; to which the plant is indigenous, not only in its depth of penetration, but in effectually fixing the involucel, pericarp and seed-coat to the earth while the cotyledons emerge and rise up free. The cotyledons afterwards become more or less spread out, oblong and petiolate.

S. graminifolia has likewise a perforated involucel. The thickening of the hypocotyl is well shown in S. atropurpurea (fig. 45). The lamina of the involucel is smaller than in S. palæstina, but there are no perforations in any part of it. The radicle easily pushes its way through the membranous portions at the

Fig. 45.—*Scabiosa atropurpurea.* Germination, × 3. *Cal,* the five segments or bristles of the calyx.

Fig. 46.—*Scabiosa caucasica*, × 3. A, commencement of germination; B, day after commencement. *B*, thickened base of hypocotyl; *C*, cotyledons.

sides between the greatly thickened ribs of the involucel. A peculiar anomaly presents itself in the germinating seedling of Scabiosa caucasica (fig. 46). The base of the hypocotyl is more or less thickened as in the other species, but it generally if not always pushes itself right through one or other of the membranous portions of the involucel, and is consequently functionless so far as its original purpose is concerned. The lamina of the involucel is reduced to a rim crowned by numerous coarse bristle-like segments. The seedling is different from all others I have noticed. The hypocotyl remains short, the oblong entire cotyledons are sessile, and the first pair of leaves are oblanceolate and entire.

In all of the above-mentioned seedlings the cotyledons are sessile on leaving the seed, but afterwards petiolate, except in Scabiosa caucasica, which is peculiar in several respects.

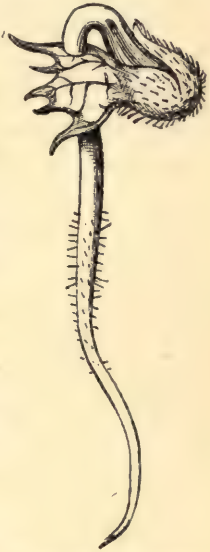


Fig. 47.—*Valerianella coronata*, × 4.

The germinating seedling of Valerianella coronata (fig. 47) shows a similar contrivance for fixing the fruit or achene to the soil and thus enabling the cotyledons to make their escape. The embryo swells up and the radicle usually bursts through the side of the fruit beneath the calyx limb; it then pierces the latter, entering by the outer face and pushing on through both sides, enters the ground, thus pinning the fruit to the soil, while the cotyledons are pulled out in a comparatively short time and spread to the light.

One embryo only out of twenty-eight made its exit at the apex of the fruit, and from the centre of the calyx limb. The radicle in this case pushed through the calyx from its inner face outwards, and not from the outer face inwards, as in the usual method.

The fact of the radicle bursting through the side of the fruit is accounted for by two cells of the three-celled ovary being small and empty, and the third containing a seed which would accordingly be excentric, and therefore in germination the radicle would normally push through one side of the fruit.

In Valerianella Auricula when the fruits have been moderately well covered with soil the embryo in most cases gets clear of the fruit simply by the elongation of the hypocotyl.

The genus Hedysarum (Leguminosæ) affords an interesting comparison with Scabiosa and Valerianella. The fruit is a lomentum, that is, a pod divided into one-seeded segments which become separated but do not open to let the seed escape.

In germination the radicle pushes itself through the end of the lomentum or through one suture, while the cotyledons make their exit by the other, as in H. coronarium (fig. 48) and H. obscurum. The wall of the fruit in H. denticulatum (fig. 49) is thin or membranous and reticulate, and the radicle generally pierces one valve, while by the swelling of the cotyledons and the elongation of the hypocotyl the lomentum is burst open and the upper valve pushed upwards, permitting the exit of the seedling. The testa is frequently carried up on the cotyledons, but the breadth of the latter and their increasing size soon split it open and get rid of it. Whatever the mode of exit of the radicle and cotyle-

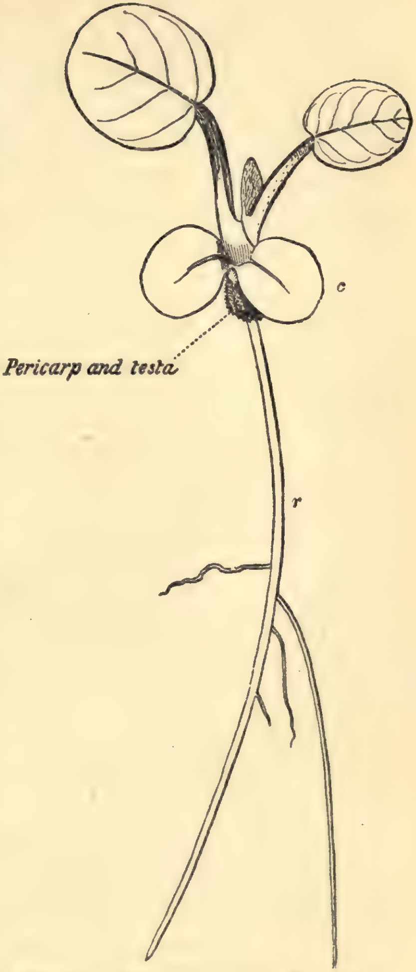


FIG. 48.—*Hedysarum coronarium*. Nat. size. *c*, cotyledon; *r*, primary root.

dons, the wall of the fruit nearly always gets pinned to the ground while the seedling rises clear above it. Thick-walled fruits last a long time in good condition after the germination of the embryo.

Fig. 1 shows the embryo germinating and splitting open the pericarp of a segment of the fruit. The radicle has pierced the lower valve of the pericarp.

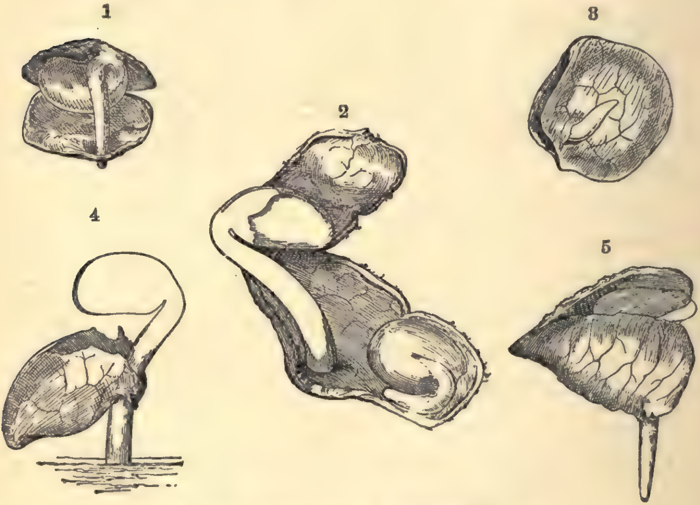


Fig. 49.—*Hedysarum denticulatum*, × 2½.

Fig. 2. A case in which two segments have remained united. One embryo is dead ; the other has forced open the pericarp of both segments, and its radicle has pierced the lower valve, a frequent occurrence.

Fig. 3. Another segment of the fruit where the radicle has already advanced considerably through the

wall; the two halves of the fruit have just commenced to split open.

Fig. 4. Another mode of germination similar to what occurs in H. coronarium, the radicle emerging at one side of the fruit and the cotyledons at the other. One day after germination.

Fig. 5 shows the ragged margin of the fissure made by the radicle through the walls of the fruit during germination.

In an allied plant, Desmodium canadense, the radicle in germination emerges at the dorsal suture of the fruit, or breaks through the side walls. It fixes itself in the ground, and the lengthening hypocotyl generally carries the lomentum and seed up with it. All the coverings, however, finally drop off, leaving the seedling free. Where the radicle pierces the sides of the lomentum the latter is fixed to the soil. The cotyledons on becoming free are ovate-oblong, obtuse, subfalcate, or rounded on the upper edge and with a shallow sinus on the lower edge, subfleshy, pale yellowish-green, shining and glabrous.

Medicago orbicularis affords an instance of a very rare case where a many-seeded pod does not dehisce before germination, but is pinned to the ground by the seedlings in their efforts to escape.

In germination the spirally coiled legume splits readily along the dorsal suture, and the radicles of the various seeds seem all to make their exit along one side, while the cotyledons push out along the opposite side.

FIG. 50.—*Medicago orbicularis*, × 2. Nine seedlings, all from one fruit.

By this means the fruit is effectually fixed to the soil while the embryos have no difficulty in getting out. The testa is, however, sometimes carried up by the cotyledons and splits irregularly as these expand.

Fig. 51.—*Phaseolus vulgaris*. **Half nat. size.**
c, cotyledons.

Twelve to sixteen seedlings from one fruit are not infrequent. A few instances occur (two to three out of fifty-six) where the radicle and cotyledons emerge together at one side of the fruit, and consequently stand out free from it. One instance occurred amongst fifty-six seedlings where the cotyledons got clear away from the fruit and seed, but the radicle failed to get out of the seed and consequently the seedling did not make the same progress as the rest and would most likely perish.

Fig. 52.—*Lonchocarpus latifolius.*
Half nat. size. *c*, cotyledons.

The competition among the seedlings from a single pod is in such cases very severe.

Phaseolus vulgaris (French bean) presents us with an intermediate stage, the cotyledons being aerial and green, but fleshy and by no means true foliage-leaves.

Lonchocarpus latifolius (fig. 52) is another instance.

FIG. 53.—*Hymenæa Courbaril.* Nat. size. *c*, cotyledons.

The cotyledons are falcate, obtuse, subsessile, and do not spread horizontally; they are aerial but fleshy, and enlarge but slightly after germination. They fall at an early date, before which they become bright yellow.

FIG. 54.—*Buchanania latifolia*, showing thin edge of cotyledons. Nat. size.

We may compare also Hymenæa Courbaril (fig. 53), where the thick, fleshy, plano-convex cotyledons are pale brownish on the back, light green above (the green part being bordered by a narrow rim).

Again, in Copaifera officinalis the cotyledons are aerial, but very fleshy, oblong, sessile, rounded on the back, flat on the inner face or becoming concave by shrivelling, and reddish or tinged with yellow.

A transition from the strictly aerial and foliaceous cotyledons to the fleshy and subterranean is also met with in Anacardium occidentale. Here they are large, fleshy, falcate, and directed to one side of the young stem, yellowish-green in colour, plano-convex, three-nerved, and slightly reticulate on the back, but showing no trace of nerves on the upper surface. Another somewhat similar case occurs in Buchanania latifolia (Anacardiaceæ) (fig. 54), having obovate, unequal-sided, fleshy cotyledons with a thick and a thin edge. They conform to the interior of the seed and that again to the endocarp, to which they owe their peculiar shape. Immediately after germination they are both directed to one side of the stem as in subterranean cotyledons; but they ultimately spread out right and left. They soon drop off.

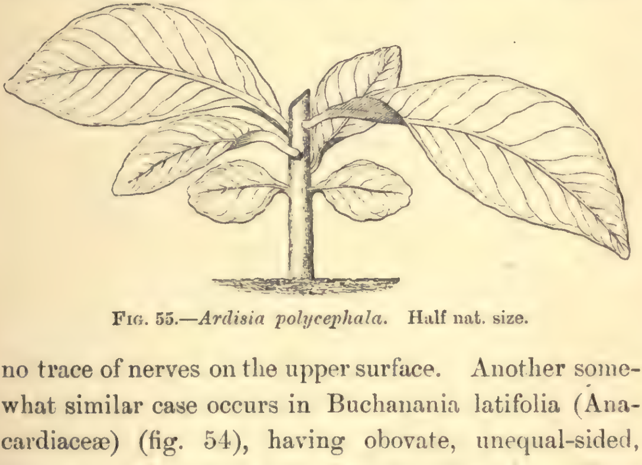


FIG. 55.—*Ardisia polycephala.* Half nat. size.

In four species of Ardisia (Myrsineæ) examined, the cotyledons differ in form, as does also more or less the mode of germination. The cotyledons of A. polycephala (fig. 55) are elliptic, emarginate, foliaceous, and persistent, with an incurved pinnate venation like that of the leaves, the first two of which are similar, but larger and entire.

FIG. 56.
Ardisia mamillata. Seedling showing emarginate cotyledons (*C*). Nat. size.

In A. mamillata (fig. 56) the hypocotyl is short but very stout and fleshy. The cotyledons are aerial but small, transversely oblong, bifid and hairy. Those of A. crenulata (fig. 58) are small, spathulate, and petiolate, but never leave the seed. The latter if fairly well covered with soil remains underground, when the petioles of the cotyledons attain a few millimetres in length; but if the fruit with its seeds is uncovered the cotyledons are almost sessile, and the seed gets carried up by the elongating hypocotyl. This is more decidedly the case in A. japonica (fig. 57), the hypocotyl of which varies from 13–30 mm. in length. The cotyledons are small, ovate and never leave the seed, which therefore gets carried up with the growth of the seedling. The petioles of the cotyledons are both directed to one side of the axis, flattened, pubescent, and become undulated as they lose substance and fade. In the two species last mentioned the cotyledons are to all intents and purposes subterranean, though carried above ground by the elongation of the hypocotyl.

The seed of A. japonica presents the remarkable peculiarity of often containing several embryos, as many as six being present on some occasions. The radicle in such a case points in various ways, and in germination each embryo makes its exit at a different place (fig. 57).

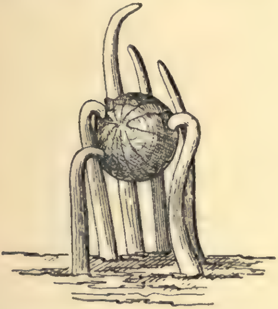


Fig. 57. — *Ardisia japonica.* Germinating seed showing six embryos, × 2.

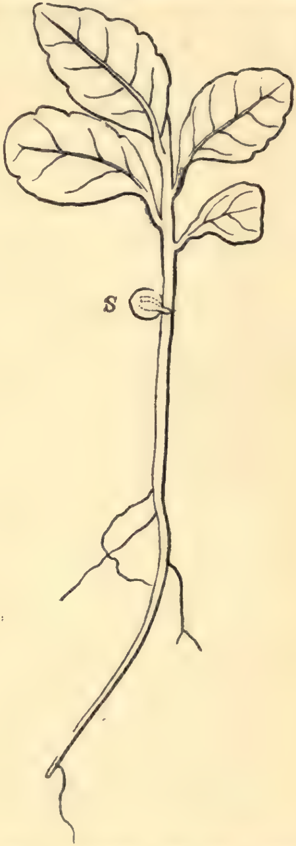


Fig. 58.—*Ardisia crenulata.* Nat. size. *S*, seed containing cotyledons.

In Trichosanthes cucumerina (Cucurbitaceæ) (fig. 59) the fleshy plano-convex cotyledons conform in outline to the shape of the seed and are strictly subterranean, but burst the testa during germination and frequently become more or less expanded beneath the soil.

FIG. 59.—*Trichosanthes cucumerina.* Nat. size. *S*, seed *C*, cotyledon.

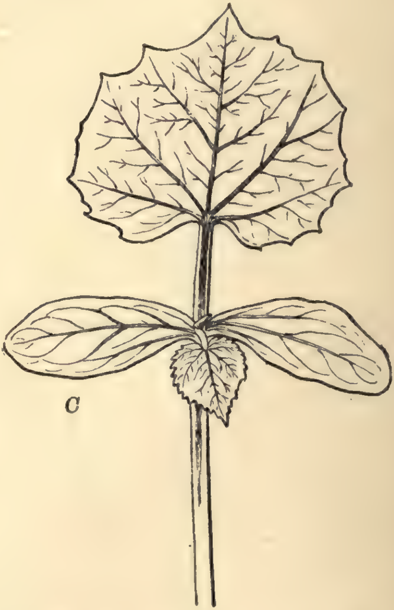


FIG. 60.—*Trichosanthes palmata* Nat. size. *C*, cotyledon.

In T. palmata (fig. 60), on the other hand, the hypocotyl is 3–4 cm. long, thrusting the cotyledons well above the soil. These are broad and spreading, and described as rather persistent, though only yellowish-green on the upper and whitish on the lower surface. In T. anguina the hypocotyl is still longer, though the aerial cotyledons are thick.

In a species of Lucuma (fig. 61), a genus belonging to the tropical family Sapotaceæ, the hypocotyl is very short, stout, and subterranean, while the very large, fleshy cotyledons are also generally subterranean, but sometimes appear just at the surface of the soil, bursting the woody testa into two halves and spreading horizontally, becoming deep green on the upper surface when exposed to light. Often one cotyledon becomes suberect while the other is deflexed.

FIG. 61.—*Lucuma sp.*, showing the two halves of the testa attached to the cotyledons. Half nat. size.

The seedling of Lucuma mammosa is very similar to the last in all leading particulars. The cotyledons are subterranean and fleshy, but split open the woody testa during germination. The stem is very stout and is notable for the length of the first internode which measures 7–10 cm., and compensates for the want of the hypocotyl. The leaves are sometimes falsely opposite, but as a rule alternate, and the first six are closely aggregated above the first internode, oblong or lanceolate-elliptic in shape, and feather-nerved.

The cotyledons of Butyrospermum Parkii (Sapotaceæ) are fleshy and perfectly subterranean, very thick, and applied to each other face to face and (in old seeds at least) inseparable, each occupying half the space in the seed, and, like it, of variable outline, but always broadest at their bases, which rest on the base of the seed.

In Melittis melissophyllum (Labiatæ), again, according to Irmisch,[1] the fleshy cotyledons generally remain in the seed, and are held together by the testa: but they sometimes burst the shell, and stand out from one another. Like true subterranean cotyledons, they have no stomata.

When the cotyledons are large, thick, and fleshy they often contain sufficient nourishment to render the plants for a time independent of any fresh supply. In such cases the seedlings sometimes push up for a while without any fully-developed leaves, the first few being reduced to a very small size or almost obsolete.

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[1] 'Zur Naturgeschichte von *Melittis melissophyllum*,' *Bot. Zeit.* 1858, p. 233.

In the following pages I have brought together some instances of truly hypogeal cotyledons.

In Clematis recta (fig. 62) the cotyledons are fleshy and do not leave the seed. As usual in such cases the first few leaves are reduced to scales.

This species is of interest from being quite exceptional in the Order Ranunculaceæ in its way of germination.

In all the other genera observed the cotyledons were truly aerial, and this is also the case in Clematis graveolens (fig. 63), where the radicle in germination pushes out at the apex of the achene, which splits rather deeply into two valves, thus allowing the embryo free exit. The primary root develops numerous root-hairs at an early stage, which fix the seedling firmly in the soil.

The achene is rarely if ever carried up by the cotyledons, but is securely fixed in the soil by the long, feathery, persistent style.

FIG 62.—*Clematis recta.* Nat. size. The scale-like leaves of Nos. 1–3 pairs inclusive had fallen off. *S*, seed.

In the family Guttiferæ the embryo is large, filling the seed, to which it conforms: it presents a remarkable and abnormal case, inasmuch as it often

FIG. 63.

Young plant of *Clematis graveolens*, var. *orientalis*. Nat. size. *C*, cotyledon.

consists mainly of a swollen fleshy radicle with small scale-like inconspicuous cotyledons at its apex as, for instance, in the tribe Clusieæ, while cotyledons are said to be absent in the Moronobeæ and wanting or very minute in the Garcinieæ. The radicle is always inferior, and in the Calophylleæ it is very short with large cotyledons sometimes grown together in one mass. In Quiina they are large and fleshy but distinct, while the radicle is very short.

In the seedlings observed the cotyledons where present are subterranean in germination, and this generally obtains where the seeds are large, exalbuminous, and contain a fleshy embryo. The cotyledons of Calophyllum Inophyllum (fig. 64) occupy a large globular seed, and their fleshy petioles are just long enough to allow the plumule to get clear out of the seed. They are also subterranean. The first pair of leaves are reduced to scales, and generally the second pair also, or these are imperfectly developed. Then follow two pairs of narrowly elliptical, obtuse leaves, after which the seedling stops growing for a season. The feather-nerved venation is remarkable on account of the close arrangement of the veins in parallel lines.

Xanthochymus pictorius (fig. 65) and Mesua ferrea agree with the above in all general particulars; but in the former the first four pairs of leaves are reduced to small, ovate, or subulate, black scales, and only one pair of lanceolate acuminate leaves are produced the first year by the seedling. In Mesua ferrea the first four pairs of leaves are small, scale-like, and caducous, followed by two pairs of lanceolate-oblong very finely feather-nerved leaves, before growth ceases for a time.

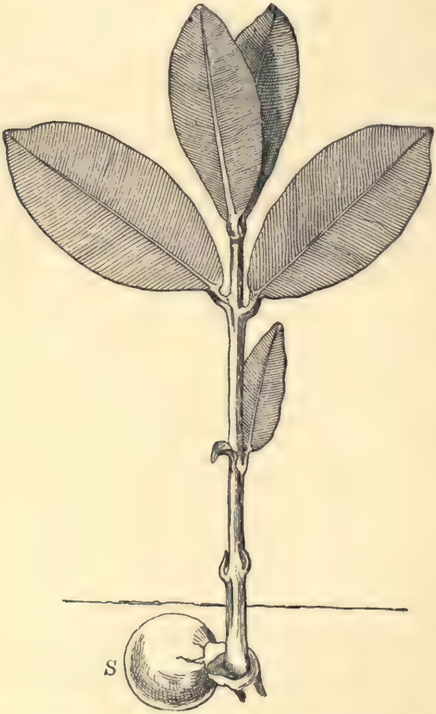


Fig. 64.—*Calophyllum Inophyllum.* Half nat. size. *S*, seed.

The tea-tree (Camellia theifera) (Ternstrœmiaceæ) offers a remarkable exception amongst its congeners in having a large, fleshy, globular embryo, with the small radicle and plumule completely surrounded or covered by the hemispherical cotyledons. The radicle of Camellia reticulata, on the contrary, projects beyond the cotyledons considerably.

Fig. 65.—*Xanthochymus pictorius.* Half nat. size.

The cotyledons of the tea-plant (fig. 66) swell up somewhat during germination, bursting the woody testa, but otherwise do not alter in size and shape. They form a hemispherical mass occupying the interior of the seeds, and are subterranean. They assume more or less of a green colour should they be exposed to light during germination by the bursting of the testa and by removal of the soil.

FIG. 66.—*Camellia theifera.* Half nat. size. *S*, seed.

In Ochna Kirkii (Ochnaceæ) (fig. 67) the fleshy cotyledons fill the seed, which in turn fills the carpel. They remain in the ground attaching the seedling to the fruit.

The first and second leaves are reduced to small, subulate scales, No. 3 is small and foliaceous, No. 4 and those following much larger.

Fig. 67.—*Ochna Kirkii.* Nat. size. *S*, fruit.

Fig. 68.—*Sapindus inæqualis.* Half nat. size. *S*, seed

In Sapindus inæqualis (Sapindaceæ) (fig. 68) the thick fleshy petioles are pushed out of the seed or elongated so as not to inconvenience the radicle and plumule in their exit.

Here also leaves Nos. 1–4 are linear-lanceolate, acute, small and scale-like.

Thick, fleshy, and truly subterranean cotyledons occur also in Rhus Thunbergiana (Anacardiaceæ) (fig. 69), a South African species with almost dry, one-celled, one-seeded fruits from three-quarters to one inch broad.

The first five leaves are minute scales; while all succeeding ones are simple, and feather-nerved.

Fig. 69.—*Rhus Thunbergiana.* Half nat. size.

In Lathyrus Nissolia (Leguminosæ) (fig. 70) the hypocotyl is subterranean, fleshy, colourless, and very short (about 1·75 mm. long). The plano-convex, fleshy cotyledons, each occupying half the interior of the seed, are unequal-sided, so that the petioles and point of attachment to the plumule are at one side. The petioles are unequal or the lower one is undeveloped, while the upper one is developed and curved just as much as will allow the cotyledons to lie horizontal. The latter do sometimes stand erect on their ends and then both petioles are equally developed.

The first two leaves are small, subulate, scale-like and adpressed to the stem. The succeeding ones are narrowly linear and convolute in bud enclosing the younger leaves.

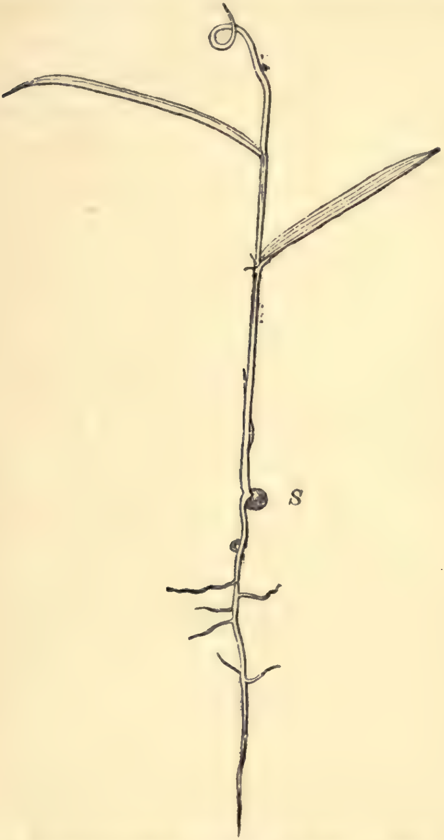


FIG. 70.—*Lathyrus Nissolia.* Nat. size. *S*, seed

Eugenia bracteata (Myrtaceæ) (fig. 71) is another example. The first and second pairs of leaves are reduced to small green scales, ultimately becoming brown, while the third pair are oval and foliaceous; the fourth pair are elliptic and much larger.

Fig. 71.—*Eugenia bracteata.* Four-fifths nat. size. *S*, seed.

Bignonia insignis (fig. 72) is of interest in having the thick fleshy cotyledons amalgamated in one piece, which remains in the seed after germination. The first pair of leaves are small and scale-like; the second, third and fourth pairs are cordate, foliaceous and simple; while the fifth pair have each a pair of leaflets and a terminal three-parted hooked tendril.

In the Walnut (Juglans regia) (fig. 73) the primary root emerging from the apex of the nut is very stout, woody, tapering downwards, and furnished with lateral rootlets.

The very short, stout, woody hypocotyl is scarcely distinguishable from the root. The cotyledons are large, fleshy, bilobed and crumpled, filling the whole cavity of the seed and remaining there after germination, attached to the young plant by their short fleshy petioles.

The ultimate leaves are compound and imparipinnate, the first eight in the specimen drawn being reduced to scales and opposite or subopposite in four pairs.

The Oak and Hazel are also common instances of this mode of germination.

The cotyledons of the Holm Oak (*Quercus Ilex*) (fig. 74) are oblong, plano-convex, fleshy and subterranean. They are auricled at the base and petiolate, and although the shell of the acorn splits longitudinally when they swell during germination, they never emerge. The first five leaves are linear-subulate, minute, scarious, brownish and caducous. The sixth is somewhat larger, cuneate and trifid at the apex; the seventh and eighth are foliaceous but small. The

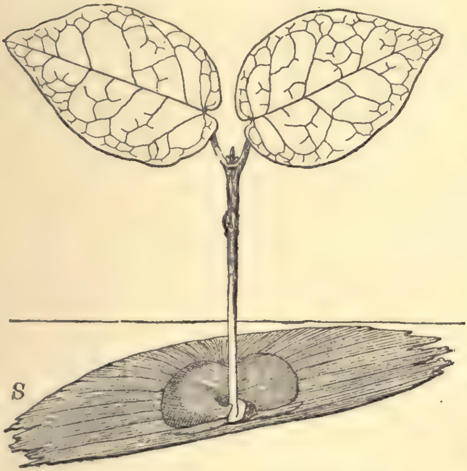


FIG. 72.—*Bignonia insignis.* Nat. size.
S, large winged seed.

FIG. 73.
Juglans regia.
One-tenth nat. size.
n, nut.

ninth is much larger, lanceolate-oblong, and distantly serrate. The tenth to the thirteenth inclusive are elliptic-oblong, irregularly penninerved and acutely serrate. The above characters of the primary leaves vary according to the vigour of the seedling and the conditions under which germination takes place. The primary internodes have not the power of elongating, so that when an acorn happens to be deeply buried with dead leaves in a wood or plantation the primary leaves are arrested in growth and scale-like, while those leaves or most of those (probably never all) which reach the light become green and foliaceous.

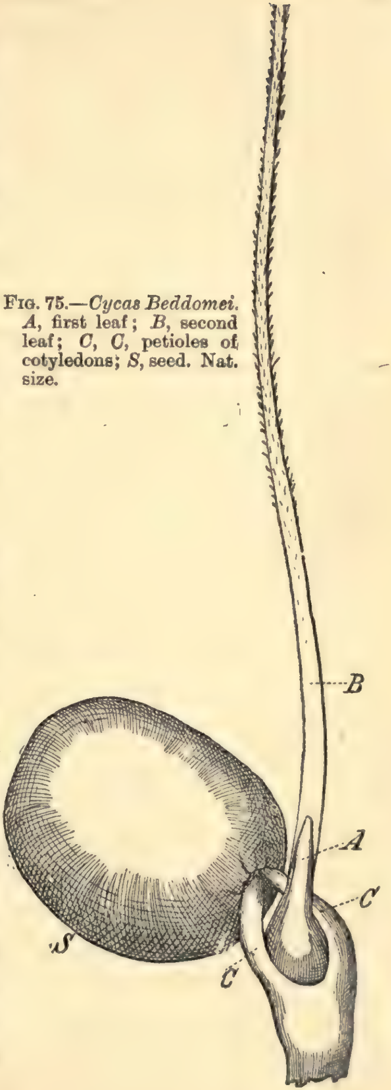
FIG. 74.—*Quercus Ilex.* Half nat. size.

The cotyledons of Q. pedunculata are also subterranean. Several of the primary leaves are reduced to scales as in the last case and for the same reason. The first green foliaceous leaf is obovate-oblong and shallowly lobed at the top. Succeeding ones are obovate or obovate-oblong, and irregularly lobed with alternate nerves running into the lobes.

In Cycadaceæ the seed is large, variable in shape, and often variously angled. The outer layer of the testa is orange or red, and the inner crustaceous or bony. Endosperm is copious and fleshy, embedding the subcylindrical embryo in its upper part; and the cotyledons are conferruminate or amalgamated in one piece, or free only at the base to permit the exit of the plumule.

The seeds are large, and in all the seedlings observed the cotyledons are subterranean, remaining in the seed till the endosperm is absorbed, when they decay. The plumule consists of a mass of stout, fleshy scales resembling a resting or winter bud, which emerges from the fissure at the base of

FIG. 75.—*Cycas Beddomei.* *A*, first leaf; *B*, second leaf; *C*, *C*, petioles of cotyledons; *S*, seed. Nat. size.



the cotyledons during germination. A solitary perfect leaf is soon after developed from the centre of the bud as seen in Zamia integrifolia. This leaf consists of two pairs of leaflets, crowded together at the apex of the petiole; the terminal pair is much the smaller, and all have numerous, longitudinal, parallel nerves.

The seed of Cycas Beddomei (fig. 75) is globose-oblong, and the bud formed by the plumule is rather small, consisting of one or two scales. The method of germination corresponds to that of Zamia integrifolia. The primary perfect leaf is pinnate with eleven to nineteen linear, entire leaflets having a distinct midrib only. Dioon spinulosum has a comparatively large, oblong seed and a large bud of four scales. The first leaf is finely pectinate or pinnate with twenty-three to twenty-five spiny-serrate leaflets, the veins of which are longitudinal, slender, and numerous. In all three cases the leaflets are circinate in vernation like most Ferns.

In most of the above species it is clearly an object to the young plant to grow upwards quickly, and the first few leaves are reduced to scales. In the garden Nasturtium (*Tropæolum majus*) (fig. 76), however, the habit is quite different, the first pair are large and green, differing from the normal adult leaves only in being opposite, not alternate, and in their shallowly trilobulate outline, the adult form of leaf being seven-lobulate.

In the Scarlet Runner (*Phaseolus multiflorus*) the first two leaves are also opposite, forming a pair of true foliage leaves. They differ, however, from the form of the subsequent leaves in being simple while the latter are trifoliolate.

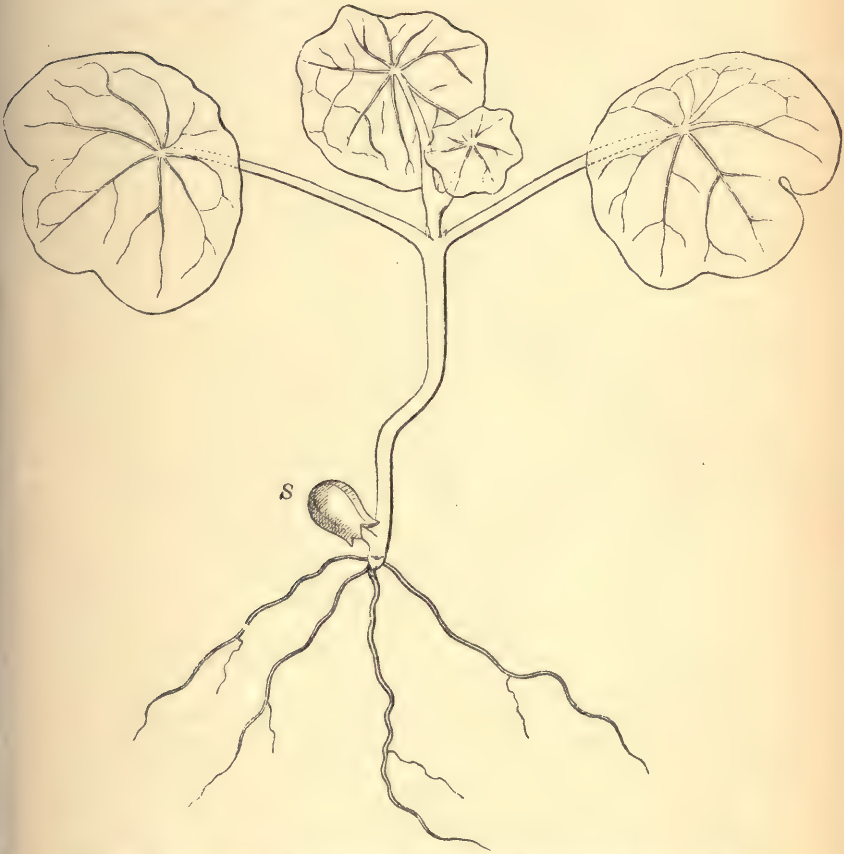


FIG. 76.—*Tropæolum majus.* Nat. size. *S*, seed containing cotyledons

In Hevea Spruceana (Euphorbiaceæ) (fig. 77) the cotyledons are very large and broad, remaining in the seed beneath the ground till they decay after absorbing the endosperm. The first two leaves, which are here also opposite, contrasting with the alternate arrangement of those following, are large and compound.

In an Australian plant, Castanospermum australe (Leguminosæ) (fig. 78), the cotyledons are enormously large, semiglobose and fleshy, filling the seed and conforming to it in shape. They remain in the testa, which splits irregularly during germination. The plumule is very large and well developed. It gives rise to an erect stem, ultimately becoming woody, and forming a tall tree.

FIG. 77.—*Hevea Spruceana.* One-fourth nat. size. *S*, seed.

The embryo of Lecythis Zabucajo (fig. 79), a member of the family Myrtaceæ, consists of a solid piece while still in the seed, to the interior of which it strictly conforms. It is narrowly ellipsoid or fusiform, and is evidently homologous with the hypocotyl, which has become thickened and fleshy in this remarkable way in order to constitute a storehouse of reserve material. By remaining in the thick woody testa both during and after germination it is protected from the depredations of animals. Cotyledons are absent or minute. This being the case it follows that the seedling must behave

FIG. 78.—*Castanospermum australe.* Nat. size. *P*, developing plumule.

differently from those having cotyledons which are also generally if not always petiolate when subterranean or remaining in the testa in germination, as in Eugenia

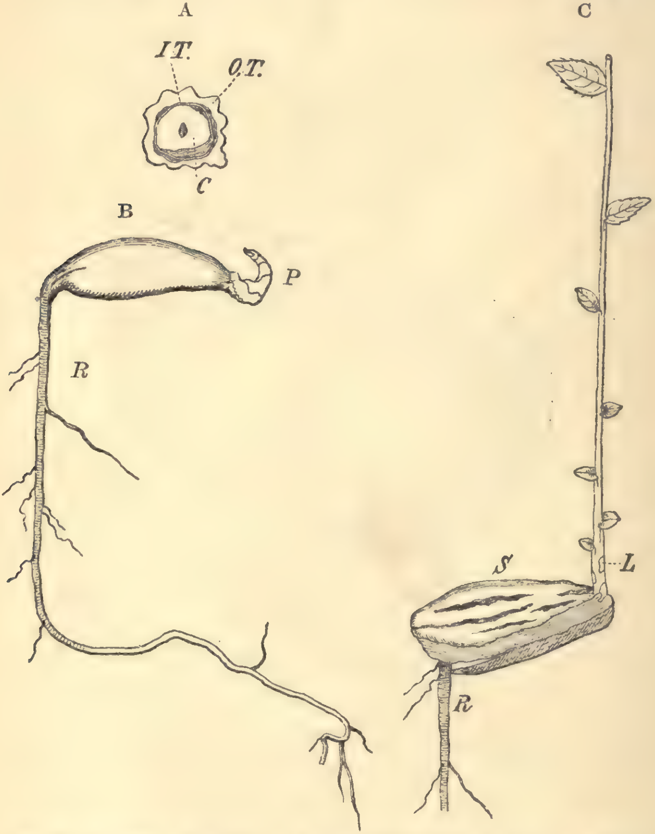


Fig. 79.—*Lecythis Zabucajo.* A, transverse section of seed: *OT*, testa; *IT*, tegmen; *C*, amalgamated cotyledons. B, germinating embryo removed from seed. C, seedling. *S*, seed; *R*, radicle; *P*, plumule; *L*, scale-like leaf. Half nat. size.

bracteata &c. The petioles in such cases allow the embryo to escape from the testa, with exception of the fleshy

FIG. 80.—*Bertholletia excelsa.* Nat. size.

laminæ of the cotyledons. On the contrary the fleshy hypocotyl of Lecythis Zabucajo is held fast while the plumule splits the testa and pushes its way out at one end of the seed and the radicle at the other. The allied Bertholletia excelsa (Brazil nut) (fig. 80) behaves in the same way.

In this plant a great number of the primary leaves are very small and completely cover the lower part of the stem owing to the non-development of the internodes. They gradually change from sheathing organs to perfect leaves, of gradually increasing length. The first eight are colourless, the next five are oblong, followed by one or more lanceolate ones, while the fifteenth and sixteenth are oblong-obovate, but very moderate in size. Only three or four of the first leaves of Lecythis Zabucajo are scale-like. In both species the colourless leaves would act as a protection to the plumule while pushing its way through soil, or whatever else might have accumulated above the seeds in a state of nature. The following four leaves of Lecythis are roundly cordate followed by four that are ovate, and then by others which are lanceolate. The ultimate form is oblong-lanceolate with serrate margin, and the leaves are alternate and distichous.

FORMS OF COTYLEDONS.

No one who has ever looked at young plants can have failed to be struck by the contrast they afford to older specimens of the same species. This arises partly from differences in the leaves, partly from the contrast which the cotyledons afford, not only to the final leaves, but even to those by which they are immediately followed.

This contrast between the cotyledons and true leaves is so great that one might almost be pardoned for asking whether they can be brought into actual correlation.

So far, indeed, are the cotyledons from agreeing with the forms of the leaves, that the difficulty is to find any clear resemblance. In one species of Ipomœa (*I. Pes-capræ*) both are, as the name denotes, somewhat like the foot of a goat; but the leaves vary considerably, and it is probable that the resemblance may be accidental. A clear case is, however, afforded by the Onagrarieæ, where in Œnothera and some allied genera the form of the mature cotyledons is evidently related to that of the leaves. Even here, however, the likeness is confined to a basal portion which makes its appearance subsequent to germination, and no trace of it is shown in the cotyledons themselves when they first appear.

The forms of the cotyledons in many species have been the subject of special memoirs by Tittmann, Irmisch, Wichura, Winkler, Tscherning, and other botanists; but they have not given any reasons for the various forms assumed.

Klebs, indeed, one of the most recent writers on the subject, in his interesting Memoir on Germination,[1]

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[1] 'Beiträge zur Morphologie und Biologie der Keimung,' *Untersuch. Botan. Inst. v. Tübingen*, Band i. p. 536.

refers to this diversity of form, and expressly says that these differences are an enigma ('Sind gewiss diese Verschiedenheiten in den Blattformen hinsichtlich ihrer biologischen Bedeutung für die Pflanze ein Räthsel'). He observes, however, that on the whole the forms of cotyledons are much simpler than those of leaves, and he suggests that while in some cases perhaps, like the first leaves, they retain the form which characterised the species in bygone ages, we may rather, as a more generally applicable explanation, apply to them the suggestion of Goebel with reference to stipules, and regard them as simplified by arrest.[1] Another suggestion has been that cotyledons are 'a survival of the universal foliage of deciduous trees in olden geological days, ere time had differentiated them into their present various forms.' Even, however, if this suggestion were the real explanation of the comparative simplicity, it would throw no light on the differences between the cotyledons of different species.

FIG. 81.—Seedling of *Fœniculum vulgare*. Half nat. size.

Though cotyledons do not present nearly such ex-

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[1] 'Beiträge zur morphol.' &c. *l.c.* p. 613.

tensive variations as leaves, still they do differ considerably from one another.

Some are narrow, in illustration of which I may refer to Fœniculum (Fennel) (fig. 81), Coreopsis (fig. 82), and Ferula (in the hollow stalk, or ferule, of which Prometheus brought down fire from heaven), &c., where the ultimate leaves are much divided; Platanus (fig. 83),

FIG. 82.—Seedling of *Coreopsis filifolia*. Half nat. size.

FIG. 83.—Seedling of *Platanus*. Nat. size.

FIG. 84.—Seedling of *Acer Pseudo-Platanus*. Half nat. size.

Fig. 85.—Seedling of *Chenopodium Bonus-Henricus* Nat. size.

Fig. 86.—Seedling of *Ricinus sanguineus.* One-fourth nat size.

Fig. 87.—Seedling of *Impatiens balsamina.* Half nat. size.

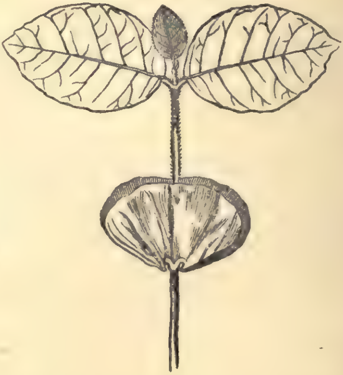

Fig. 88.—Seedling of Beech (*Fagus sylvatica*). Half nat. size.

and Acer (fig. 84), where the ultimate leaves are palmate; and Chenopodium (fig. 85), where they are more or less triangular.

Some cotyledons are broad, in illustration of which I give figures of Castor-oil plant (*Ricinus*) (fig. 86), Impatiens (fig. 87), Beech (*Fagus*) (fig. 88), Brassica (fig. 11), Hippophaë (fig. 89), Rivina (fig. 90), Asystasia[1] (fig. 91), Rhus typhina (fig. 92), and Flax

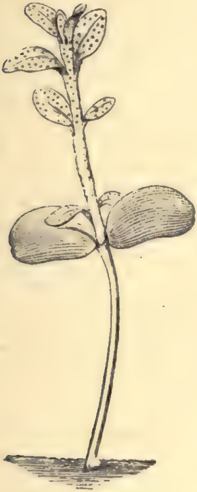

FIG. 89.—Seedling of *Hippophaë rhamnoides.* Half nat. size.

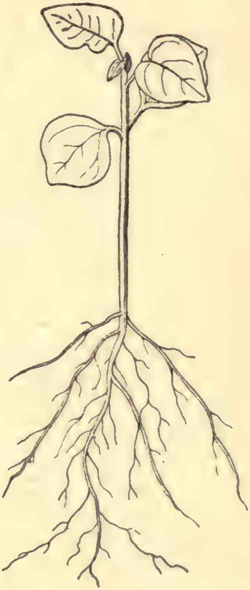

FIG. 90.—Seedling of *Rivina lævis.* Nat. size.

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[1] In Asystasia coromandeliana there is an interesting peculiarity. The first pair of leaves of each branch, or at any rate of the lower branches, approximate to the form of the cotyledons.

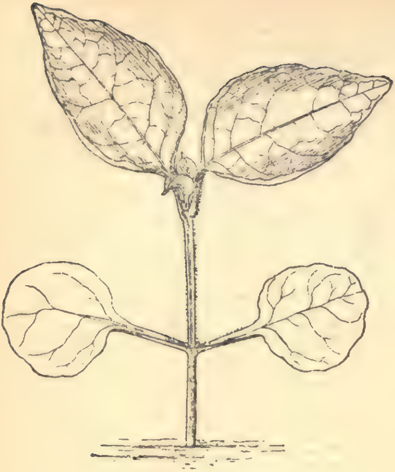

FIG. 91.—Seedling of *Asystasia coromandeliana*. Half nat. size.

FIG. 92.—Seedling of *Rhus typhina*. Half nat. size.

FIG. 93.—Seedling of *Menispermum canadense*. Half nat. size.

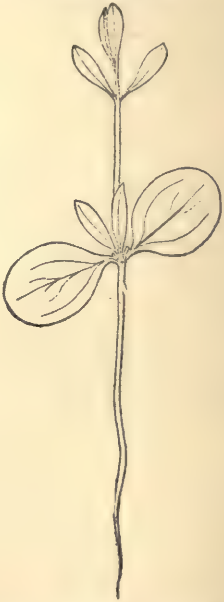

FIG. 94.—Seedling of *Linum monogynum*. Nat. size.

(*Linum*) (fig. 94). We find some species with narrow cotyledons and broad leaves, as Menispermum (fig. 93), while in others the cotyledons are broad and the leaves

Fig. 95.—Seedling of *Olea cuspidata.* Two-thirds nat. size.

Fig. 96.—Seedling of *Hakea acicularis.* Half nat. size.

Fig. 97.—Seedling of Pink (*Dianthus Caryophyllus*). Nat. size.

Fig. 98.—Seedling of *Cerastium.* Half nat. size.

narrow, as in an Australian Flax (*Linum monogynum*) (fig. 94), Hakea (fig. 96), and the Pink (*Dianthus*) (fig. 97).

In some cases we find instances of broad and narrow cotyledons in the same family, as in Cerastium (fig. 98) and Pink (fig. 97), belonging to the Caryophyllaceæ; sometimes even in the same genus, as Galium saccharatum (fig. 99) and Galium Aparine (fig. 36).

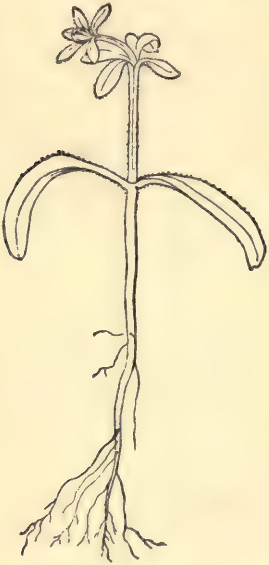

Fig. 99.—Seedling of *Galium saccharatum*. Nat. size.

Fig. 100.—Seedling of *Geranium sanguineum*. Nat. size.

In some cases the two cotyledons are unequal, as in the Mustard (fig. 11), Cabbage, Radish, Cereus (fig. 134): in some the two halves of each cotyledon are unequal, as in the Geranium (fig. 100); or they are otherwise unsymmetrical, as in the Lupine and the Laburnum (fig. 101). Sometimes they are sessile, as in Acer (fig. 84), Hakea (fig. 96), Laburnum (fig. 101), &c.; sometimes they are supported on petioles, as in Microloma

Fig. 101.—Seedling of Laburnum (*Cytisus vulgare*). Nat. size.

Fig. 102.—Seedling of *Microloma*, × 1½.

(fig. 102), which again are occasionally connate. These differences may occur in very closely allied species; for instance, in Delphinium Staphysagria (fig. 104) the cotyledons are sessile, while in D. elatum (fig. 103) they are petioled, and in D. nudicaule (fig. 105) the petioles are connate.

Fig. 103.—Seedling of *Delphinium elatum* Two-thirds nat. size.

Fig. 104.—Seedling of *Delphinium Staphysagria.* Half nat. size.

Fig. 105.—Seedling of *Delphinium nudicaule.* Half nat. size. *C*, cotyledons.

Fig. 106.—Seedling of *Cordia subcordata.* Half nat. size.

Fig. 107.—Seedling of *Pelargonium australe.* Half nat. size.

Fig. 108.—Seedling of *Malva moschata.* Nat. size.

Fig. 109.—Seedling of *Spathodea campanulata.* Nat. size.

Fig. 110.—Seedling of *Catalpa Kæmpferi.* Half nat. size.

FIG. 111.—Seedling of *Eucalyptus sp.* Half nat. size.

FIG. 112.—Seedling of *Eschscholtzia californica.* Nat. size.

FIG. 113.—Seedling of *Pterocarya caucasica.* Nat. size.

FIG. 114.—Seedling of *Poterium Sanguisorba.* Twice nat. size.

Generally the cotyledons are entire, but sometimes crenate, as in Cordia (fig. 106), or lobed, as in Pelargonium (fig. 107) and Malva (fig. 108). Often they are emarginate, as in Impatiens (fig. 87), Mustard (fig. 11) and Cabbage, Ipomœa (fig. 159), Convolvulus, Galium Aparine (fig. 163), and Eucalyptus (fig. 111). They are sometimes even bifid, as in Eschscholtzia (fig. 112) and Ipomœa dasysperma (fig. 160); trifid, as in the Cress (*Lepidium*) (fig. 12); or in four long lobes, as in Pterocarya (fig. 113). Sometimes auricled at the base,

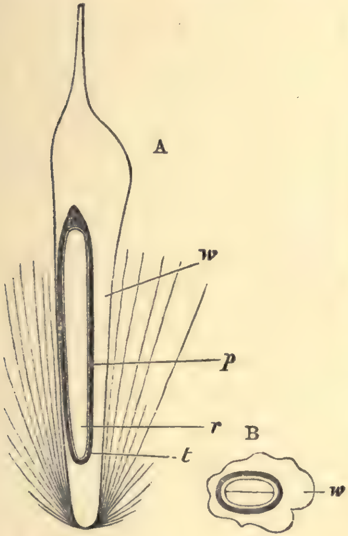

Fig. 115.—A, fruit of *Platanus*, longitudinal section, × 6. B, transverse section, × 12. *w*, woody part; *p*, endosperm; *r*, radicle; *t*, testa.

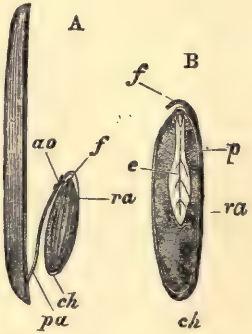

Fig. 116.—A, samara of *Fraxinus excelsior*, nat. size. with one half removed and the seed pulled out: *pa*, placental axis; *ao*, abortive ovules; *f*, funicle; *ra*, raphe; *ch*, chalaza. B, longitudinal section of seed, × 2: *p*, endosperm; *e*, embryo. In germination the embryo grows to the whole length of the seed.

as in Poterium (fig. 114) and Cuphea (fig. 191). Sometimes they are large; sometimes small. Generally they are leaf-like; but sometimes, as we have already seen in studying germination, they are thick and fleshy.

NARROW COTYLEDONS.

Let us now begin with such species as have narrow cotyledons, and see if we can throw any light on this characteristic. The problem is simple enough in such cases as the Plane (*Platanus*), where we have on the one hand narrow cotyledons (fig. 83) and on the other hand a long narrow seed fully occupied by a straight embryo (fig. 115). Again, in the Ash (*Fraxinus*) (fig. 116) and Ursinia (fig. 117), the cotyledons lie parallel to the longer axis of the seed, which is narrow and elongated. Such cases, however, are comparatively few; and there are a large number of species in which the seeds are broad and even orbicular, while yet the cotyledons are narrow, as for instance in Chenopodium (fig. 85) and Menispermum (fig. 93).

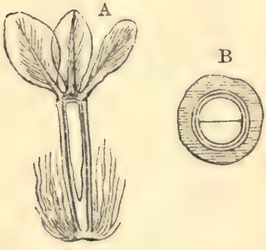

FIG. 117.—Achene of *Ursinia speciosa*. A, longitudinal section, × 2½. B, transverse section, × 10.

In these it will generally be found that the cotyledons lie transversely to the seed. In Menispermum (fig. 118) the fruit is laterally compressed and horseshoe-shaped, with a crest along the edge; the seed conforms to the shape of the fruit, and the embryo is curved and linear, the cotyledons being applied to one another face to face, and at right angles to the plane of the seed, so that their edges touch the walls of the seed at each side.

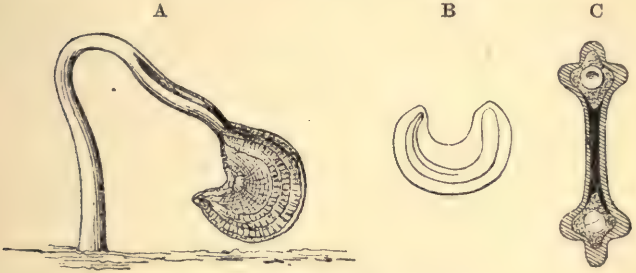

FIG. 118.—*Menispermum canadense.*
A, germinating seedling, × 2. B, vertical section of seed, × 2.
C, transverse section of seed, × 4.

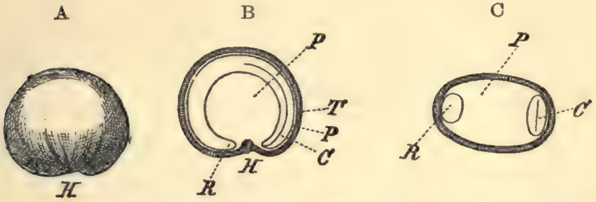

FIG. 119.—*Chenopodium Bonus-Henricus*, × 8. A, seed. B, vertical section of seed. C, transverse section of seed: *H*, hilum; *R*, radicle; *C*, cotyledon; *P*, endosperm; *T*, testa.

The seeds of Chenopodium Bonus-Henricus (fig. 119) are reniform, small and black with a crustaceous testa. The embryo entirely surrounds the periphery of the endosperm except a small portion at the hilum. The cotyledons are linear, plano-convex, lying in the narrow plane of the laterally compressed seed, and

Fig. 120.—*Spinacia glabra.* Nat. size

incumbent, of the same length as the radicle, but slightly wider.

In Spinacia glabra (fig. 120) the narrow cotyledons ultimately attain a length of 30–80 mm.

The Sycamore (*Acer Pseudo-Platanus*) (fig. 84) has also narrow cotyledons; but the arrangement is very different. The fruit (fig. 121) is winged, the seed somewhat obovoid and exalbuminous, the embryo occupying the whole cavity of the seed. Now if we wished to pack a leaf into a cavity of this form, it would be found convenient to choose one of a long strap-like shape, and then roll it up into a sort of ball. This is, I believe, the reason why this form of cotyledon is most suitable in the case of the Sycamore. The mode of folding, however, as shown in fig. 121, A and B, is not always the same. I shall suggest a reason for the difference further on.

FIG. 121.—*Acer Pseudo-Platanus.* Fruit, nat. size. A, B, embryo, showing two modes of arrangement of cotyledons.

In other species the narrowness of the cotyledons is perhaps an advantage in facilitating the exit from the seed. See, for instance, the cases of Galium (p. 115) and Symplocos (p. 46).

BROAD COTYLEDONS.

I now pass to species with broad cotyledons. The Acorn, Nut, Scarlet Runner (fig. 122), and Pea afford familiar cases, in which the two broad, fleshy, thickened cotyledons conform to and occupy the whole seed. In the Castor-oil plant (*Ricinus*) (fig. 123) the seed is

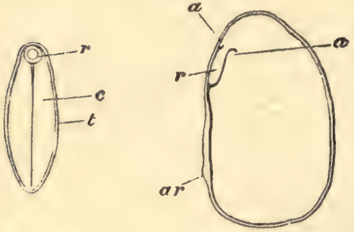

FIG. 122.—*Phaseolus multiflorus.* Section of seed parallel and vertical to cotyledons, three-fourths nat. size: *a a*, auricles; *ar*, arillode.

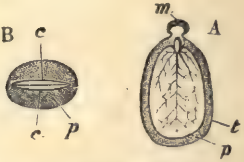

FIG. 123.—*Ricinus sanguineus.* A, longitudinal section of seed, nat. size. B, transverse section of seed, nat. size: *t*, testa; *p*, endosperm; *c*, cotyledons; *m*, caruncle.

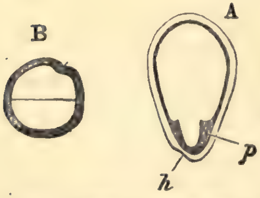

FIG. 124.—*Hippophaë rhamnoides.* A, longitudinal section of seed, × 4. B, transverse section of seed, × 4.

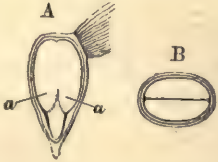

FIG. 125.—*Moscharia pinnatifida.* A, longitudinal section of seed, × 8. B, transverse section of seed, × 8: *a a*, auricles.

ovoid-oblong, somewhat compressed dorso-ventrally, and beautifully mottled, while the projecting knob (caruncle) at the hilum gives it very much the appearance of a beetle or large tick. The endosperm is abundant, fleshy, white, and surrounds the embryo. The latter is straight, flat, large, central, and white; the cotyledons broad, obtuse-oblong, and approximately following the general outline of the seed. In Hippophaë (fig. 124) we have a somewhat similar case; but the cotyledons are fleshy and occupy almost the whole of the seed. In Euonymus, again, the seed is obovoid, and slightly compressed laterally. The endosperm is abundant, fleshy, firm, and white, entirely surrounding the embryo, which is straight, flat, central, pale green in colour, and extends very nearly from one end of the seed to the other. In the Flax the seed is ovate, obliquely pointed, plano-convex, and laterally much com-

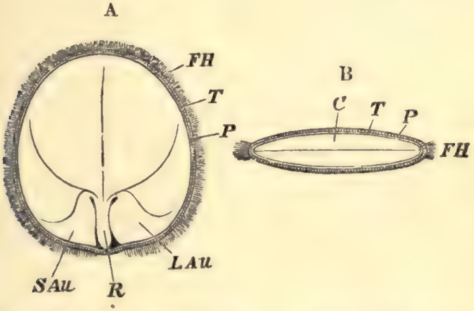

Fig. 126.—*Ruellia longifolia.* A, longitudinal section of seed, × 10. B, transverse section of seed, × 10: *FH*, fringe of hairs; *LAu*, larger, and *SAu*, smaller auricle; *R*, radicle; *C*, cotyledons; *P*, endosperm.

pressed, placed edgeways on the placenta, and the cotyledons lie parallel to the flattened axis. In other cases the seeds are still more flattened, as in Ailanthus, Passiflora, Cobæa, and Stephanotis.

The Compositæ generally have narrow cotyledons. In Moscharia, however, they are somewhat broader, the seed (fig. 125) being obovoid, with the cotyledons lying the broad way.

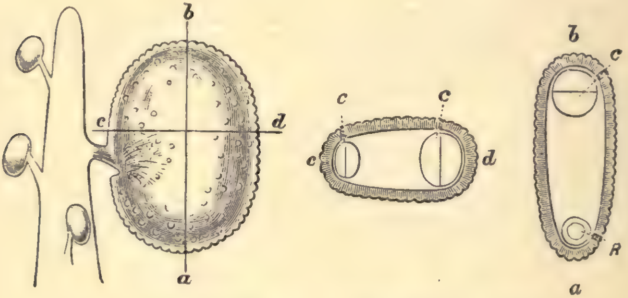

FIG. 127.—*Cerastium*, × 15. *C*, cotyledons; *R*, radicle.

In many cases, seeds of the same shape produce cotyledons of very different form.

Compare together, for instance, Ruellia (fig. 126) and Cerastium (fig. 98 seedling, and fig. 127 seed). Both have compressed, nearly orbicular seeds, but in Ruellia the cotyledons are broad, in Cerastium they are narrow. If, however, we make sections of the seeds, the cause of this difference becomes obvious, because in one (fig. 126) the cotyledons lie parallel, in the other (fig. 127) transversely, to the seed.

The form of the cotyledons often differs greatly even in the same family.

The Caryophyllaceæ, for instance, afford us an interesting illustration. The cotyledons in this family are placed with their backs to the placenta, and in most species are narrow, as in Cerastium. In some of them, however, such as the Pink itself (*Dianthus*) (fig. 97) and Tunica, they are wide.

Now in most genera, as in Stellaria, Spergularia, Cerastium, &c., the seeds are laterally compressed; the cotyledons consequently lie transversely to the seed, and their width therefore is limited by the thickness of the seed, as in fig. 127. The case is, however, somewhat complicated by the fact that the seed and embryo are both curved.

On the other hand, in the Pink (fig. 128) the seeds are not laterally but dorsally compressed, and attached to the columnar placenta (fig. 128, *pl*) by the middle of the interior face, so that the cotyledons are straight, parallel to the seeds, and have in consequence plenty of room to widen out.

In Solanum the fruit is roundish, indehiscent, and many-seeded. The seeds are kidney-shaped, much compressed laterally, and placed with their narrow edge to the placenta, surrounded by a paler margin, glabrous and white; the hilum is small, and on the middle of the ventral edge. The embryo is, in the mature seed, much curved, embedded in, but lying near the outer edge of, the endosperm. The radicle occupies the lower and narrow part of the seed. The cotyledons are linear, not broader than the radicle, curved, with their tips close to the hilum, and their backs to the placental axis, and at right angles to the plane of the seed, the whole width of which accordingly they occupy, so that they cannot grow any wider. On the other hand, while the fruit of Cestrum is not very unlike that of Solanum, the seeds are very different in shape, being peltate, and

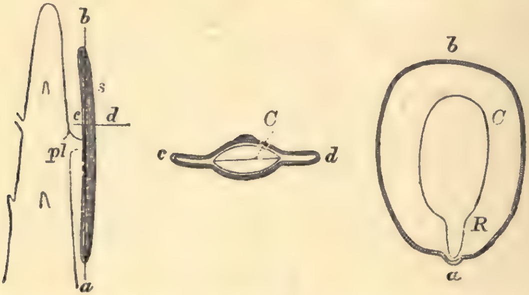

Fig. 128.—*Dianthus Caryophyllus*, × 15 : *pl*, placenta ; *s*, seed ; *C*, cotyledon ; *R*, radicle.

(In figs. 127 and 128 the letters *a*, *b*, and *c*, *d* indicate the directions of the sections.)

more or less obovate, with the broad end towards the apex of the seed, so that the cotyledons have room to widen themselves.

Sometimes we meet with species having both narrow and broad cotyledons, even in the same genus. For instance, Coreopsis filifolia has narrow, Coreopsis auriculata broad, cotyledons. If, however, we examine the seeds we find that those of C. filifolia are narrow or subcylindrical (fig. 129), while those of C. auriculata (fig. 130) are broadly obovate; and as in both cases the embryo fills the seed, this difference sufficiently accounts for the dissimilarity in the cotyledons.

The genus Galium is an interesting case. Here also we find some species with narrow, some with broad, cotyledons; but the contrast seems to be due to a very different cause. G. Aparine has broad, G. saccharatum narrow, cotyledons. In G. saccharatum the fruit (fig. 131) is deeply lobed, two-celled, two-seeded, indehiscent, and densely covered with tubercles. The seed is globose, deeply hollowed on the

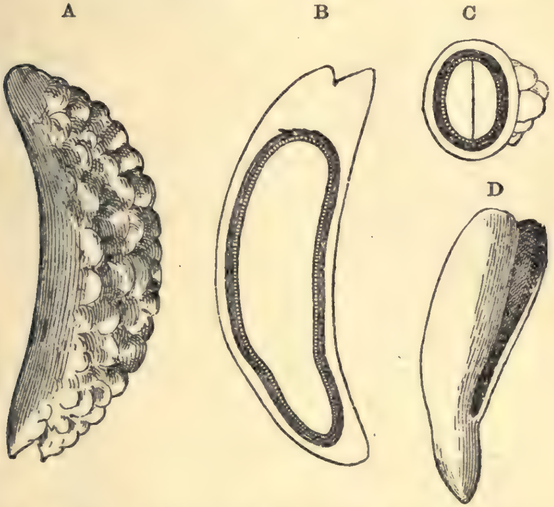

FIG. 129.—*Coreopsis filifolia*, × 14. A, achene. B longitudinal section, C, transverse section. D, embryo.

ventral surface. The embryo (fig. 131, A, *r*, *c*) is curved, following the concavity of the hollow, with the

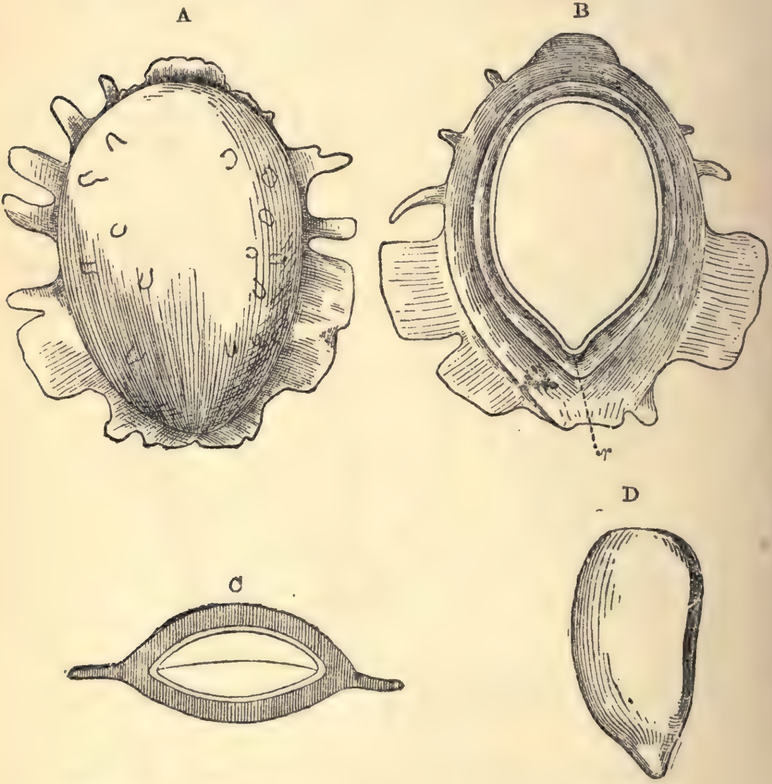

Fig. 130.—*Coreopsis auriculata*, × 14. A, achene. B, longitudinal section. C, transverse section. D, embryo.

larger part of the endosperm lying towards the periphery. The cotyledons are linear and obtuse. Fig. B shows that, so far as the form of the seed is concerned, there is no reason why the cotyledons should not be much broader than they are. The explanation may

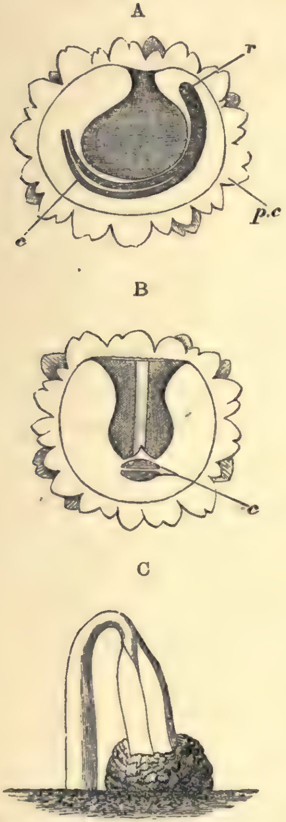

FIG. 131.—*Galium saccharatum.* A, longitudinal section of seed, × 8. B, transverse section of seed, × 8. C, germinating seedling, × 4.

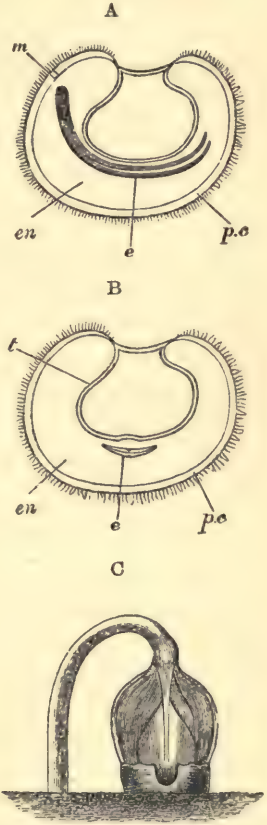

FIG. 132.—*Galium Aparine.* A, longitudinal section of seed, × 8. B, transverse section of seed, × 8. C, germinating seedling, × 4.

p.c, pericarp; *r*, radicle; *t*, testa; *en*, endosperm; *c*, cotyledons.

perhaps be found in the structure of the pericarp (*p.c*), which is thick, tough, and corky. It is very impervious to water, and may be advantageous to the embryo by resisting the attacks of drought and of insects, and perhaps if the seed be swallowed by a bird, by protecting it from being digested. On the other hand it does not split open, and is too tough to be torn by the embryo. The cotyledons, therefore, if they had widened, as they might otherwise have done, would have found it impossible to emerge from the seed. They evade the difficulty, however, by remaining narrow (fig. C). On the other hand, in G. Aparine (fig. 132) the pericarp is much thinner, and the embryo is able to tear it open (fig. C). In this case, therefore, the cotyledons can safely widen without endangering their exit from the seed.

The thick corky covering of G. saccharatum is doubtless much more impervious to water than the comparatively thin testa of G. Aparine. The latter species is a native of our own isles, while G. saccharatum inhabits Algiers, the hotter parts of France, &c. May not, then, perhaps the thick corky envelope be adapted to enable it to withstand the heat and drought?

In all these species the cotyledons are flat or nearly so, but a large number are enabled to widen themselves by being more or less folded. One form of this is afforded by the Radish (*Raphanus*) and Cabbage (*Brassica*). Fig. 133, A, shows a seed of the Radish, and, as shown in figs. B–E, the last of which represents a young seedling, the cotyledons are applied to one another face to face, and then folded along the middle.

UNEQUAL COTYLEDONS.

I now turn to those species in which the two cotyledons are unequal in size.

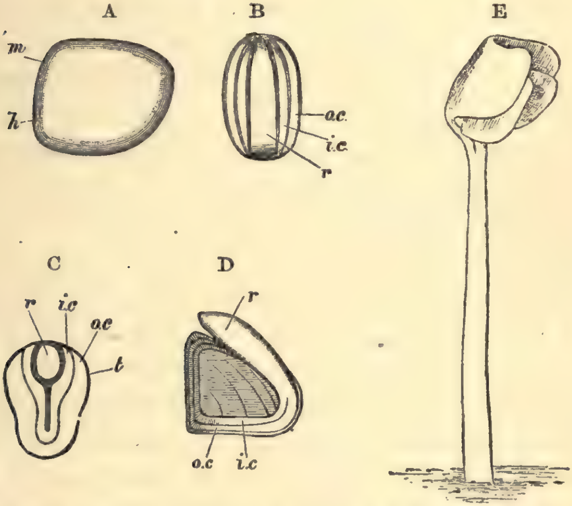

FIG. 133.—*Raphanus sativus.* A, outline of seed, × 4 : *m*, micropyle; *h*, hilum. B, embryo extracted from seed, × 4. C, embryo, × 4; vertical section. D, embryo, seen from the side, × 4 : *o.c*, outer cotyledon; *i.c*, inner cotyledon; *r*, radicle; *t*, testa. E, germinating seedling, × 2, showing the cotyledons still folded.

Several of these cases have been discussed by Darwin,[1] who attributed the inequality to the fact of 'a

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[1] *Movements of Plants*, p. 94.

store of nutriment being laid up in some other part, as in the hypocotyl, or one of the two cotyledons, or one of the secondary radicles.' I differ with the greatest hesitation from so high an authority; but do not see the connection between the store of food being partly laid up in some other part of the plant and the inequality between the cotyledons. Why should it affect one more than the other? I venture to suggest that the difference is due rather to the position of the embryo in the seed, which in some cases favours one cotyledon more than the other. For instance, in many cases the cotyledons are what is called 'incumbent,' that is to say, the radicle is folded upon one of the cotyledons, and in such species the outer cotyledon is often rather larger than the other, as, for instance, in Hesperis matronalis (see *ante*, p. 32).

The Hemp (*Cannabis*) and Caylusea present us with cases more or less resembling that of Hesperis.

In the Mustard (fig. 11), Cabbage, Radish (*Raphanus*), and some other Crucifers, the difference is more marked, and is due to a different cause. The cotyledons, as just mentioned, are applied to one another face to face (fig. 133, B–D), and then doubled longitudinally one inside the other. The outer one, therefore, having more space, becomes larger and the petiole is longer. In Cereus (fig. 134) the embryo is much curved, and the cotyledons being thick and fleshy, the inner one is naturally smaller than the outer.

In Nyctagineæ the cotyledons were always unequal in the seeds observed, but in some cases one was nearly aborted. The anthocarp of Mirabilis longiflora is obovoid, closed by constriction above the true fruit, hardened or crustaceous and sculptured on the outer surface. The wall of the fruit itself is thin and membranous as is the testa which adheres to it. The embryo is doubled upon itself with unequal-sized, concave cotyledons occupying the periphery of the seed and enclosing the farinaceous endosperm. The radicle is long, terete, stout and occupies the other side of the seed, and together with the outer cotyledon determines the smaller size of the inner cotyledon by restricting its growth.

Fig. 134.—*Cereus Napoleonis.* Section of seed, × 9 : *oc*, outer coat of testa; *ic*, inner coat of testa.

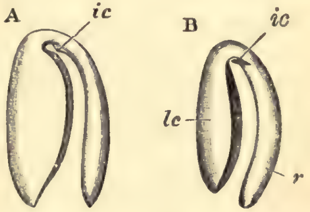

Fig. 135.—A, embryo of *Abronia arenaria*, × 6 : *ic*, smaller cotyledon. B, embryo of *A. umbellata*, × 6 : *ic*, right and inner cotyledon; *lc*, left cotyledon; *r*, radicle.

In Abronia umbellata (fig. 135, B) the embryo is large, much curved or doubled on itself, and lies outside the endosperm, the two edges of one cotyledon reaching almost to the radicle. The second cotyledon (*ic*) is minute, generally not more than one-seventh the length of the outer one, though in one seed it attained nearly half the length of the other. In another species of the same genus, A. arenaria, the smaller cotyledon is reduced to a mere knob (fig. 135, A, *ic*).

The cotyledons remain very unequal for a considerable time after germination. Thus the oblong lamina of the larger one eight days after germination was 8–8·5 mm. long, 4·5–6 mm. wide, and twenty-eight days after germination 14–14·5 mm. long and 9 mm. wide; while that of the smaller one eight days after germination was obovate, 1·25 mm. long, 1 mm. wide, and twenty-eight days after germination obovate, tapering to the base, 14–18 mm. long and 8·75–10 mm. wide above the middle. The petiole of the larger one eight days after germination was 5–12 mm. long, and twenty-eight days after germination 24–28 mm. long; that of the smaller one eight days after germination very small or almost absent, but twenty-eight days after germination 25–30 mm. long.

The larger cotyledon eight days after germination exhibits a distinct midrib and two lateral nerves near the base, but twenty-eight days after germination the cotyledon becomes rather fleshy, and has the midrib only discernible; the smaller cotyledon at first exhibits a midrib only, and that very indistinctly, but twenty-eight days after germination it is obovate, tapered to the base and trinerved, about the same size as the originally large cotyledon or larger, with a longer or shorter petiole. In all these characters it seems to behave like a true leaf, but maintains the position of a cotyledon.

Fifty-six days after germination the originally large cotyledon measured as follows:—Petiole 27 mm. long, with the lamina 18·5 mm. long, 11 mm. wide; the originally small one now the largest, with a lamina 23 mm. long, 12 mm. wide, and its petiole 49 mm. long, faintly trinerved.

Cases in which one of the cotyledons is rudimentary also occur in the genera Ranunculus[1] and Carum.[2] Cyclamen also has only one cotyledon, which soon becomes foliaceous and of large size resembling a true leaf. The cotyledon of Cyclamen persicum is cordate and more or less crenate, greatly resembling the first true leaf. In a batch of seedlings, individuals may frequently be found having the cotyledons divided into two reniform, sessile, or stalked pieces resembling a compound leaf with a pair of leaflets. The apparently compound character is further strengthened by the complete suppression of what should be the midrib of the lamina of the originally and normally simple cotyledon.

In Petiveria octandra (Phytolaccaceæ) (fig. 136, A) the cotyledons are very interesting. The one is about 3 cm. long, $1\frac{1}{4}$ broad, oblong, tapering at both ends, and entire. The other is shorter and broader, 2 cm. long by $1\frac{3}{4}$ broad, subcordate, with a large terminal lobe, and one,

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[1] See Irmisch, *Beitr. zur vergl. Morphol. der Pflanzen* (Halle, 1854).

[2] Hegelmaier, *Vergl. Untersuchungen* (Stuttgart, 1878).

more or less pronounced, on each side. At first I thought this curious want of symmetry must be accidental. It is, however, normal, and is explained by the peculiar form and arrangement of the embryo (fig. 136, B–D) in the seed. The fruit is an achene of peculiar form; it is oblong-linear, subcuneate, and laterally compressed, bifid at the apex, crowned with 2–6 unequal, closely reflexed, acute bristles, and more or less hairy, one-celled, one-seeded, and indehiscent. The seed is oblong-linear, and tapers somewhat, conforming to the interior of the fruit. The embryo is large; the inner cotyledon is

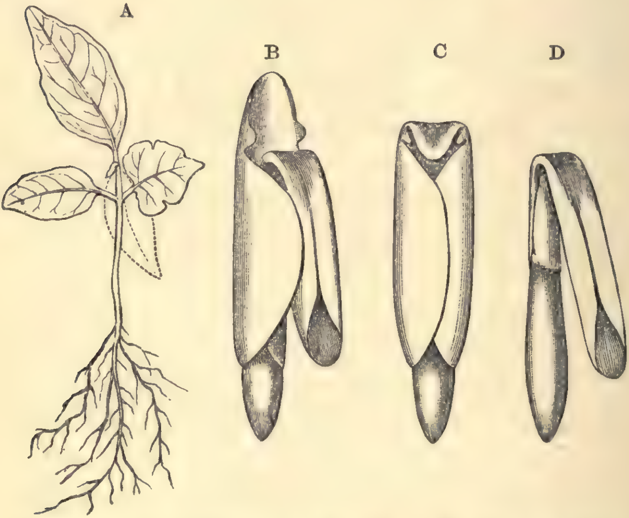

FIG. 136.—*Petiveria octandra.* A, seedling, half nat. size. B, embryo partly unfolded, × 6. C, outer and shorter cotyledon. D, inner and longer cotyledon.

doubled on itself; the outer one is also turned over at the end, and wraps round the narrower one,[1] not reaching, however, to the narrow end of the seed: the terminal lobe of the shorter and broader cotyledon is the part which is folded over, and the lateral lobes, which are much smaller in the embryo, are also due to the fold, as shown in figs. B–D.

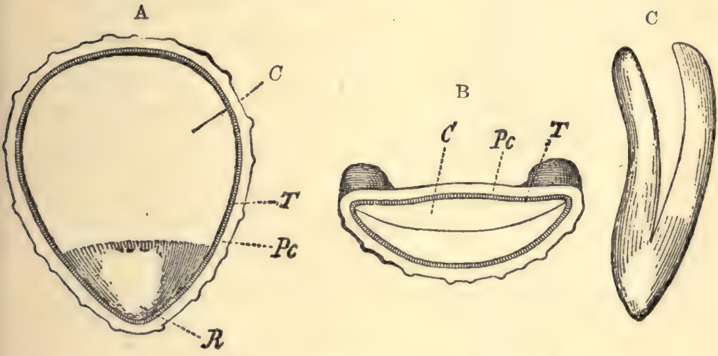

Fig. 137.—*Coreopsis Atkinsoniana*, × 10. A, longitudinal section of achene. B, transverse section of achene. C, embryo. *Pc*, pericarp; *T*, testa; *C*, cotyledon; *R*, radicle.

In Coreopsis Atkinsoniana the seeds are obovate, curved longitudinally, and compressed dorso-ventrally, conforming to the interior of the fruit. The embryo again is slightly bent, following the direction of the seed. Consequently the one cotyledon occupies the inner, the other the outer side of the curve; and, as shown in fig. 138, the outer one is distinctly larger than the other.

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[1] The narrow cotyledon is sometimes absent.

In Thunbergia reticulata the cotyledons are unequal, ovate, obtuse, slightly emarginate, and cordate at the base. The larger one is slightly denticulated, and has a curious embossed area in the centre; the smaller one is, on the contrary, smooth and entire, or nearly so. The seed is orbicular or oblong; exalbuminous, 3–4 mm. in diameter, and compressed, with a cavity on the inner side. The embryo is slightly curved; and the cotyledons lie with their faces towards the hilum, which is very prominent; the inner cotyledon is turned up at the edges, and wraps, to a certain extent, round the outer one. The raised or embossed patch in the centre of this cotyledon is due to the inward curvature of the testa.

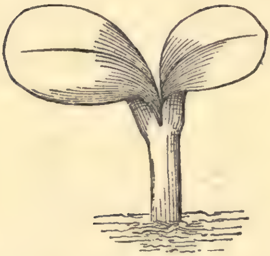


FIG. 138.—*Coreopsis Atkinsoniana.* Seedling, × 10.

UNSYMMETRICAL COTYLEDONS.

In other cases, as in the Geraniums (fig. 140), Schinus (the False Pepper) (fig. 145), Clitoria (fig. 144), Laburnum (fig. 101) Lupines, and others, there is inequality, not between the two cotyledons, but between the two halves of each cotyledon. In the Geraniums this is due to the manner in which the cotyledons are folded. In the Cabbage and Mustard we have seen that one cotyledon is folded inside the other; in the Geranium they are convolute (fig. 139), one half of each being folded inside one half of the other—the two inner halves being the smaller, the two outer the larger ones.

In the last case the seed is oblong or subcylindrical, finely tuberculated, about equally thick at both ends, and fixed to the placenta a little above its middle. The chalaza is at the lower end close to the base of the carpel. Endosperm is absent, and the curved embryo, which is green, at least while fresh, occupies the whole of the seed.

Fig. 139.—Section through embryo of *Geranium*, showing the mode of folding of the cotyledons.

Fig. 140.—*Geranium Wallichianum.* Nat. size.

Taking G. Wallichianum (fig. 140) as a type, we find that the radicle is the only part that is curved; and assuming that the embryo starts from near the micropyle above the middle of the seed, then it would grow until it reached the upper end of the seed, when the apex curves downwards until it reaches the base, and here we always find the apex of the cotyledons pointing to the base of the carpels or ovary. There still being room for the cotyledons to develop laterally, they commence to coil longitudinally round the sides of the seed in the direction of the sun when the seed is held in its natural position.

The result is that one longitudinal half of each cotyledon grows faster than the other, and grows over, enclosing the smaller half of the other; and when the embryo is full grown, a transverse section shows each of the cotyledons coiled in the shape of the letter S, but the small coil of each is inserted in the large coil of the other, as in the figure. The coils are, however, closely drawn together so as to fill the seed compactly, and the radicle is incumbent on the back of the cotyledons, but on the ventral face of the seed; there is a small notch or cavity in the centre of the bundle or coil at its lower end into which the rather prominent chalaza fits. When flattened out the cotyledons are now transversely oblong or reniform, slightly sinuate at the apex, with the midrib excurrent, forming a small tooth; the base is deeply cordate. The two halves are unequal, the smaller one occupying the interior of the coil. The cotyledons are even already petiolate, and examination shows that this is necessary in order to allow of their becoming convolute. The inner or upper faces are always applied to one another, but the coils or smaller enfolded half of each prevents the two midribs from coming in contact as they would do if the cotyledons were flat. Hence the necessity for petioles while yet in the seed.

The seed of Buckwheat (*Fagopyrum esculentum*) (fig. 141) is large, ovoid, trigonous, rarely with the angles nearly obliterated and rounded. The embryo is relatively very large, variously folded and convolute longitudinally, similar to what occurs in Geranium, except that endosperm is here present and is nearly divided in half by the cotyledons. In transverse section the latter are seen to be twisted in the form of the letter **S**, with endosperm occupying the sinus. They are deeply but unequally auricled at the base, and the two halves of the lamina are unequal, and the whole therefore unsymmetrical for the same reason as in

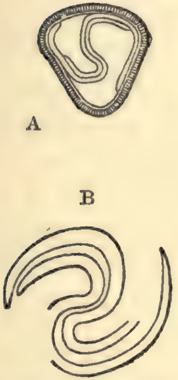


Fig. 141.—*Fagopyrum esculentum.* A, transverse section of seed, × 4. B, embryo, × 8.

Fig. 142.—*Fagopyrum tataricum.* Half nat. size.

Geranium. The larger halves are outermost and hug the testa, closely following two out of the three angles of the seed and enclosing the smaller halves. The latter retain their smaller size after germination (see also F. tataricum, fig. 142). The radicle is large, fusiform, and completely enclosed by the folds of the cotyledons.

The embryo in the young state becoming too wide for the interior of the seed, becomes first folded together longitudinally, and growth continuing the cotyledons become spirally convolute, forming a large open spiral with all the intermediate spaces filled with a white floury mass of endosperm. The cotyledons at length get outside the endosperm and direct their course into two out of the three angles of the seed, thus obtaining the greatest possible width. Looking from the apex of the seed—that is, from the radicle end of the embryo to the lower end of the seed—the cotyledons are after the first folding all twisted in the same direction, from right to left, or in the opposite direction to the course of the sun, or this direction may be reversed. In consequence of this one half of each cotyledon is enclosed by the other half, so that the outer half of each has more

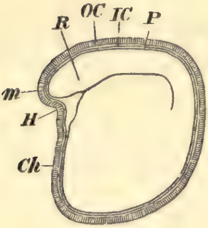


FIG. 143.—Seed of *Laburnum vulgare*, × 6: *OC*, outer coat; *IC*, inner coat.

room to develop, and is both larger and has larger auricles.

In the Laburnum (fig. 101) and in Clitoria (fig. 144), on the other hand, the inequality in the two sides of the cotyledon is due to the inequality between the two sides of the seed (fig. 143).

Fig. 144.—Seedling of *Clitoria ternatea*. Half nat. size.

Fig. 145.—Seedling of *Schinus terebinthifolius*. Two-thirds nat. size.

In Heritiera macrophylla (Sterculiaceæ) the cotyledons fill the seed, which conforms to the shape of the carpels, and the fact that these are somewhat unequal-sided renders the seed and consequently the cotyledons so likewise.

In the Lupines the seeds are obliquely oblong, compressed laterally, and without endosperm, the embryo being large, fleshy, yellowish, and occupying the whole seed. It is doubled on itself, and the cotyledons are folded along the radicle, which nearly equals them in length, with the smaller halves turned towards the radicle, and in such a manner that they and the radicle together occupy one half of the seed, and about equal the larger halves of the cotyledons, which fill the other.

In Triphasia the inequality is due, partly at any rate, to a different cause. The oval seeds are somewhat flattened, especially on the ventral aspect. The embryo is large, and occupies the whole seed. The cotyledons are very unequal in size, and the smaller one is more or less enclosed in the larger. But, in addition to this, there are often, indeed generally, two and sometimes three embryos in each seed; these differ in size, and the smaller ones often intrude more or less on one of the cotyledons belonging to the larger ones.

A similar condition prevails in the seed of the Orange (*Citrus Aurantium*). Each contains from two to four embryos sufficiently large to germinate and grow into plants, besides a similar or even greater number of very small ones that are unable to germinate. The large ones are fleshy, colourless, and generally or always have very unequal cotyledons of various shapes owing to mutual compression. There is usually one large cotyledon in each seed, belonging probably to the true embryo, while all the rest are smaller, and packed on to the face of the large one, completely filling the seed. The large cotyledon is often deeply concave with the others packed into the cavity. Strasburger states that the supernumerary embryos are developed by prolification from the tissue of the nucellus bordering on the embryo-sac.

FIG. 146.—*Schinus Molle*, × 3. A, germinating seed. B, seedling four days after germination.

In Schinus (figs. 145, 146) the shallow sinus on one side owes its origin to the indentation of the lower side of the horizontal seed by a thickening or elevation of the receptacle in that region.

Crenate Cotyledons.

The vast majority of plants have the edges of the cotyledons entire. There are some few, however, in which they are more or less crenate, as, for instance, in Cordia subcordata (fig. 106).

Fig. 147.—Embryo of *Cordia subcordata*, × 2: *r*, radicle.

In this species the embryo occupies the whole of the ovoid-conical seed. There is no endosperm, and the cotyledons, in order to occupy the whole space, are longitudinally folded (fig. 147), thus giving rise to the crenations on the margin.

Lobed Cotyledons.

The great majority of cotyledons are entire, but some are more or less lobed. For instance, those of the Mallow (fig. 108) are broadly ovate, minutely emarginate, cordate at the base, and three-lobed or -angled towards the apex, with three veins, each running into one of the lobes.

Those of Lavatera and Althæa are similar. The embryo is green, curved, and in a young state occupies a great part of the seed. The cotyledons are applied face to face; then, as growth continues, the tip becomes curved, and depressed into a median longitudinal furrow, the fold of the one lying in that of the other.

The embryo is of the form shown in fig. 148: the horn or process *r* is the radicle; the rest is the cotyledon, of which the free end *f* is folded on itself and turned downwards. In this way the embryo fills the seed, leaving a small space between the cotyledons and also between *f* and *r* which is occupied by endosperm. Perhaps it may make the arrangement clearer to take a piece of note-paper, cut it into the form of an egg (fig. 149), turn the broad portion *a b* downwards, so that the parts *a* and *b* have their under faces turned to one another, and then press down the line *e f*, and bring the points *c* and *d* together, so that *c e f* and *d e f* have their upper surfaces together, and the apex *f* pointing downwards. We shall then have an object shaped as

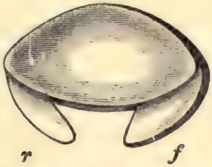
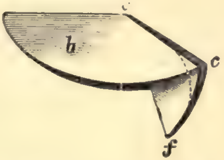


Fig. 148.—Embryo of Mallow. Enlarged.

Fig. 149

Fig. 150.



Figs. 149 and 150.—Piece of paper prepared to show the mode and effect of the folding of the embryo.

in fig. 150, with a sharp point at *c*, which would not conform to the rounded shape of the seed. If, now, to make it do so, we cut off the point *c* along the dotted line and then unfold the paper, we shall find that it has the form of the cotyledon of Malva (fig. 108) with a bay or notch on each side. In Erodium the arrangement is somewhat similar, and it seems clear that the lobes are due to the manner in which the embryo is folded.

In Œnothera and some allied species the cotyledons also present a terminal lobe. This, however, is not due to folding. The terminal lobe is the original cotyledon, and the basal portion an altogether subsequent growth, which, moreover, to some extent, assumes the character of the true leaf. I shall presently refer to this interesting group in more detail.

The case of Petiveria octandra (fig. 136) has been already described.

EMARGINATE COTYLEDONS.

In a great many species the cotyledons are emarginate, and even in some more or less deeply bifid. No explanation of this has, so far as I know, yet been offered. It is, in fact, as I shall hope to show, by no means always due to the same cause.

One of the simplest cases is that of the Oak, where the thick fleshy embryo occupies the whole of the seed. The chalaza is situated at the centre of one end, at the extremity of the cotyledons, and the walls of the seed being at that point somewhat thickened, the cotyledons are slightly pressed in. The same explanation applies to various other species, as, for instance, to the Impatiens (figs. 87 and 151), Poterium (figs. 114 and 152), Cuphea (figs. 153 and 191), and Nettle (*Urtica*) (fig. 154).

In Helianthus Cucumis the seed itself is slightly notched at the point where it articulates with the receptacle; and the cotyledons, which, with the rest of the embryo, eventually occupy the whole interior of the seed, conform to this notch.

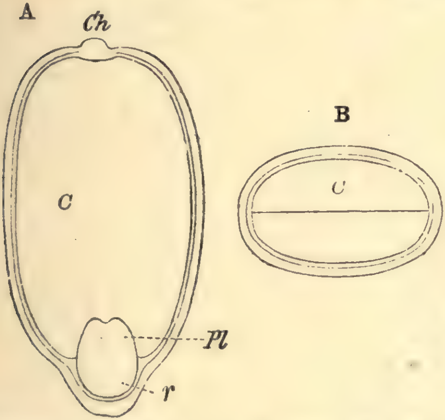


FIG. 151.—Longitudinal, A, and transverse, B, sections of seed of *Impatiens parviflora*, × 10: *Pl*, plumule; *C*, cotyledons; *r*, radicle; *Ch*, chalaza.

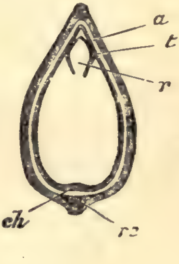


FIG. 152.—Longitudinal section of *Poterium Sanguisorba*, × 9: *a*, achene; *re*, receptacle; *t*, testa; *ch*, chalaza; *r*, radicle.

In such cases as the Mustard, Cabbage, Radish, and many other Crucifers, the emargination is due to a totally different cause. The seed (fig. 133, A) is oblong, thick, and slightly narrower at one end than the other. There is no endosperm, so that the embryo occupies the whole seed, and as this is somewhat deep, the cotyledons, in order to occupy the whole space, are folded and arranged one over the other, like two sheets of note-paper, as shown in fig. 133, B–E, the radicle being folded along the edge. Fig. 133, D, represents

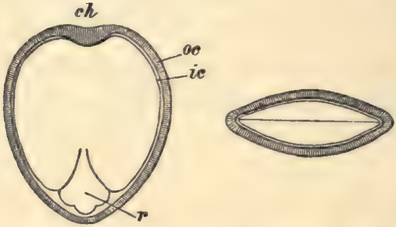


Fig. 153.—Longitudinal and transverse sections of seed of *Cuphea silenoides*, × 10: *oc*, outer coat; *ic*, inner coat.

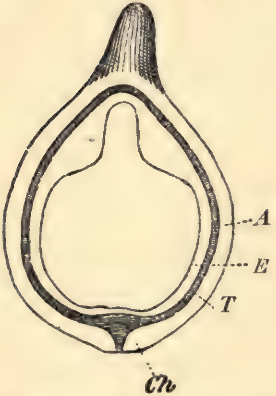


Fig. 154.—Achene of Nettle (*Urtica dioica*), × 30: *A*, pericarp; *E*, endosperm; *T*, testa; *Ch*, chalaza.

Fig. 155.—*Zilla myagroides*. Nat. size.

the embryo a little opened out; and fig. 133, C, a section showing the radicle and the outer and inner cotyledons. To this folding the emargination is due. If a piece of paper be taken, folded on itself, cut into the form shown in fig. A, with the fold along the edge from *m* to *h*, and then unfolded, the reason for the form of the cotyledon becomes clear at once. Zilla myagroides, another Crucifer, affords a similar case (fig. 155).

But it may be said that in the Wallflower the seed has a similar outline, and yet (fig. 156) the cotyledons are not emarginate. The reason of this is that in the Wallflower (*Cheiranthus Cheiri*) (figs. 28 and 29) the seed is more compressed than in the Mustard and Radish, and the cotyledons are not folded; so that the whole, not the half, of each cotyledon corresponds to the form of the seed.

In the Bignoniaceæ, again, a large number of species have emarginate cotyledons; and this would appear also, as for instance in Pithecoctenium Aubletii, to be due to the chalaza, though in a different manner. The seeds themselves are transversely oblong, much compressed dorsally, and surrounded on all sides except the base by an extremely thin, transparent, membranous wing, which is traversed by nerves radiating from the central part of the testa, and is uneven at the margin. The raphe is ventral, extending from the hilum to the centre of the embryo. The chalaza is attached to the embryo-sac a little above the middle of the embryo. The radicle is very small, distant from, but pointing to, the hilum. The embryo is straight and flat; the cotyledons grow until they come to the point of attachment of the chalaza, when they extend forwards on each side, forming two lobes.

In Oroxylum indicum the general structure of the seed is very similar, but the growth of the two lobes of the cotyledons is even more luxuriant, so that they actually overlap. A structure more or less similar occurs in other genera of this family. Compare, for instance, Eccremocarpus scaber (fig. 157).

Fig. 156.—Seedling of *Cheiranthus Cheiri.* Two-thirds nat. size.

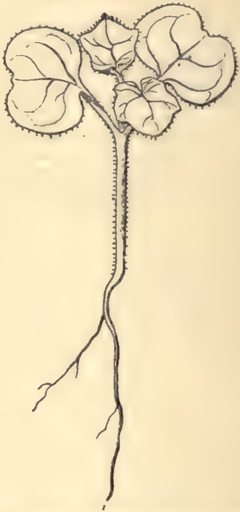


Fig. 157.—*Eccremocarpus scaber*, × 2

The emargination is very much deeper in other groups, and due to other conditions, for instance in the

Convolvulaceæ. In Convolvulus Soldanella (fig. 158) the embryo, which is eventually very large, lies at first straight in the seed embedded in a clear jelly-like endosperm, and rests on a solid ovate, grooved, white ridge (fig. 158, B and C, *a*), which rises from close to the micropyle. This tongue-like ridge grows with the embryo. At the opposite end of the seed the raphe and chalaza form a somewhat prominent ridge (*b*) projecting into the endosperm. The cotyledons in this stage are plano-convex, applied face to face, orbicular, entire, green, with distinct petioles, 5-nerved, with two lateral, subopposite branches from the midrib some distance below the apex. The plumule and radicle are small. The cotyledons gradually increase in size and grow over the process (*a*) in which the radicle lies, extending to the apex of the seed, doubling over and abutting against the ridge formed by the raphe and chalaza (*b*), and thus becoming more and more emarginate at the apex. The notch is therefore due to

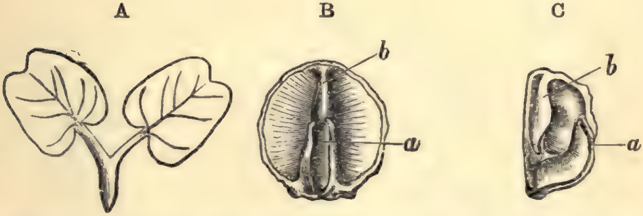


FIG. 158.—*Convolvulus Soldanella*, × 2. A, embryo. B, section of seed after removal of the dorsal surface, embryo, and endosperm. C, side view of ditto.

their continuing to grow at the sides after their apex has reached this ridge.

In Ipomœa purpurea (fig. 159, A–C), where the seed is constructed generally on the same model as in Convolvulus Soldanella, the ridge formed by the raphe and chalaza (fig. 159, B and C, *b*) is more prominent, and consequently the notch of the cotyledon is deeper. Lastly, in Ipomœa dasysperma (fig. 160, A–C) the projecting ridge of the chalaza is still more developed and reaches nearly to the process which supports the radicle; the cotyledons are thus precluded from growing in length, and in consequence send out two long wings, so that they are divided almost to the base (fig. 160, A).

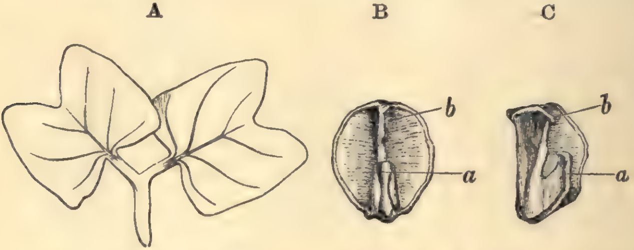


FIG. 159.—*Ipomœa purpurea*, × 2. A, embryo. B, section of seed after removal of dorsal surface, embryo, and endosperm. C, side view of ditto.

In Shorea (Dipterocarpeæ), again, the division of the cotyledons is perhaps due to an internal process of the seed. I have not, however, had an opportunity of examining a specimen.

In Eucalyptus (fig. 111) we have a different case. The embryo is (with the exception of the petioles) straight or nearly so, fleshy, white, occupying the whole of the seed, and conforming to it in general outline; the cotyledons are deflexed and convolute round the radicle, which the lobes equal in length, while half of one cotyledon lies over half the other; one half of each consequently lying against the testa. The radicle is stout, fleshy, truncate at the end where it lies against the testa, but otherwise entirely enclosed by the folded cotyledons. The true length of the cotyledon is determined by the distance between the end of the petiole and the opposite pole of the seed. The side of the cotyledons, however, being folded back, that part which lies beyond the petioles is enabled by folding round the radicle to widen, and this conse-

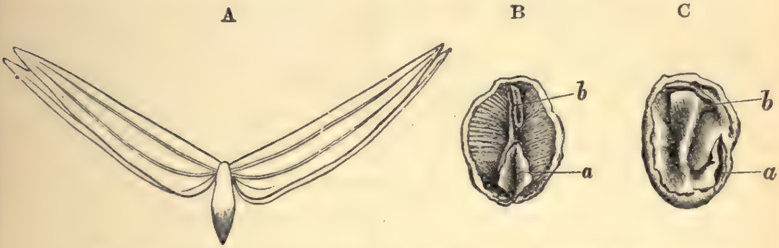


FIG. 160.—*Ipomœa dasysperma*, × 2. A, embryo. B, section of seed after removal of dorsal surface, embryo, and endosperm. C, side view of ditto.

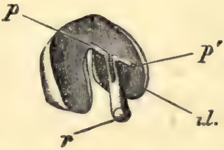


FIG. 161.—Embryo of *Eucalyptus Globulus*, one cotyledon being cut away: *p*, petiole; *p′*, cut end of petiole; *i.l*, inner lobe of cotyledon; *r*, radicle. × 4.

quently gives the cotyledons their more or less pronounced hour-glass shape.

Moreover, in speaking of emarginate cotyledons, we must distinguish between two very opposite cases, of which I may take Galium Aparine and Œnothera Lindleyana as illustrations. In the former the cotyledons commence with an entire end (fig. 162), and subsequently, not as a rule till they have left the seed, become emarginate (fig. 163); in Œnothera Lindleyana, on the contrary, the cotyledons are at first emarginate, but ultimately entire. The embryo gradually appropriates all the endosperm, but the supply being largest at the wider end of the seed, this is the last part to be absorbed. In neither of these cases does the emargination appear to be directly due to the structure of the seed, nor to be in itself of any advantage to the plant. It seems rather to depend on the conditions of growth. In Galium Aparine the cotyledon terminates in a peculiar gland,[1] which would appear in this and

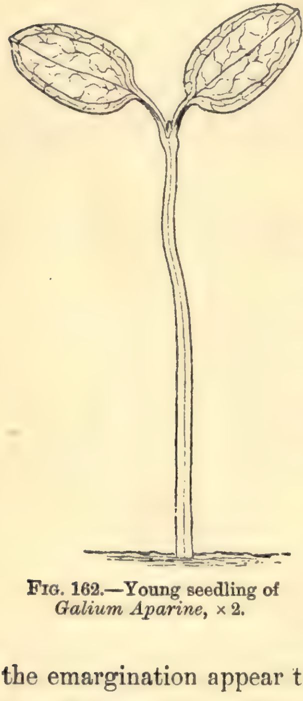


Fig. 162.—Young seedling of *Galium Aparine*, × 2.

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[1] This gland has already been mentioned by Gravis in his work on *Urtica dioica* (Brussels, 1886), p. 139. He observes that about a

other cases, after the emergence of the cotyledon, to stop its growth at that point, and thus to produce the emargination.

In a number of Cruciferæ the notch or sinus is not due to any peculiar conformation or structure of the seed, as the cotyledons are, as far as can be seen before germination, entire; but to the subsequent greater growth of the sides as compared with the organic apex.

FIG 163.—Young seedling of *Galium Aparine*, a few days older, × 2.

Such emarginate cotyledons occur in Nasturtium sylvestre, Arabis Turczaninowii, Cardamine hirsuta, C. græca, Lunaria biennis, Cochlearia glastifolia, Sisymbrium officinale (fig. 164), and others. The entire (A) and emarginate states (B) are shown in the figures of Sisymbrium officinale.

dozen small stomata occur on it, while they are entirely absent on the rest of the upper surface. He regards it as a water-gland, 'un organe destiné à remédier à l'excès de tension dans l'appareil aquifère.'

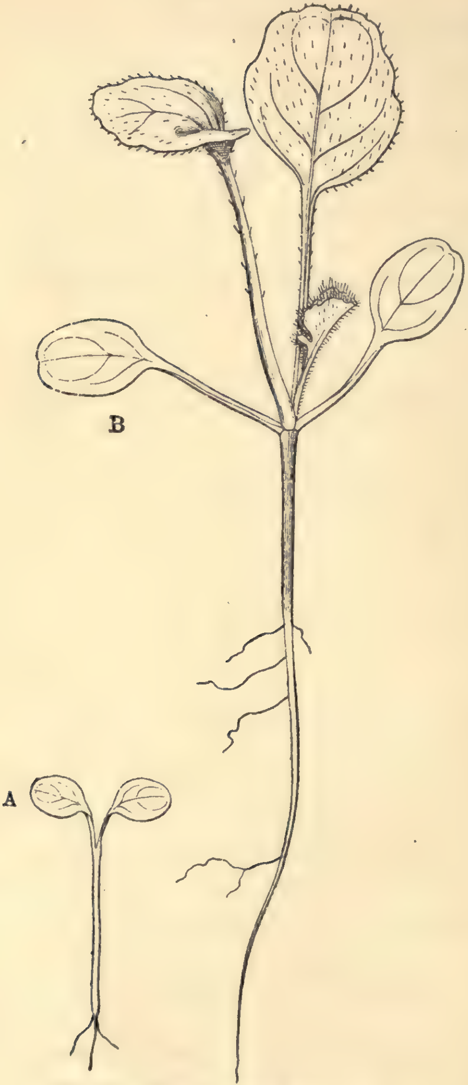

Fig. 164.—*Sisymbrium officinale*, × 2.

A few terminal pores or *water-stomata* are found at the apex of the midrib.

In Senécio, again, the majority of species have entire cotyledons. In some, however, as in S. erucæfolius, they are emarginate. Even here, however, they are at first entire (fig. 165), and the emargination does not make its appearance until after germination, when the cotyledons gradually become much widened (fig. 166). In fact, S. squalidus, S. viscosus, S. vulgaris, and others, have the cotyledons narrow and entire; while in S. erucæfolius and S. cruentus, where they grow more in width than in length, they become emarginate. Among other cases where the cotyledons are at first entire, but after germination become emarginate, may be mentioned some species of Lithospermum.

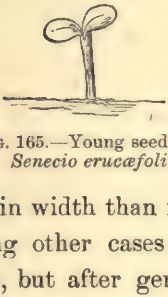

FIG. 165.—Young seedling of *Senecio erucæfolius.*

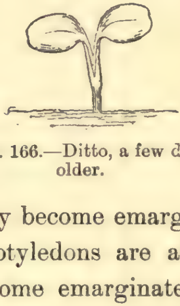

FIG. 166.—Ditto, a few days older.

Bryonia laciniosa (fig. 203) also has the cotyledons emarginate, while in B. dioica (fig. 204) they are entire. They are, however, originally entire in both cases, and the emargination in B. laciniosa is due to the fact that in that species the cotyledons grow much more than in B. dioica. There is no great difference in size between the seeds, those of B. laciniosa being perhaps one-tenth larger. On the other hand, the cotyledons of B laciniosa attain a length three times greater than those of B. dioica, as shown in the figures. In the genus Tacsonia, the cotyledons are entire in T. Van-Volxemii (fig. 167) and T. Leschenaultii, and emarginate in T. ignea (fig. 168). Here also, however, they are at first entire (fig. 169), and only become emarginate after leaving the seed.


Fig. 167.—*Tacsonia Van Volxemii.* Half nat. size.


Fig. 168.—*Tacsonia ignea.* Nat. size.

In Berberis Aquifolium the embryo is surrounded on all sides by endosperm, being only three-quarters as

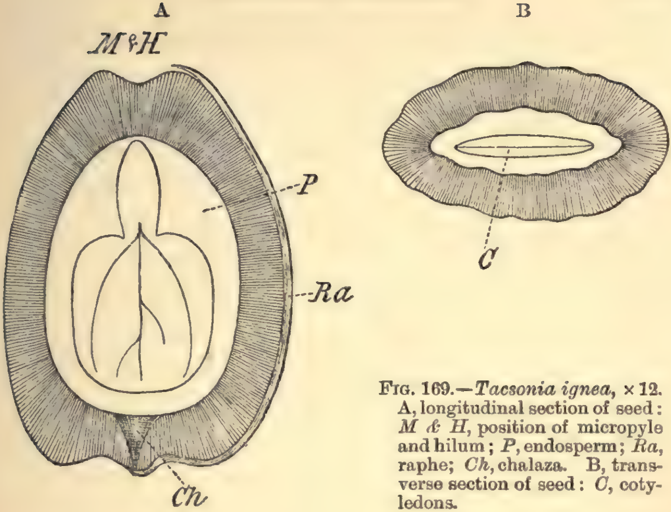

FIG. 169.—*Tacsonia ignea*, × 12. A, longitudinal section of seed: *M & H*, position of micropyle and hilum; *P*, endosperm; *Ra*, raphe; *Ch*, chalaza. B, transverse section of seed: *C*, cotyledons.

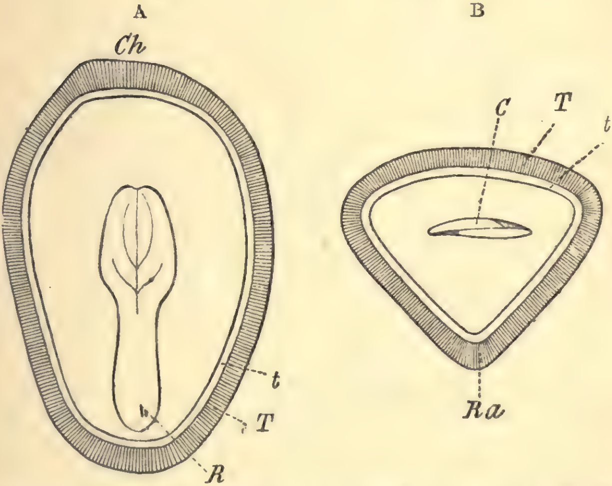

FIG. 170.—*Berberis Aquifolium*. A, longitudinal section of seed, × 10: *Ch*, chalaza; *R*, radicle; *T*, testa; *t*, tegmen. B, transverse section of seed, × 10: *C*, cotyledon; *T*, testa; *t*, tegmen; *Ra*, raphe.

long as the seed, but has nevertheless emarginate cotyledons. The notch is exceptionally large in this instance, but the structure of the seed does not give any explanation of its presence. It is moreover often altogether absent; and when present, is apparently due to the slower growth of the organic apex. The seed itself is bluntly triangular in transverse section, and shows the cotyledons lying in the broader plane of the seed, but not always strictly in apposition, a circumstance possibly due to the squeezing produced by the endosperm, while the cavity is a little wider than the embryo it contains. The shape of the seed is due to the mutual pressure of several seeds in a berry or fruit. Either the dorsal aspect of the seed, or the sides, may be the broader according to the position of the same on the placenta. The general

Fig. 171.—*Berberis Aquifolium.* Nat. size.

shape of seeds in the Order is obovoid, oblong, or globose, and they are generally immersed in pulp without being subject to much pressure.

In the seedling (fig. 171) the oblong cotyledons are obtusely pointed.

DIVIDED COTYLEDONS.

The genus Pterocarya has very curious cotyledons (fig. 180), due to a cause entirely different from any of those we have considered hitherto.

They are bipartite, each primary division narrowing to a cuneate base, and being again deeply divided, so as to make in all four ultimate, linear-oblong, obtuse, entire segments. In this case the endocarp is thickened and bony, and its cavity is divided at the base into four cells (fig. 172, A, *cccc*) by the thickening and consequent intrusion of the dorsal and ventral walls.

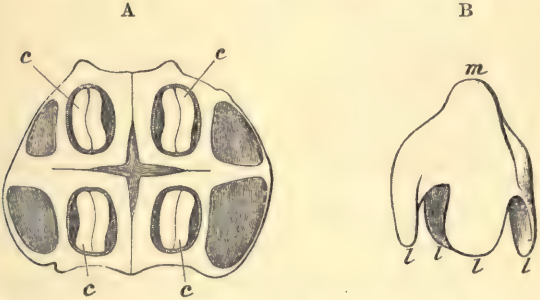

FIG. 172.—*Pterocarya caucasica.* A, transverse section of nut, × 6; showing the four hollows *c*, *c*, *c*, *c*, which are occupied by the four prolongations of the seed. B, seed, × 6.

The seed (fig. 172, B) is conical above, deeply four-lobed below (fig. 172, B, *l l l l*), one lobe passing into each of the cells of the endocarp. The embryo again follows suit, each cotyledon sending a lobe into each of the four seed-lobes, and thus assuming the peculiar form characteristic of the species.

Pterocarya caucasica flowers with us early in May. The pistil is syncarpous and inferior; the ovary of two carpels, one-celled, one-ovuled; the ovule basal, erect, and orthotropous.

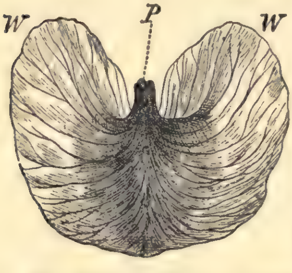

Fig. 173.—Fruit of *Pterocarya*, × 2: *P*, perianth; *W*, *W*, wings.

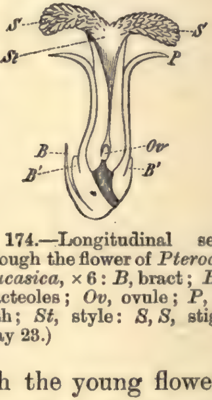

Fig. 174.—Longitudinal section through the flower of *Pterocarya caucasica*, × 6: *B*, bract; *B'*, *B'*, bracteoles; *Ov*, ovule; *P*, perianth; *St*, style: *S*, *S*, stigmas. (May 23.)

Fig. 174 is a section through the young flower at the end of May, showing a bract *B* at the base, two bracteoles *B' B'* at the sides, the ovule *Ov*, perianth *P*, and *S S* the two large, spreading, papillose stigmas. The cavity of the ovary is small and nearly filled by the ovule.

By about the middle of June the young fruit has grown considerably in thickness, though not much in length. The ovary and ovule are longer, and at the base of the former the tissue has in two places (fig. 175, *Co*, *Co*) become almost colourless from the removal of the protoplasm.

By the end of June the fruit has still further increased in length as well as in breadth. The growth in length has especially taken place between the base and the uppermost point of attachment of the bracteoles, which therefore seem to have been carried up. The bracteoles have also increased in size, while the perianth remains unaltered. The two masses of colourless tissue as seen in longitudinal section at the base of the ovary are still solid or unbroken.

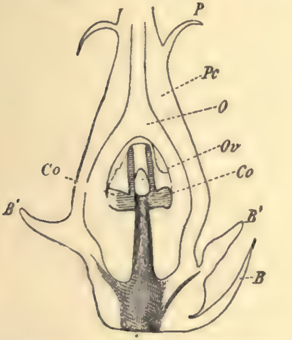

Fig. 175.—*Pterocarya caucasica.* Longitudinal section of fruit, × 6. (June 25.) *Co*, *Co*, two places where the tissue has become colourless; *Pc*, pericarp. (Other letters as in fig. 174.)

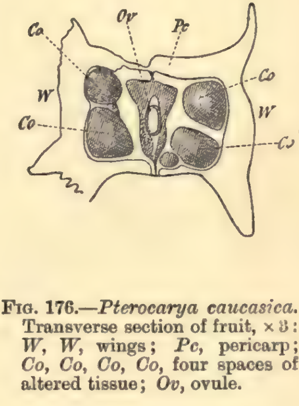

Fig. 176.—*Pterocarya caucasica.* Transverse section of fruit, × 8: *W*, *W*, wings; *Pc*, pericarp; *Co*, *Co*, *Co*, *Co*, four spaces of altered tissue; *Ov*, ovule.

The fruit continues to grow rapidly, especially at the base, so that by the end of July the posterior half of the bracteoles seems to be carried still further up, distinctly more so than the anterior. The neck of the fruit, on the contrary, has increased considerably in thickness, but scarcely at all in length. Fig. 176 represents a transverse section, and on each side of the ovule (*Co*, *Co*, *Co*, *Co*) are the four approximately circular patches of colourless tissue, which in a longitudinal section appear more elongated. In them the tissue is commencing to disintegrate, while round them, on the contrary, it is becoming distinctly sclerenchymatous. From the development of the lower part of the fruit, especially on the posterior side, the posterior portion of each bracteole appears to be nearly on the summit of the fruit, the anterior portion being rather lower down.

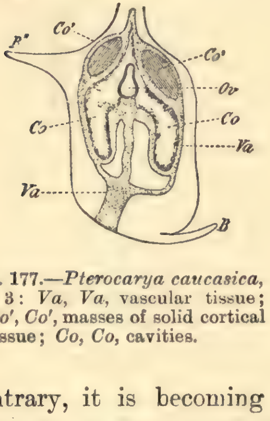

FIG. 177.—*Pterocarya caucasica*, × 3: *Va*, *Va*, vascular tissue; *Co'*, *Co'*, masses of solid cortical tissue; *Co*, *Co*, cavities.

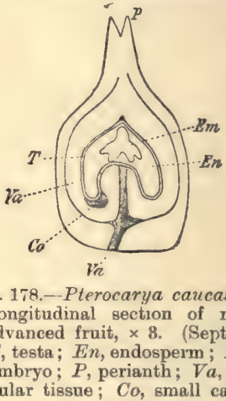

FIG. 178.—*Pterocarya caucasica*. Longitudinal section of more advanced fruit, × 8. (Sept. 1.) *T*, testa; *En*, endosperm; *Em*, embryo; *P*, perianth; *Va*, vascular tissue; *Co*, small cavity not yet filled by the seed.

Fig. 177 is a longitudinal section taken on August 8. It passes through two of the masses of loose tissue mentioned above, which now form cavities; while, on the other hand, the surrounding tissues have become much denser, leaving, however, oval spaces of cortical tissue shown in section at *Co′*, *Co′*.

The ovary has not materially altered, and the ovule is still very small.

A few days later, however, the ovule has grown considerably and nearly fills the cavities. Fig. 178 shows a longitudinal section taken on September 1. *T* is the testa, showing that the seed has now assumed its four-lobed form, though it has not yet quite filled the cavities in the fruit. The greater part, however, is occupied by endosperm, the embryo (*Em*) being still comparatively small.

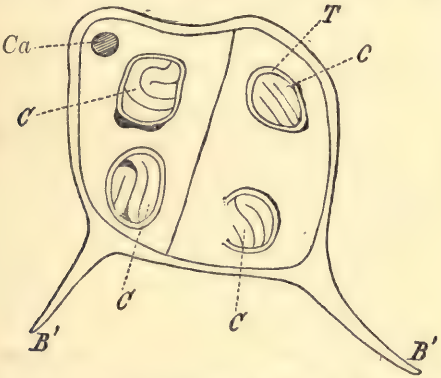

FIG. 179.—*Pterocarya caucasica.* Transverse section through a more advanced fruit near the base, × 6. (Sept. 21.) *T*, testa; *C*, *C*, *C*, *C*, folds of cotyledons; *B′*, *B′*, bracteoles or wings; *Ca*, small mass of cortical tissue.

Fig. 179 represents a transverse section near the base of the fruit, taken on September 21, when the fruit and embryo had attained nearly their full size, but had not yet reached maturity. Neither the placenta nor the original true cavity of the ovary is shown in this section, because they were situated at a higher level. The ovule from the first was basal, and the seed, even at maturity, may be looked upon as lying astride the basal placenta, with its four lobes projecting into as many cavities excavated from the originally solid base of the fruit. The testa is shown at *T*, lining the interior of the cavities and enclosing the variously folded lobes of the cotyledons (*C*, *C*, *C*, *C*). The walls surrounding the cavities are thick and sclerenchymatous, with exception of the thin outer rind and its appendages, the bracteoles or wings, shown at *B′*, *B′*. The cotyledons of the embryo diverge, one to each side of the fruit, and their lobes pass in pairs into each of its four cavities. As growth proceeds and the short lobes become too wide for the cavities, they become conduplicate in order to accommodate themselves to the restricted space and at the same time to fill it. The secondary fission seems intended to facilitate folding, and was probably originally brought about by excessive plication. If the two lobes had been in one piece, the latter would have had to be twice conduplicate longitudinally, which would have been difficult to accomplish. The folding is not always on the same plan, as may be seen by reference to the figure.

The Walnut (Juglans).—The fruit of the Walnut differs from that of Pterocarya in several remarkable particulars, and while the cotyledons of Pterocarya are leaf-like and aerial in germination, those of the Walnut never emerge from the seed.

Chabræus long ago remarked on the wonderful richness of nature as displayed in the Walnut, 'præsertim miranda figuræ luxuria naturam in hoc fructu lusisse certum est.' The Walnut, from its fancied resemblance to a head, the outer woody covering being compared to the skull, and the folds of the cotyledons to the convolutions of the brain, was formerly supposed to be especially efficacious in brain-disease.

In the Walnut (*Juglans regia*) the ovary is one-celled or imperfectly four-celled, and one-ovuled; the ovule is erect and orthotropous, with the micropyle superior. The fruit is drupaceous, oblong-globose, crowned with a small point consisting of a three- to five-toothed involucre formed by the union of the bract and bracteoles, and by the remains of the four-toothed perianth and of the style. The smooth rind is rather fleshy, and beset with submerged glandular dots; it bursts irregularly when mature. The corrugated endocarp is hard, bony, or brittle, with a spongy lining or inner coat which forms large irregular corrugations internally, and is apparently excavated into four large cavities at the base; the excavations are continued to the top of the main cavity of the ovary, hollowing out the sides of the endocarp so as to furnish a larger amount of space for the seed than is originally provided for it. In Bentham and Hooker's 'Genera Plantarum' the base of the endocarp is said to be intruded, imperfectly dividing the fruit into two or four cells. The endocarp further consists of two valves or halves, which, however, cannot be separated without force.

The seed is large, strongly and irregularly corrugated, seated on the central and originally basal placenta, which in the mature fruit is about one-third above the base of the cavity of the endocarp; it is deeply four-lobed at the base, filling the four cavities. The pale brown testa is thin, closely applied to the corrugations of the endocarp externally before the seed becomes dried up, and internally to the lobes of the embryo.

In the young state the endosperm fills the interior of the seed with a clear jelly-like mass, in the apex of which is the small embryo, with the radicle upwards. Gradually, however, the cotyledons grow and eventually absorb the whole of the endosperm, thus filling the interior of the seed, except, of course, the small portion occupied by the plumule and radicle.

We have seen that in the fruit of Pterocarya four hollow spaces gradually form themselves in the originally solid fruit, and that into these spaces the seed sends four prolongations, into which again the cotyledons subsequently grow. Now in the Walnut a very similar process takes place, only the hollow spaces are much larger and confluent with the ovarian cavity, so that instead of a solid wall with hollow spaces filled by the seed, it gives the impression as if the seed were thrown into folds occupied by the wall of the fruit. To occupy these spaces fully, the cotyledons themselves were thrown into folds as we now see them. The fruit of Pterocarya is much smaller than that of the Walnut, the ancestors of which doubtless had a smaller fruit. As it increased, the cotyledons became fleshier and fleshier, and found it more and more difficult to make their exit from the seed, until at last they have given up any attempt to do so. Hence the curious folds, with which we are so familiar, are due to the efforts made by the original leafy cotyledons to fill the interior of the nut.

Comparison of the Fruits of Pterocarya and Juglans.—Thus, then, while essentially similar, the fruits of Pterocarya and of the Walnut offer several remarkable differences. They recall in some respects the relations between the fruits of the Hornbeam and of the Beech. The fruit of Pterocarya, like that of the Hornbeam, is winged, which is not the case with the Walnut or the Beech; it is in the two former smaller, and a great deal

Fig. 180.—*Pterocarya caucasica.* Nat. size.

Fig. 181.—*Juglans regia.* One-tenth nat. size. *n*, nut.

harder than in the two latter. Again, the cotyledons of Pterocarya are aerial (fig. 180), while those of the Walnut (fig. 181) no longer perform the functions of leaves and never quit the seed.

In the Walnut, as in some other trees, it is an advantage that the seeds should be large rather than numerous. In this way they are able to contain a large supply of nutriment, which suffices rapidly to carry the young plant above the grasses and other low herbage. These seeds form the food of squirrels and other animals, which accordingly serve to disperse them, and thus perhaps they are enabled to dispense with any other means of transport. Moreover, for such large fruits wings would perhaps be scarcely adequate.

In Pterocarya, on the contrary, the fruits are much smaller, and wings therefore more suitable. Possessing in themselves the means of dispersal, they have no need of offering any attraction to animals. In fact every one which is eaten is so much pure loss. Hence, while the shell of the Walnut is sufficiently hard to protect the seed from the severity of the weather, and from the attacks of small species which would not help in their dispersal, it offers no obstacle to larger animals. That of Pterocarya, on the contrary, is very hard and strong, and even the interior portion (the walls and pillars surrounding the four hollows) are of the same character, while in the Walnut they are, comparatively, quite soft.

One reason why the similarity of construction in the two seeds does not at first strike the observer, is that in Pterocarya the lobes of the seed evidently enter the pericarp; in Juglans, on the contrary, the lobes are so much larger that it rather seems as if the pericarp sent projections into the seed.

That the present condition of the Walnut seedling is not original, we have interesting evidence in the presence of small leaves reduced to minute scales, as in the Oak and many other plants with subterranean cotyledons.

These scales evidently indicate the former presence of actual leaves which are now no longer required. The curious lobings and foldings of the seed in the Walnut also remind us of the time when the cotyledons were variously lobed and folded so as to occupy the whole space in the gradually enlarging seed. At present they seem to fulfil no useful function, but are an interesting indication of the past history of the plant.

In Eschscholtzia (fig. 112) the cotyledons are deeply bifid, resembling a hay-fork with two long prongs. In this case we find no such structure of the fruit or seed to account for the peculiarity. My first idea was that such cases might possibly be due to some difference in the endosperm, as occurs in certain Umbellifers, Delphinium, &c., which might have permitted growth more readily in certain directions than in others. Thin sections, however, showed no such differences. Moreover, Schizopetalon Walkeri (one of the Cruciferæ) (fig. 183) has the cotyledons as deeply divided as in Eschscholtzia; and as there is no endosperm, but the embryo occupies the whole seed, within which the long lobes of the cotyledons wind about more or less irregularly, the division cannot be due to differences in the endosperm. There are, moreover, other plants, such as the Sycamore (fig. 84) and Hop, where the cotyledons are also narrow, winding, and occupy the whole seed, but are not divided. We must therefore seek some other explanation, and I will suggest the following.

In most of the species which I have examined, when the cotyledons remain in the seed they do not leave the ground. In some cases, however, as in Anona (fig. 182), the hypocotyl is long, stout, and rises in the form of a loop during germination, while the cotyledons, which at first are very small, gradually increase almost to the length and breadth of the seed, throw themselves into undulations, and, it being perhaps on this account impossible to withdraw themselves from

FIG. 182.—Germinating seedling of *Anona*. Nat. size.

the seed, are eventually torn from the hypocotyl. In Bignonia insignis, again, the cotyledons, though flat and leaf-like, are unable to emerge from, or at any rate do not emerge from, the seed. This may possibly give us a clue to such cases as Eschscholtzia and Schizopetalon, which, I would venture to suggest, may have reference to the manner in which the cotyledons free themselves from the seed. If this is delayed, the young plant suffers considerably, and indeed often perishes. That the process is not, however, so simple as might be imagined, may be seen from the interesting case afforded by the Dipsaceæ (see *ante*, p. 50) or Cucurbitaceæ, where, in Mr. Darwin's words,[1] 'the seed-coats are ruptured by a curious contrivance, described by M. Flahaut. A keel or peg is developed on one side of the summit of the radicle or base of the hypocotyl; and this holds down the lower half of the seed-coats (the radicle being fixed into the ground), whilst the continued growth of the arched hypocotyl forces upwards the upper half, and tears asunder the seed-coats at one end, and the cotyledons are then easily withdrawn.'

May not the narrowness of the cotyledons in Eschscholtzia and their deep fission be due to a similar cause? The seed is slightly pyriform, and the radicle emerges from the narrower end. It bursts through the soil in an arch, and instead of leaving the seed-coats in

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[1] *Movements of Plants*, p. 102. Bower has pointed out that in Welwitschia a corresponding process serves to absorb the endosperm, acting in fact as a feeder to the young plant (*Quart. Journ. Micr. Sci.* vol. xxi.).

the earth as usual, carries them up with it. Then the two arms of the cotyledons separate, widen the orifice, and draw themselves out.

This suggestion seems to be confirmed by the evidence of Schizopetalon (fig. 183), one of the other few cases where the cotyledons are bipartite. Here, also, the radicle emerges through a comparatively small orifice, and the seed-coats, from which the cotyledons seem to have some difficulty in freeing

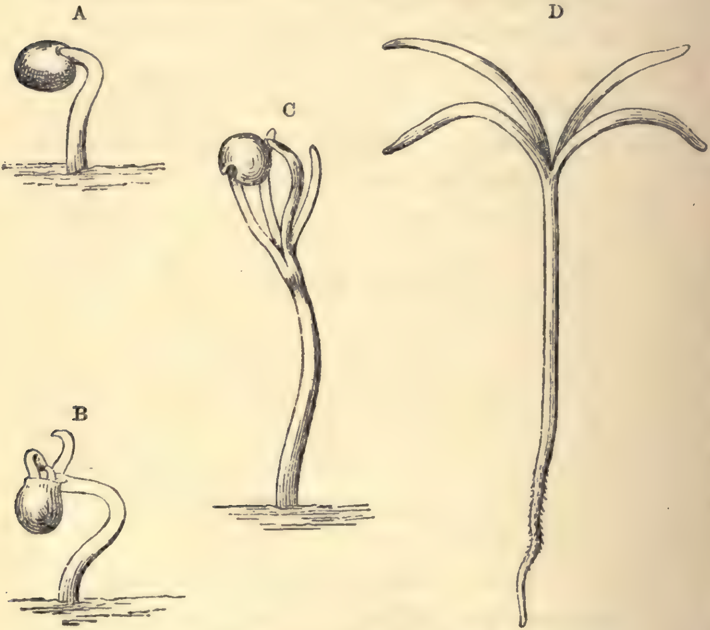

Fig. 183.—Stages in the growth of seedling of *Schizopetalon Walkeri*, × 2½.

themselves, are carried up by the hypocotyl, while eventually the lobes of the cotyledons draw themselves out one by one. In Opuntia basilaris, again, which differs from O. Labourtiana in having narrow cotyledons, the seed-coats are similarly carried up, and the cotyledons free themselves by divergence. In this species, also, it is interesting that one or both cotyledons are often bifid. Is it possible that the multiplicity of the cotyledons in Conifers (fig. 184) can be due to the same cause?

Fig. 184.—Seedling of *Pinus rigida*, × 2.

Fig. 185.—Section of seed of *Lepidium graminifolium*, × 15.

Fig. 186.—Section of seed of *L. sativum*, × 15.

In Ephedra there is a special membrane, which remains attached to the root, and thus prevents the testa from being carried up on the tips of the cotyledons.

The common Cress (*Lepidium sativum*) (fig. 187), to which I have already referred, is a very interesting case, for while in the other species, at any rate in the other English species, of the genus the cotyledons are entire (see fig. 188), in Lepidium sativum, on the contrary, each possesses two long, narrow lateral lobes.

Fig. 185 represents a section through the seed of L. graminifolium, which may be taken as representing the ordinary arrangement in the genus. The seeds, conforming to the shape of the capsule, are somewhat triangular, with the radicle in the narrow end. The embryo occupies the whole of the seed, there being no endosperm. In L. sativum (fig. 186) the seed is of the same form, but nearly twice as large, and if, therefore, the cotyledons were to occupy the whole additional space, they would become extremely thick. In endospermic seeds this would present no difficulty, as the additional space would be simply filled by endosperm. In Lepidium, however, this device cannot be resorted to; but the two lobes just fill up the vacancy.

FIG. 187.—*Lepidium sativum*, × 3.

In the Lime (*Tilia*) (fig. 189) we have another very interesting case.

The cotyledons are broad, foliaceous, rhomboid-subtriangular, and 5-lobed. The lobes are oblong and obtuse, with a strong nerve running into each, the outer ones always largest and sometimes ovate; the middle pair always the smallest, and oblong or subulate.

FIG. 188.—*Lepidium graminifolium*, × 2.

The fruit is an ovoid or subglobose woody nut, with five obtuse angles, tomentose with somewhat rufous hairs, one-celled by the rupture of the septa, one-seeded, indehiscent, tipped with the persistent base of the style, and attached to a large deciduous bract which serves to disseminate it by the aid of the wind.

The seed is ascending or erect, obovoid or subglobose, deep brown, and smooth, with a firm or crustaceous testa.

Fig. 189.—*Tilia vulgaris.* Seedling. Nat. size.

The endosperm in the mature seed is copious, firm, pale yellow, and homogeneous. There is nothing in any way analogous to the causes which have led to the existence of the lobes in the species previously described.

The embryo is at first straight; the radicle is stout and obtuse; the cotyledons ovate, obtuse, plano-convex, fleshy, pale green, and applied face to face. The latter, however, grow considerably; and when (fig. 190, A) they meet the wall of the seed bend back on themselves, and then curve round, following the general outline of the seed (fig. 190, B). If anyone will take a common tea-cup and try to place in it a sheet of paper, the paper will of course be thrown into ridges. If these ridges be removed and so much left as will lie smoothly inside the cup, it will be found that the paper has been cut into lobes more or less resembling those of the cotyledons of Tilia. Or if, conversely, a piece of paper be cut out into lobes resembling those of the cotyledons, it will be found that the paper will fit the concavity of the cup. The case is almost like that of our own hand, which can

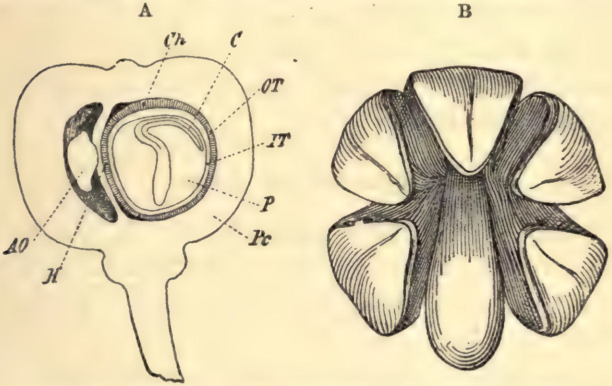

FIG. 190.—*Tilia*. A, section of fruit, × 4. *Pc*, pericarp; *AO*, aborted seed; *OT*, testa of perfect seed; *IT*, tegmen; *P*, endosperm; *C*, cotyledon. B, embryo, × 8.

be opened and closed conveniently owing to the division of the five fingers.

It may be said that the seed of the Sycamore (*Acer*) is not very dissimilar in form to that of the Lime; and yet the cotyledons are long, narrow, and strap-shaped, while those of the Lime are rhomboid and five-lobed; but it must be remembered that in the Sycamore the embryo occupies the whole seed, while in the Lime it is embedded in endosperm.

The peculiar lobed form of the cotyledons of Tilia thus enables them, I would suggest, to lie conveniently in the globose seed.

AURICLED COTYLEDONS.

Some cotyledons are markedly auricled. As illustrations I give Poterium (fig. 114) and Hakea (fig. 96). This form is, I am disposed to suggest, a provision to fill up vacant space in the seed. In the seed of Hippophaë (fig. 124) the form of the cotyledon leaves at each side of its base two spaces (*p*), which are occupied by endosperm. In Cuphea (fig. 153), Ruellia (fig. 126), and Poterium (fig. 152), on the other hand, there is no endosperm, and it is consequently an advantage that the cotyledon should develope auricles in order to fill up the space.

If this is the explanation of the auricles, we should expect to find them developed principally in families where the endosperm is deficient. Now in the species I have examined, auricled cotyledons occur in 35 genera, belonging to 22 families, of which 13 have no endosperm, while in 6 of the 9 others it is reduced almost to a film.

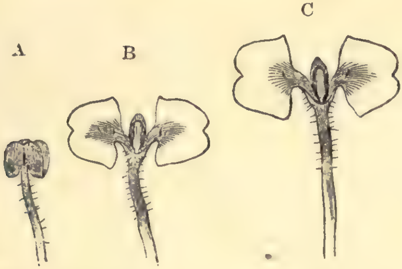

FIG. 191.—Three stages in the growth of the seedling of *Cuphea silenoides*.

FIG. 192.—*Leucæna glauca*. Nat. size.

The argument in the case of Cuphea is further strengthened by the peculiar conformation of the radicle (fig. 153), which is three-lobed, the reason being, I would suggest, that the radicle co-operates with the cotyledons in the endeavour to fill up the vacant spaces.

Fig. 193.—*Acacia Burkittii.* Nat. size.

In support of this view I would also observe that the auricles seem to be of little use to the young plant. For instance, the embryo of Cuphea, while in the seed (fig. 153) has very large auricles, which in the seedling (fig. 191) soon disappear. In Ruellia, again (fig. 126), we have a similar case.

Auricles are well developed in the leguminous species Leucæna glauca (fig. 192) and Acacia Burkittii (fig. 193).

SUCCULENT COTYLEDONS.

In the family Crassulaceæ the cotyledons observed are all succulent like the plants themselves. Like the leaves, the cotyledons of Crassula quadrifida (fig. 194) are covered with glands secreting a white substance. They persist for a long time, attain considerable size, and are generally very unequal.

In the Cactus family and the closely allied Ficoideæ the succulent, fleshy nature of the adult plant is generally foreshadowed in the cotyledons.

Among the species of Mesembryanthemum they are broadly or narrowly oblong, rounded at the apex, sessile and connate, or perfoliate at the base, and so succulent that no venation is discernible, except sometimes a faint indication of a midrib.

Mesembryanthemum tricolorum (fig. 195) presents a short and comparatively broad type. The leaves are linear or semiterete, and succulent with the first pair developed close to the cotyledons, or if the seedlings are crowded at some distance from them. The leaves of M. capitatum are also semiterete. The cotyledons of

M. serratum and M. echinatum (fig. 196) closely conform to those of M. tricolorum; and the primary leaves are subulate, semiterete or obtusely trigonous and succulent.

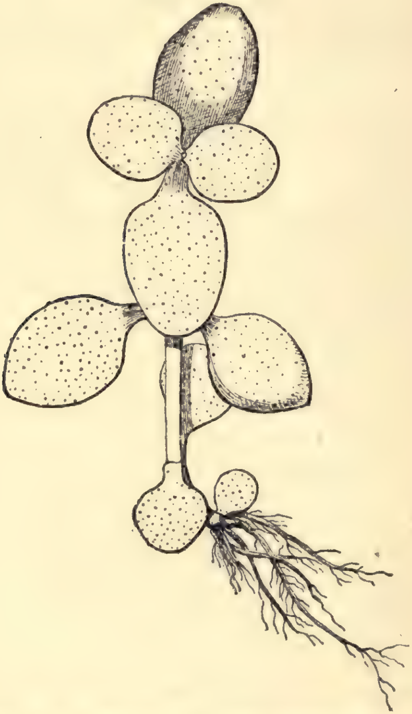

Fig. 194.—*Crassula quadrifida.* Nat. size.

A modification of the above type is exhibited in the cotyledons of M. cordifolium, which are broadly oblong, foliaceous, and flat but succulent. It is a significant fact that the leaves are also flat and ovate, or subcordate, from the first pair onwards.

Other instances are afforded by Phyllocactus ctenopetalus (fig. 197) and Opuntia occidentalis (fig. 198). In these the leaves are represented by spines, while the leaf-functions are performed by the deep-green fleshy stem.

FIG. 195.
Mesembryanthemum tricolorum.
Nat. size.

FIG. 196.
Mesembryanthemum echinatum.
Nat. size. *C*, cotyledon.

In many succulent plants the hypocotyl becomes much swollen, and the cotyledons more or less reduced in size; in some cases they may be considered as absent, or at all events functionless, although morphologically represented. The Cactus family will again supply some good examples. In the seeds of Mamillaria longimamma they appear as the edges of a three-cornered cleft, and in the seedling of M. Goodrichii they are no more conspicuous and soon become indiscernible. Similar instances are furnished by Echinocactus viridescens (fig. 199) and E. Orcutii. The seedling of the first-named eleven months after sowing of the seed appears as a small obovoid body representing a short fleshy turbinate hypocotyl bearing minute tooth-like cotyledons, above which the short stem is even stouter, leafless, and covered with small spines in tufts arranged in five or six longitudinal rows. Seven months after the sowing of the seeds, E. Orcutii is similar to the last, but smaller.

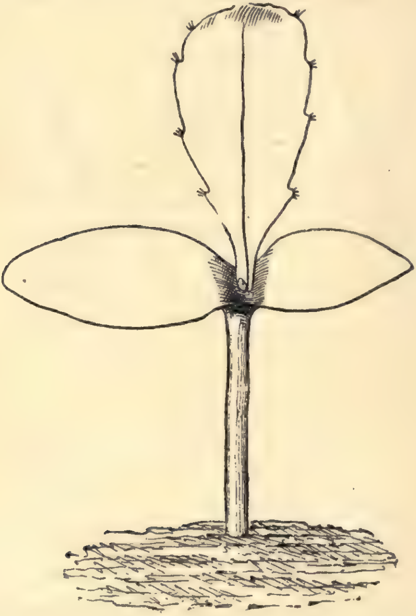

FIG. 197.—*Phyllocactus ctenopetalus.* Nat. size.

The cotyledons of Echinocactus Wislizeni attain some size in the seed, but after germination they become merged in the succulent axis by the swelling of the latter, so that seven months after sowing they appear as small triangular teeth about 1 mm. long, and of the same breadth, projecting from the sides of the seedling. About four months after sowing, the cotyledons of Cereus tilophorus borne by the clavate succulent hypocotyl were only 1·25 mm. long, and 2 mm. broad.

Fig. 198.
Opuntia occidentalis.
Nat. size.

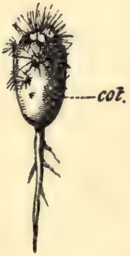

Fig. 199.
Echinocactus viridescens.
Nat. size.

Fig. 200.
Cereus Emoryi.
Nat. size.

In C. Emoryi (fig. 200) they are short, very fleshy, amalgamated with the hypocotyl and stem, and about 3 mm. long.

Similar forms occur in some succulent members of the family Asclepiadeæ.

In Sarcostemma brevistigma (fig. 201) the cotyledons are oblong-ovate, obtuse, entire, subfleshy and glabrous. They soon drop off. The leaves are all reduced to ovate or subulate, acuminate scales so small as to give the stems a leafless appearance.

In Stapelia variegata (fig. 202) the club-shaped hypocotyl is succulent and compressed the opposite way to the cotyledons, which are ovate, obtuse, twisted obliquely and each facing an opposite way, broad, sessile and persistent. The succulent stem is smooth, and made bluntly four-angled by the decurrent bases of the leaves. The simple leaves are small, succulent, and coloured like the stem and hypocotyl.

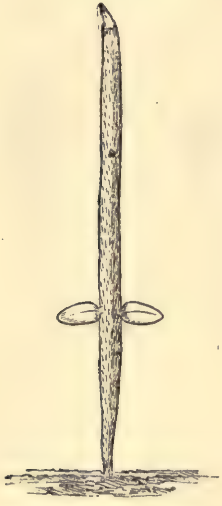

Fig. 201.—*Sarcostemma brevistigma.* Nat. size.

Fig. 202.—*Stapelia variegata.* Nat. size. *C*, cotyledon.

PETIOLES.

The cotyledons are sometimes sessile, as in Acer (fig. 84), Hippophaë (fig. 89), Hakea (fig. 96), Clitoria (fig. 144); sometimes supported on petioles, which in many cases, as in Microloma (fig. 102), attain a considerable length.

FIG. 203.—Seedling of *Bryonia laciniosa*. Half nat. size.

Occasionally we meet with both sessile and petioled cotyledons even within the limits of the same genus. For instance, Delphinium Staphysagria (fig. 104) has the cotyledons sessile, while those of D. elatum (fig. 103) have petioles. In Bryonia laciniosa (fig. 203) the cotyledons are nearly sessile, while those of B. dioica (fig. 204) have petioles.

There is nothing, so far as I know, in the structure of the seed to account for this difference. It is observable, however, that while the cotyledons of Bryonia laciniosa (fig. 203) and those of D. Staphysagria (fig. 104) are raised by the hypocotyl somewhat above the level of the ground, those of Bryonia dioica (fig. 204) and of D. elatum (fig. 103) are attached close to the ground. In fact the cotyledons are carried up in both cases, but in B. laciniosa and D. Staphysagria by the hypocotyledonary portion of the axis or stem of the plant, in B. dioica and in D. elatum, on the other hand, by their own petioles.

FIG. 204.—Seedling of *Bryonia dioica*. Nat. size.

I may also refer to Vitis hypoglauca (fig. 205) and V. cebennensis (fig. 206), the former with a short hypocotyl and long petioles, the latter with a long hypocotyl and short petioles.

Three species of Eucalyptus form an interesting series in this connection. The cotyledons are about on the same level in each, but in one (E. Globulus) (fig. 207) are shortly stalked, in the second (E. calophylla) (fig. 209) are

FIG. 205.—*Vitis hypoglauca.* Half nat. size.

FIG. 206.—*Vitis cebennensis.*
Half nat. size.

FIG. 207.—*Eucalyptus Globulus.*
Half nat. size.

borne on stalks of moderate length, while in the third (E. marginata) (fig. 209) they have long stalks. The length of the hypocotyl varies inversely as that of the stalks.

In short we may say that the cotyledons are, as a general rule, sessile when they are raised by the growth of the hypocotyl, while they are petiolate when they take their origin close to the ground. There are no doubt some exceptions; for instance, in some species of Hedysarum, *e.g.* H. coronarium (fig. 210), the cotyledons are radical and yet sessile. I have, however, in Algeria often seen seedlings of this group in hot, exposed situations, where they 'held the field' alone, and being

Fig. 208.—*Eucalyptus calophylla*. Nat. size.

sure of ample heat and light, did not require to be raised above the surface.

The opposite exception is perhaps more common, namely, when the cotyledons, though raised, are still petiolate. Here, however, they are probably petiolate for the same reason as the leaves—namely, when the foliage is large, leaf-stalks are an advantage in carrying the lower leaves out of the shadow of those immediately above them. Pentapetes phœnicea (fig. 211) is a good example.

FIG. 209.—*Eucalyptus marginata.* Nat. size.

In another species of Delphinium (*D. nudicaule*)

FIG. 210.—*Hedysarum coronarium.* Nat. size. *c*, cotyledons; *r*, primary root.

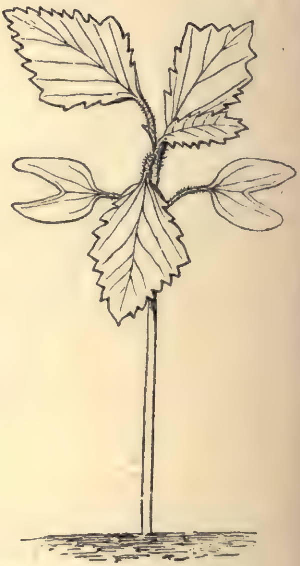

FIG. 211.—Seedling of *Pentapetes phœnicea.* Nat. size.

(fig. 105) the cotyledons are raised well above the surface of the ground on a stem consisting of their own two stalks or petioles, which are connate, though readily separable from one another. Connate cotyledons also occur in Phlomis tuberosa, Smyrnium perfoliatum (fig. 212), Polygonum Bistorta, Podophyllum Emodi (fig.

FIG. 212.—Seedling of *Smyrnium perfoliatum.* Half nat. size. *C*, cotyledons.

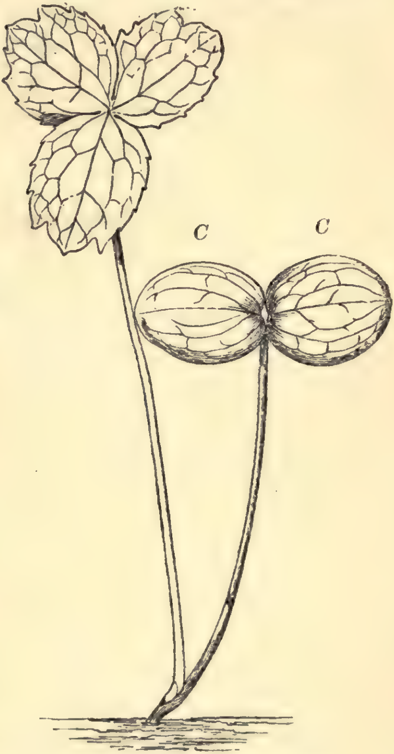

FIG. 213.—*Podophyllum Emodi.* Nat. size. *C*, cotyledons.

213), &c. Gray[1] observes that the economy of this arrangement is not apparent. Assuming, however, that the elevation of the cotyledons is an advantage, perhaps, as I have suggested, from carrying them above the surrounding herbage, the combination of the two petioles—reversing the old fable of the bundle of sticks—would, with the same amount of material, give a considerable addition of strength.


Fig. 214.—Germinating seedling of *Geranium bohemicum*, × 6.

For instance, in Smyrnium perfoliatum (fig. 212) the hypocotyl is undeveloped, the cotyledons are oblong-elliptic, generally unequal-sided, with long petioles connate into one terete piece for 5·5–7·5 centimetres of their length, split a little way at the base to allow the plumule to emerge, and free in the upper part.

In this case it is obvious that if the petioles had been separate, they would have been far too weak to stand upright, and their length therefore would have been comparatively useless.

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[1] *Structural Botany*, p. 21.

In Polygonum polystachyum, again, the petioles are connate, and form a hollow tube through which the leaves pass; so that the seedling has the appearance of possessing an erect hypocotyl with nearly sessile cotyledons.

In other cases, however, the existence of petioles apparently has reference to the arrangement of the embryo in the seed.

In the Geraniums, for instance, as has been already mentioned, the cotyledons are folded on themselves, one half of each lying within the other. Fig. 214 represents an embryo partially unfolded, and it will be seen that in the position assumed by the cotyledons the petioles are necessarily as long as half their breadth. In Eucalyptus Globulus, again (fig. 215), the mode of folding of the cotyledons would be impossible but for the petioles.

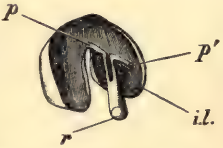

FIG. 215.—Embryo of *Eucalyptus Globulus*, one cotyledon being cut away: *p*, petiole; *p′*, cut end of petiole; *i.l*, inner lobe of cotyledon, × 4.

Lastly, in cases where the cotyledons do not leave the seed, the petioles leave room for the free growth of the plumule, as in Sapindus (fig. 168)

STIPULATE COTYLEDONS.

Stipules are generally absent, but occur in Genipa and Psychotria, two genera of Rubiaceæ, a stipulate family *par excellence*.

FIG. 216.—*Genipa clusiifolia*. Nat. size

In Genipa clusiifolia (fig. 216) one stipule of each cotyledon unites with the adjacent stipule of the opposite cotyledon, forming one ovate, acute piece (S) which is colourless and subscarious.

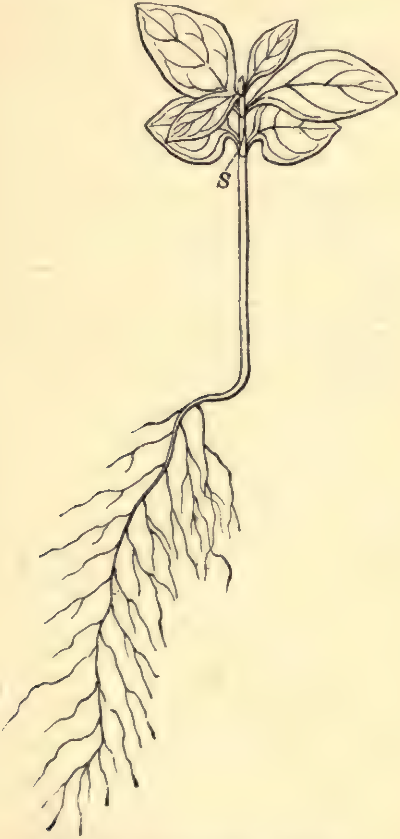

FIG. 217.—*Psychotria sp.* Nat. size.

Similarly in Psychotria (fig. 217) the stipules are united so as to form one ovate, acuminate piece (*S*) between each petiole, soon becoming dry, brown, and scarious.

Size of Cotyledons.

It is hardly necessary to say that the size of the plant does not determine that of the cotyledons. Winkler has pointed out that the largest of our Nettles has the smallest cotyledons.[1] It is, on the other hand, natural that large seeds, as a general rule, produce large cotyledons. This is, however, by no means a complete explanation. There are many cases in which the cotyledons grow considerably after quitting the seed. In the wonderful genus Welwitschia it was at one time supposed that the two great leaves were persistent cotyledons. This view is now abandoned. In many of the Monocotyledons, however, the cotyledons acquire a considerable length. I have already had occasion to allude to cases among the Dicotyledons in which the cotyledon continues to grow for some time after quitting the seed.

The cotyledons of a species of Capparis (fig. 218) from Melbourne were large, foliaceous and evergreen, and persisted for more than a year on the plant.

A very curious case presents itself in the different species of Streptocarpus (Gesneraceæ). The cotyledons

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[1] 'Ueber die Keimblätter der deutschen Dicotylen,' *Verh. Bot. Ver. Brandenburg*, 1874, p. 11.

are quite normal for some time after germination. They are small or even minute, orbicular, entire, sessile, and thinly glandular-hairy, or they develop a

FIG. 218.—*Capparis*. Nat. size.

very short petiole and become roundly ovate or triangular, showing a midrib, but no other venation. The

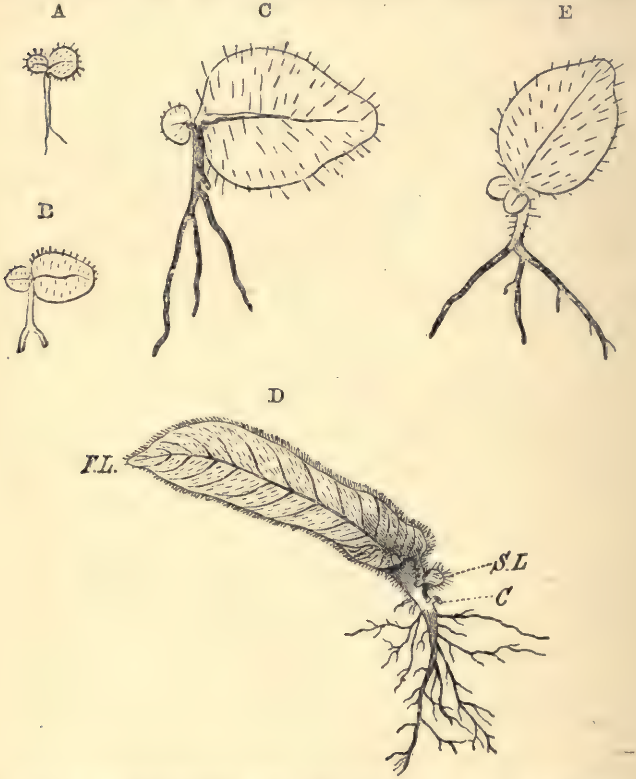

FIG. 219.—*Streptocarpus Rexii*, var. *parviflorus*. A, B, C, different stages of seedling, × 5. D, older seedling, nat. size : *F.L*, first leaf; *S.L*, second leaf; *C*, persistent cotyledon. E, seedling with three cotyledons, from one of which the first leaf is developed, × 5.

different stages of growth after germination are well shown by S. Rexii, *var.* parviflorus (fig. 219). There are two or not infrequently three cotyledons. The first leaf is developed from one of them by intercalary growth which sets in at the base of the lamina and continues for a considerable time. The original true lamina of the cotyledon is carried up on the apex of the leaf, and the tip is therefore the oldest part. Finally it withers and dies away, and the apex of the leaf dies away from above downwards in the same fashion. In the early stage the leaf as a whole becomes obovate, then broadly ovate and obtuse. It retains this shape for some time; but ultimately becomes oblong or strap-shaped with a more or less cordate base, attaining a length of six to ten inches or more. This variety develops a rosette of leaves, the second one of which seems to arise from the short, thick, fleshy petiole of the first. S. Rexii, *var.* floribundus, is a strong-growing form of the species. In its early stages it behaves in the same way as the last, the first leaf being developed from one of the cotyledons by intercalary growth at the base. A rosette of leaves is ultimately formed, and when the plants are strong the leaves vary from six to twelve inches or more in length. The cotyledons of S. Dunnii are also perfect and normal in the early stages, small, rotund and entire. The only leaf the plant produces is developed from one of the cotyledons and becomes oblong, narrowed toward the apex, lobulate and dentate, cinereous above from the presence of grey hairs, and rusty beneath with reddish ones; it varies from twelve to thirty-six inches in length, and nine to twenty inches in width at the broadest part.

Some of the Onagrarieæ have seedlings with very curious cotyledons. For instance, I was greatly puzzled by the seedling of Œnothera bistorta, in which (fig. 231) the cotyledons were long and linear, suddenly widening at the end into a large orbicular expansion, which gives them a very peculiar appearance.

Fig. 220.—Very young seedling of *Eucharidium grandiflorum*, × 3.

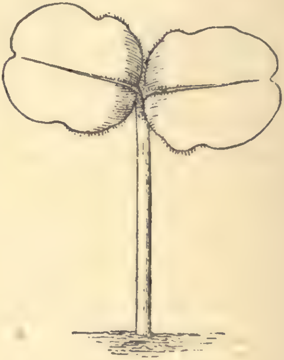

Fig. 221.—*Eucharidium grandiflorum*: 10 days after germination, × 3.

In Eucharidium grandiflorum (fig. 222) the form of the cotyledon might not unnaturally be supposed to be a case similar to that of Malva. In reality, however, the explanation is very different. In Eucharidium the lobes have nothing to do with the arrangement of the embryo in the seed. The young plant, indeed, immediately after germination, presents no trace of them. The cotyledons, when they first emerge from the seed (fig. 220), are oblong-orbicular, sessile, cordate or auricled at the base, and emarginate at the apex, with a small purple tooth in the notch: they grow rather rapidly, become shortly petioled, and develop one or two lateral, incurved nerves on each side of the midrib.

In the next stage, about eight days after germination, they exhibit a very slight constriction near the base of the cotyledons, with a small obtuse tooth. This basal portion increases much more rapidly, while the growth of the terminal portion (which is, in fact, the original cotyledon) becomes gradually arrested. The tooth becomes more marked, and by the tenth day (fig. 221) the new portion is obtusely bidentate or crenate, and nearly equals the original cotyledon in size.

In its final form (fig. 222) the new portion is both broader and longer than the true cotyledon, and differs from it not only in the crenations, but in the possession of a more conspicuous midrib and rather stiff hairs. Not only is this basal portion interesting in its mode of development, but also from its similarity to the subsequent leaves. In fact, as fig. 222 shows, it may be

Fig. 222.—*Eucharidium grandiflorum*: showing final form of cotyledons. Nat. size.

said that we have a compound structure formed of a leaf at the base, terminated by the cotyledon.

If, indeed, this species stood alone, we might regard the resemblance as accidental; but we find a very similar growth in other allied species.

In Clarkia pulchella the cotyledons immediately after germination closely resemble those of Eucharidium grandiflorum (fig. 220). In a short time they become broadly ovate, emarginate, suddenly narrowed, and rounded at the base. In this case there is no great change of form; but while the margin of the original cotyledon is glabrous, that of the new growth and of the true leaves (fig. 223) is finely ciliate.

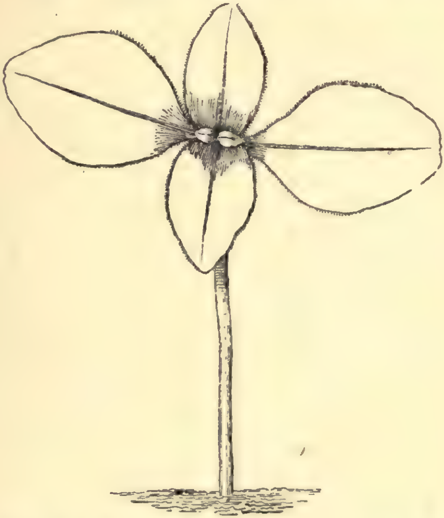

FIG. 223.—*Clarkia pulchella.* Two-thirds nat. size.

In Clarkia gauroides the cotyledons immediately after germination are oblong-orbicular, minutely emarginate, with a small tooth in the notch, slightly auricled

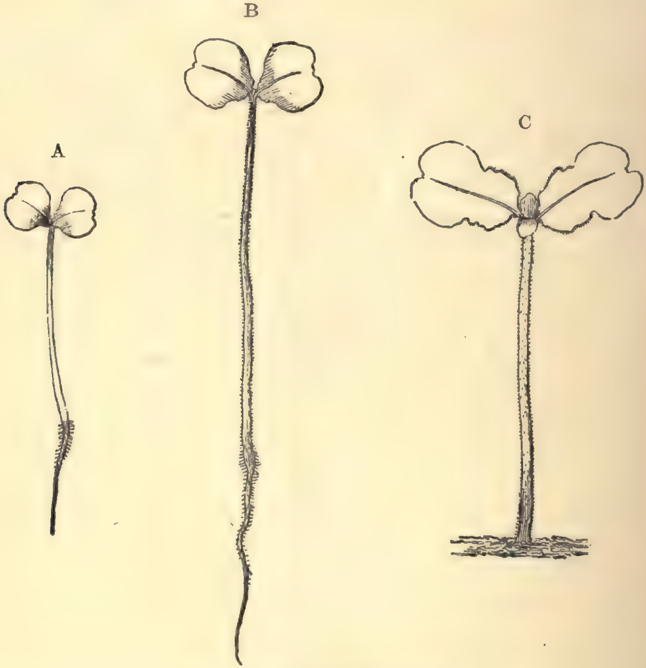

Fig. 224.—*Clarkia gauroides*, × 2.

at the base, and sessile, with a scarcely discernible midrib.

They then enlarge, and three days after germination (fig. 224, A) become orbicular or broadly obovate, subcuneate at the base, and shortly petiolate.

A new growth now occurs at the base of the cotyledons, which is at first narrower and soon becomes con-

FIG. 225.—*Clarkia gauroides*, × 2.

spicuous by the presence of a small tooth on each side. (Fig. 224, B. Five days after germination.)

The new growth elongates, bearing two to four teeth on each side, and the whole cotyledon becomes oblong, with a broad emarginate upper half consisting of the true cotyledon, and a basal narrower half which is truly foliar with the characteristic white and reddish midrib of the leaves, and the marginal teeth. (Fig. 224, C. Ten days after germination.)

Finally the cotyledons become broadly ovate, cuneate at the base, petiolate, and in all or most cases more or less distinctly alternate; the lower part or new growth has four to six small obtuse teeth on each side, and is broadly subelliptic in outline, and minutely ciliate at the margin. The upper part or true cotyledon is comparatively small, suborbicular, and emarginate, with a tooth in the notch. (Fig. 225. Eighteen days after germination.)

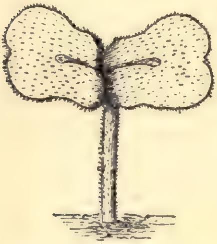

FIG. 226.
Clarkia rhomboidea, × 3.

In Clarkia rhomboidea (figs. 226, 227) the cotyledons are at first orbicular, entire or faintly emarginate with a prominent apical tooth, sessile, and like the hypocotyl purplish, glabrous, but soon become minutely and papillosely pubescent.

Fig. 226 shows their appearance nine days after germination. The constriction below the middle denotes the line between the upper part or true cotyledon, which is minutely pubescent, and the lower part or new growth, which is much more conspicuously pubescent with a pale pink or purplish midrib ending in a broader purple blotch on the base of the true cotyledon.

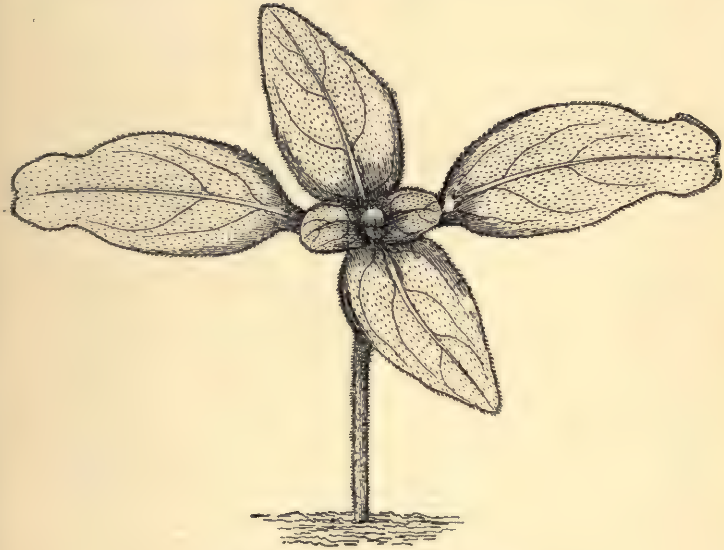

FIG. 227.—*Clarkia rhomboidea*, × 2.

The lower foliar portion soon becomes broader and longer than the upper cotyledonary part, which is also only very slightly pubescent.

Thirty-five days after germination (fig. 227) the cotyledons are oblong, distinctly petiolate, constricted near the apex at the union of the foliaceous and cotyledonary part, emarginate with a minute tooth in the notch, cuneate at the base, and with a distinct midrib throughout, minutely pubescent all over the upper surface, but more sparingly on the under surface, which is reddish-purple.

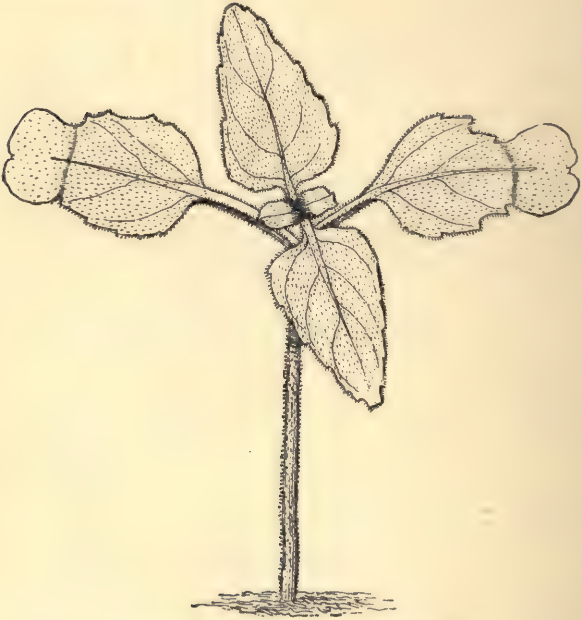

Fig. 228.—*Clarkia integripetala*, × 2.

As seen from the figure, there is a strong resemblance between the foliar portion of the cotyledons and the leaves which immediately succeed these.

In Clarkia integripetala the cotyledons immediately after germination are shortly oblong, emarginate with a minute tooth in the notch, shallowly auricled at the base, sessile and glabrous.

The day after germination they have become transversely oval, and a shallow semicircular depression and a grey midrib have appeared at the base of each.

Next day a tooth on each side near the cuneate base denotes the point where the true cotyledon ends, and the foliar portion begins, and four days after germination they are obovate and very shortly petiolate; the upper part transversely oblong, emarginate, with the apical tooth now almost obsolete: the lower rotund-subcuneate with one to two small teeth on each side, shorter and narrower than the upper, and minutely and papillosely pubescent.

Eight days after germination the cotyledons are as a whole oblong. The lower part has become broadly oblong with three to four minute teeth on each side, and a distinct reddish or silvery midrib, and is suddenly narrowed into a distinct petiole.

Seventeen days after germination (fig. 228) the lower part is broadly ovate with three to five teeth on each side and one to two pairs of very faint somewhat curved nerves running towards them, and a silvery midrib terminated above by a transverse brown line. It is papillosely pubescent all over. The upper part is transversely oblong or oval, emarginate, with a tooth in the notch, and minutely and much less conspicuously pubescent than the lower.

In Œnothera stricta the cotyledons immediately after germination are oblong, obtuse, slightly auricled at the base, otherwise entire; sessile, thinly glandular-pubescent on the upper surface, and ciliate. By continued intercalary growth at the base they eventually become (fig. 229) spathulate, obovate or oblong-obovate, and obtuse, with a tooth on each side, indicating the point of union of the original cotyledon and the new growth; the lower part has a distinct midrib, tapers

FIG. 229.—*Œnothera stricta*: 30 days after germination. Nat. size.

much at the base, and is glabrous; the puberulous-pubescent petioles are connate at the base.

The first leaves are alternate, lanceolate, obtuse, tapering to the petiole, obsoletely and distantly toothed at the margins, and, like the cotyledons, glabrous with pubescent petioles.

FIG. 230.—*Œnothera bistorta*, × 3.

In Œnothera bistorta immediately after germination the cotyledons are oblong, obtuse, entire and sessile with a few long, scattered, glandular hairs, especially at the base.

Six days after germination the base has become elongated petiole-like, and glandular-pubescent, suddenly narrowed to a short petiole; the upper half remains rotund and glabrous except at the base and possibly a few short hairs underneath.

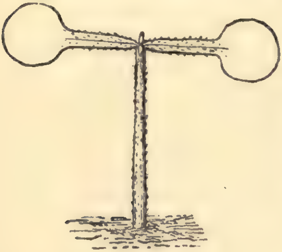
Fig. 231.—*Œnothera bistorta.*

Eight days after germination (fig. 231) they are much longer; the upper true cotyledonary part is larger, but otherwise unaltered, while the foliar basal and narrow part has become linear, sometimes with a minute tooth on either side.

The lower portion elongates greatly, and in the ultimate stage of the cotyledons (fig. 230) is linear, tapering at the base into a petiole. The very short upper part or true cotyledon is roundish or oval, entire, glabrous, and without an evident midrib. The lower part terminates abruptly below the upper, and is linear, tapering gradually to the base, with one or two minute and distant teeth on each side. It is thinly hairy, and greyish-green in colour with an evident midrib sunk on the upper surface, and prominent beneath.

The first eight leaves are linear, obtuse, tapering at the base into the petiole, thinly silky with adpressed pubescence, minutely and distantly toothed at the margin, greyish-green, and more or less distinctly marked near the margin with black dots, with a very distinct, colourless midrib, flattened above and prominent beneath. They bear, in fact, a close resemblance to the lower portion of the cotyledons.

Œnothera macrantha (fig. 232) affords a similar instance.

Here, therefore, we have an interesting group in which at first the cotyledons are very similar, but by subsequent growth at the base develop into several distinct types, in each case closely resembling the leaf characteristic of the species. We can therefore have little, if any, doubt that this growth is influenced by the form of the leaf.

Fig. 232.—*Œnothera macrantha*, × 3.

A similar intercalary growth of the cotyledon occurs in Mimulus luteus (fig. 233) and in Linaria. The cotyledons of the former are triangular and incipiently trifid when full grown. The terminal tooth represents the original lamina of the cotyledon soon after germination. The seedling itself is dimorphic according to circumstances. If it has plenty of room to develop in the seed-bed the primary leaves are triangular, while the internodes of the stem are hardly developed; but if the seedlings are crowded, the primary internodes elongate considerably and the leaves become oval.

FIG. 233.—*Mimulus luteus.* Nat. size.

RELATION BETWEEN COTYLEDONS AND SUCCEEDING LEAVES.

It is but rarely, however, that we can trace any connection between the characteristics of the cotyledons and of the succeeding leaves. Among the few cases, I may mention here that of Embelia Ribes (fig. 234). The leaves are simple, exstipulate, petiolate, alternately incurvinerved, and indistinctly reticulate, shining on both surfaces, bright green above, paler beneath, and punctate with dark green sunken glands eventually becoming black, and thinly glandular-pubescent on both surfaces. The petioles are semiterete, channelled above, closely glandular-pubescent, and taper downwards. The first leaf is broadly ovate, or short-elliptic, acute, and serrate except towards the base. The second is similar, but narrower; the third, fourth, and fifth lanceolate, each rather narrower than the preceding.

FIG. 234.—Seedling of *Embelia Ribes*. Half nat. size.

The cotyledons are ovate, obtuse or subacute, indistinctly alternately incurvinerved, and reticulate, distantly serrate in the upper half, tapering into the petiole below, glabrous, bright green and shining above, paler beneath, thinly glandular on both surfaces, and dotted with sunken black glands. The petioles are semiterete, slightly furrowed above, and finely glandular-pubescent. Here it will be observed that the cotyledons are strikingly like the first leaves; and, moreover,

FIG. 235.—*Platystemon californicus*. Nat. size.

that there is a regular gradation from the broad ovate cotyledon to the final leaves, which are narrow and lanceolate. The serration of the cotyledons is a very rare character, which makes the resemblance in this respect all the more significant.

FIG. 236.—*Sagina procumbens*, × 3.

In this connection also I may perhaps mention Eschscholtzia tenuifolia. I have already described [1] and

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[1] Vide *supra*, p. 161.

figured (fig. 17) the germination of E. californica, in which the cotyledons are long, narrow, and deeply bifid, and suggested that this form enabled them more easily to make their exit from the seed. In that species the leaves also are much cut up. In E. tenuifolia, on the contrary, both the leaves and cotyledons are long and linear. Here also the form probably facilitates the exit; and one may perhaps suggest that E. californica exhibits a form of which E. tenuifolia represents an earlier and simpler condition.

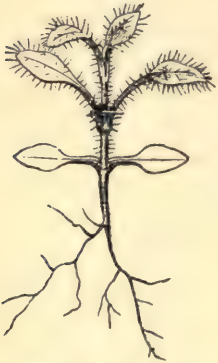

FIG. 237.—*Cerastium.* Half nat. size.

A marked similarity in form is noticeable also in the following species from various orders.

In Platystemon californicus (Papaveraceæ) (fig. 235), the cotyledons are linear, acute, entire, sessile, green, and indistinctly one-veined like the leaves.

Again, in Sagina procumbens (fig. 236) the cotyledons are narrow and sharply pointed like the leaves, which they also resemble in their united base, forming a little cup round the stem. In another plant of the same family (Caryophyllaceæ), Cerastium (fig. 237), the cotyledons differ from the succeeding pair of leaves only in being free from hairs.

Fig. 238 depicts a striking example in an Umbellifer.

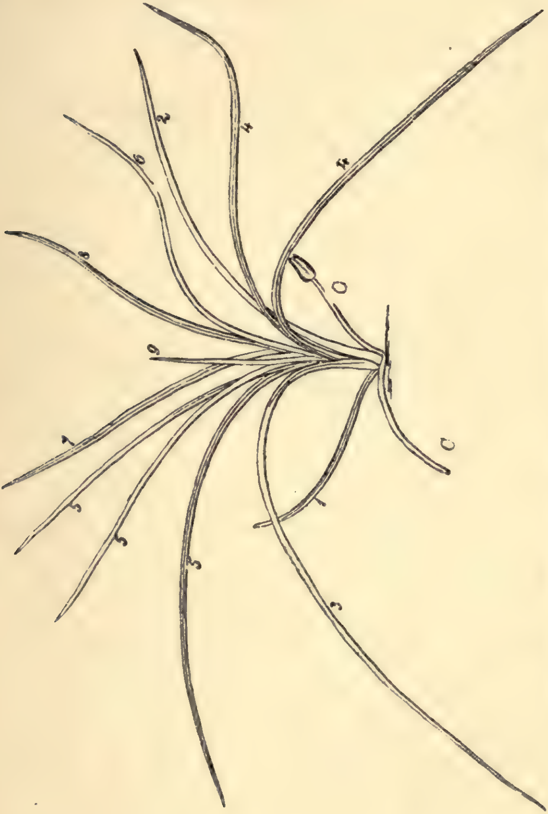

Fig. 238.—*Aciphylla squarrosa.* Half nat. size. *C*, *C*, cotyledons.

Two species of Plantago afford an interesting comparison. In P. media (fig. 239) the cotyledons incline to a spathulate form like the leaves, while in P. Coronopus (fig. 240) both are linear, the primary leaves being larger and longer.

In the three species of Illecebraceæ which I have observed there is in each case a marked resemblance (figs. 241–243).

Other instances are afforded by the Rhubarb (*Rheum officinale*) (fig. 244), where the young leaves are also glabrous like the cotyledons, and have their pale green petioles likewise often stained with red; and Coccoloba uvifera (fig. 245), of the same family, where among other points the venation of the large foliaceous cotyledons closely resembles that of the succeeding leaves.

Fig. 239.—*Plantago media.* Nat. size. *C*, *C*, cotyledons.

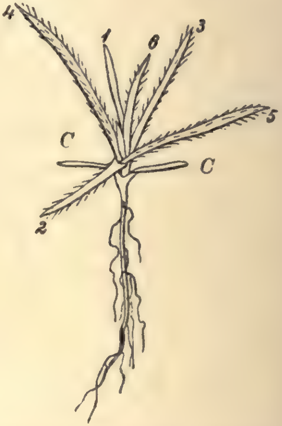

Fig. 240.—*Plantago Coronopus.* Nat. size. *C*, *C*, cotyledons.

In Piper celtidifolium (fig. 246) and the three members of the Euphorbia family which I have figured

FIG. 241.—*Paronychia dichotoma*, × 3.
C, *C*, cotyledons.

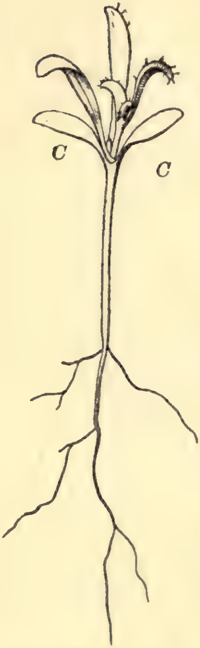

FIG. 242.—*Herniaria hirsuta*, × 2.

FIG. 243. *Illecebrum verticillatum*, × 3.

C, *C*, cotyledons.

(figs. 247–249) the likeness is also well marked and in the species of Phyllanthus is very close.

Perhaps the Conifer family is most instructive in this respect. The cotyledons vary greatly in different genera[1] of the Order and in the different species of Pinus, Abies, and Picea; even the individuals of a species vary in the number of cotyledons according to the vigour of the seedling. They also vary more or less in shape

Fig. 244.—*Rheum officinale*.
Nat. size.

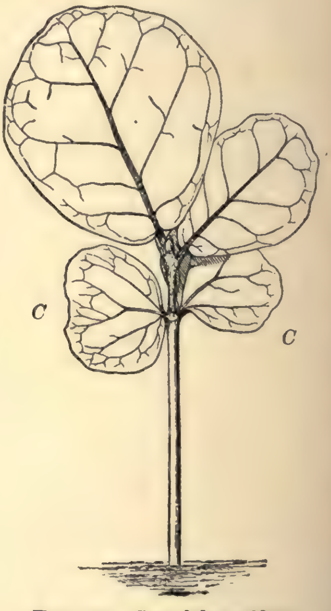

Fig. 245.—*Coccoloba uvifera*.
Half nat. size.

C, C, cotyledons.

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[1] See Dr. Masters' valuable paper in *Journ. Linn. Soc.* vol. x.

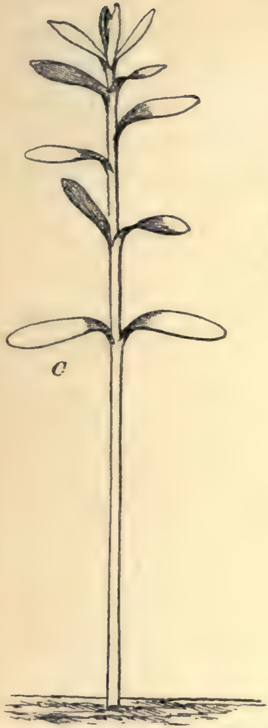


FIG. 247.—*Euphorbia exigua*, × 2.

FIG. 248.—*Phyllanthus flaccidus.*
Half nat. size.

FIG. 246.—*Piper celtidifolium.* Nat. size.

FIG. 249.—*Jatropha Curcas.*
Half nat. size.

according to their number, in the same way as do the secondary leaves of Pinus. When there are only two they are flat or plano-convex, but when more numerous they are triangular in section, or form some segment of a cylinder.

The cotyledons of the Yew (*Taxus baccata*) (fig. 250) are linear and flat, as are also the leaves.

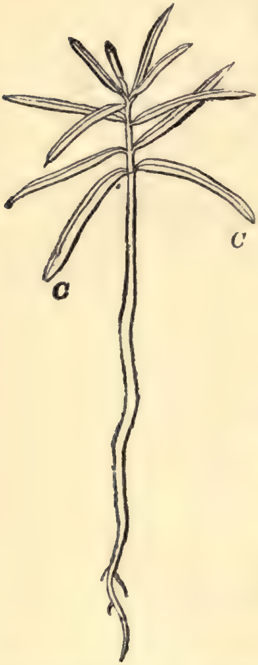


FIG. 250.—*Taxus baccata*. Nat. size. *C*, *C*, cotyledons.

The cotyledons of Thuja occidentalis are linear, acute, tapered to the base, one-nerved, flat or nearly so, and two in number. The two first leaves are opposite, spreading, similar to, but smaller than the cotyledons, and are followed by five or more whorls of three similar ones. In some cases one of the three is inserted at a slightly higher level than the rest, or they may even all be scattered with a spiral arrangement. The ultimate leaves are opposite decussate, and adnate for great part of their length to dorso-ventrally flattened shoots. The cotyledons of Thuja gigantea (fig. 251) conform to the above type. The first four leaves are in opposite pairs decussating with the cotyledons, and

FIG. 251.—*Thuja gigantea.* Nat. size. *C*, cotyledon.

are followed by a number of whorls or pseudo-whorls, of similar but longer and more decidedly acicular leaves. Above the first dozen or so of whorls, lateral branches are given off bearing sometimes a few acicular and spreading leaves at their bases, while succeeding leaves are imbricate and decurrent, gradually giving place to closely imbricate decurrent leaves, arranged in four rows and decussate. The branches are then horizontal or drooping, and dorso-ventrally flattened.

The second well-defined type of cotyledons is met with in Pinus (fig. 184), where they are needle-shaped like the primary leaves of the seedling and the fascicled foliage-leaves of the shortened shoots of the adult.

In Actinostrobus pyramidalis the three cotyledons are linear-subulate, subtriquetrous, and 9 mm. long. The primary leaves are similar in outline, and verticillate in whorls of three, but are biconvex, and decurrent upon the axis, covering the whole of the internodes; the free portion is 8–13·5 mm. long.

FIG. 252.—*Loasa prostrata.* Nat. size.

Mention has already been made of the succulent nature often noticeable in the cotyledons of succulent plants (see p. 171).

In Loasa prostrata (fig. 252) the stinging hairs which characterise the whole plant are present even on the hypocotyl and cotyledons.

A similar case also occurs in Amsinckia intermedia (Boragineæ) (fig. 253) and in Eccremocarpus scaber (Bignoniaceæ) (fig. 254), where the surfaces and margins of both cotyledons and succeeding leaves bear glandular hairs.

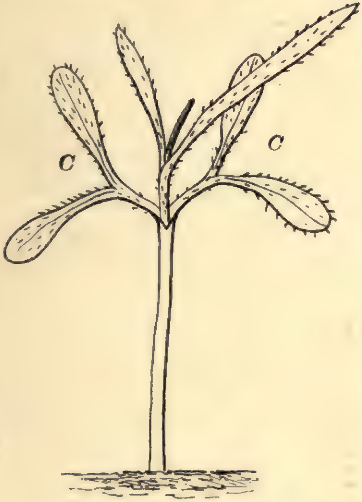


Fig. 253.—*Amsinckia intermedia*, × 2

Fig. 254.—*Eccremocarpus scaber*, × 2.

C, *C*, cotyledons.

Again, in Nepeta nuda (Labiatæ) (fig. 255) both cotyledons and leaves are densely glandular-pubescent on both surfaces, and dull opaque green or slightly hoary; and in Gunnera chilensis (fig. 256) both have a ciliated margin and a minutely pubescent surface.

FIG. 255.—*Nepeta nuda*, × 2.

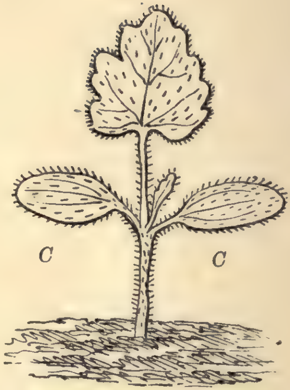


FIG. 256.—*Gunnera chilensis.* Nat. size.

C, C, cotyledons.

FIG. 257.—*Ranunculus arvensis.* Half nat. size.
C, cotyledons.

Forms of First Leaves.

The first leaves are generally simple, or at any rate simpler than those which follow. Thus, in species with trifoliate leaves, the first leaf is generally simple, as in the Clovers. When the mature leaves are pinnate, the first ones are generally trifoliate; and when the final leaves are bipinnate, the first ones are generally pinnate. I have already observed that species with lobed or palmate leaves often commence with one or more which are entire and heart-shaped.

In the few examples which follow there is a gradual transition from the simple cotyledon to the often deeply cut or compound ultimate leaves.

In a Buttercup (*Ranunculus arvensis*) (fig. 257) the cotyledons have an oblong blade with an entire margin. Of the succeeding leaves, No. 1 is rotund-cuneate and five-toothed; No. 2 broadly obovate-cuneate, obscurely five-nerved with five large teeth above; No. 3 tripartite; the divisions cuneate, tridentate above, basal ones not opposite; No. 4 tripartite, with the basal divisions nearly opposite, teeth more numerous above; No. 5 trisected; the middle segment acutely cuneate, unequally trifid, lobes slightly toothed at the apex; the lateral segments bipartite with their anterior lobes trifid, narrowly cuneate, and their posterior lobes bifid above; No. 6 trisected; the middle segment tripartite, divisions linear, entire or slightly toothed; the lateral segments bipartite, divisions divaricate, more or less cut up into linear pieces.

Ceratocephalus falcatus (fig. 258), as the figure shows, is also a good instance of transition, as also is Meconopsis cambrica (Papaveraceæ) (fig. 259).

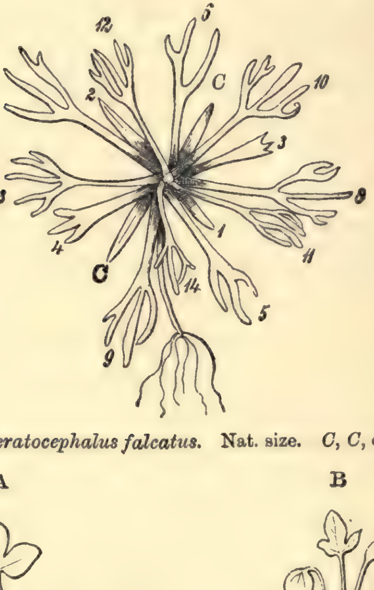


FIG. 258.—*Ceratocephalus falcatus.* Nat. size. *C, C,* cotyledons.

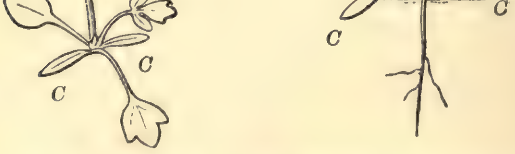


FIG. 259.—Seedlings of *Meconopsis cambrica.* Nat. size.
A, cotyledons (*C*) sessile; B, stalked.

In leguminous plants with compound leaves the ultimate form is frequently reached by gradual stages, as in Indigofera australis (fig. 260), where Nos. 1 and 2 are opposite, with a single oblong-obovate, emarginate leaflet. No. 3 is sometimes unifoliolate, as in the figure, but most frequently pinnately trifoliolate; with the terminal leaflet obovate and emarginate; the lateral leaflets oval. No. 4 is pinnately trifoliolate; leaflets oblong emarginate; terminal one largest. No. 5 pinnately five-foliolate; with the lowest pair of leaflets oval, the rest larger and oblong. No. 6 is pinnately seven-foliolate.

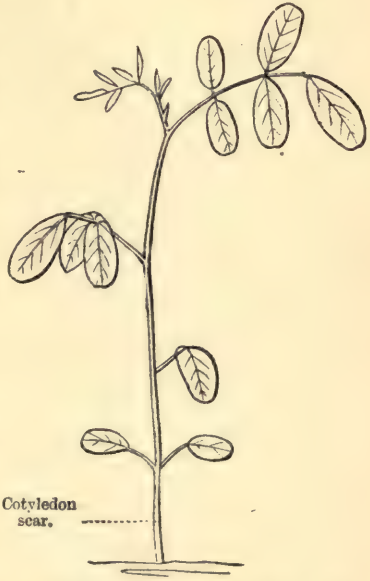


FIG. 260.– *Indigofera australis.* Two-thirds nat. size.

Astragalus thianschanicus (fig. 261) affords another instance.

In Passiflora cærulea (fig. 262) the transition is at the last somewhat abrupt, the lanceolate leaf (No. 8) with hollowed sides and pinnate venation being followed by the characteristic, deeply tripartite, trinerved form.

Fig. 261.—*Astragalus thianschanicus.* Half nat. size. *C, C,* cotyledons.

The water-lilies are also of interest in this respect. The cotyledons are subterranean, while the leaves of most species are floating and afford but a few types. Seedlings are generally heterophyllous, a circumstance of frequent occurrence amongst aquatic plants whether phanerogams or cryptogams. In the adult state of the plants, all of which are aquatic or marsh-loving herbs, four distinct types of leaf may be found, namely, the oblong, orbicular, scutiform, or subsagittate, represented by Nymphæa and Nuphar; secondly, peltate

FIG. 262.—*Passiflora cærulea.* One-third nat. size. *Cs*, cotyledons.

floating leaves, as seen in Brasenia, Victoria, and Euryale; thirdly, peltate aerial leaves, characteristic of Nelumbium; and lastly, the finely-divided submerged leaves of Cabomba, which are palmately cut up into slender thread-like segments, resembling those of some forms of Ranunculus aquatilis. The floating leaves of Cabomba are peltate and orbicular.

The stages of the advancing seedling from the juvenile to the adult state, with regard to the leaves, may be readily examined in Nymphæa, Victoria, or Euryale. The seedling of Nymphæa Lotus, var. thermalis, in germination throws down a long root (primary root) into the soil or mud, while the first internode of the plumule grows a little and gives off the first leaf, which is short, slender, and filiform. The first leaf in other species is often longer than in this case. The second, third, and fourth leaves are oblong-lanceolate, obtuse, and all submerged in the water where the seeds have germinated. The ultimate leaves are peltate, orbicular, and wavy at the margin, but the basal sinus is open, or at least not connate.

The primary leaves of Victoria and Euryale are even more varied, and, like those of Nymphæa, are produced in a rosette. The first internode in both these genera is more elongated than in the Nymphæa described, while the succeeding ones are undeveloped. From the base of this rosette, strong, adventitious roots are developed, which soon supplant the primary root. The first leaf of Victoria is filiform and slender, without a spreading blade; the second is narrowly oblong and petiolate; the third is hastate, petiolate, with a long, slender point; and the fourth is oval in outline, peltate, with the basal sinus partly connate, and furnished with a petiole capable of elongating to 18 or 24 inches or even more, according to the depth of the water in which the seeds have germinated.

The seedling of Euryale ferox behaves in exactly the same way as that of Victoria, but the second and third leaves are rather stronger and broader. The whole seedling is larger, due no doubt to the larger seed and greater amount of reserve food-material at its command. The fourth leaf in both cases is a floating one, and marks a great advance in the development of the plant. The three primary ones are always submerged, at least when the water is deep enough, and probably indicate the ancestral forms through which the leaves have passed to their present condition in the adult plant. After the fourth, which is usually the first floating leaf in both Victoria and Euryale, the succeeding ones become connate along the whole of their basal edges, attaining a perfectly orbicular form by rapid stages. Those of Victoria become turned up at the edges after the plant has reached a considerable size, while those of Euryale always remain flat, merely increasing in diameter. The largest leaves of Victoria are from 6 to 7 feet across, with a circumference of 18 to 21 feet, perfectly orbicular, with the edges turned up to a depth of from 3 to 6 inches.

The peltate aerial type of leaf is exhibited by Nelumbium speciosum, whose strong terete petioles vary from 3 to 6 feet in height, bearing at the top a nearly horizontal, peltate, orbicular, umbilicate, glaucous-green lamina, 12, 18, or more inches in diameter.

Finely-cut leaves occur only in the genus Cabomba, the greater number of which are submerged even in the adult state of the plant. Aerial, peltate, orbicular, and entire leaves seem to be developed chiefly from the apex of the stem when flowering, as the blooms are aerial. The leaves of Barclaya are linear, oblong, or orbicular, recalling in a measure the early stages of Nymphæa. The stem of Cabomba and Brasenia is slender and terete, with elongated internodes, whereas the stem of the other Nymphæaceæ forms a stout, fleshy rhizome or is shortened to a tuber.

Passage to the final form may, on the other hand, be extremely abrupt, as the following cases show.

In Argemone mexicana (Papaveraceæ) (fig. 263) the linear cotyledons are followed by a leaf which, in its general outline and sharp teeth, approaches closely the ultimate spiny form.

In Lupinus arboreus (fig. 264) the digitate form is assumed at once by the first leaves, as also in L. sulphureus (fig. 265); and in two other leguminous plants (figs. 266 and 267) the abruptly pinnate form is assumed with equal rapidity.

The cotyledons of Casuarina Cunninghamiana (fig.

268) are oval, obtuse, and sessile. The stem is quadrangular in the seedling stage. The first two leaves are opposite, followed by at least nineteen whorls of four leaves each, decussating and forming the angles of the stem. They are adnate to the stem for the greater part of their length and free at the tips only. In this respect

FIG. 263.—*Argemone mexicana.* Nat. size.
C, *C*, cotyledons.

FIG. 264.—*Lupinus arboreus.*
Nat. size. *C, C,* cotyledons.

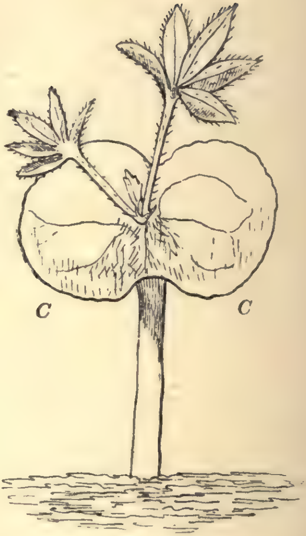


FIG. 265.—*Lupinus sulphureus.*
Nat. size. *C, C,* cotyledons.

they bear a strong resemblance to the Equisetaceæ and some of the Coniferæ.

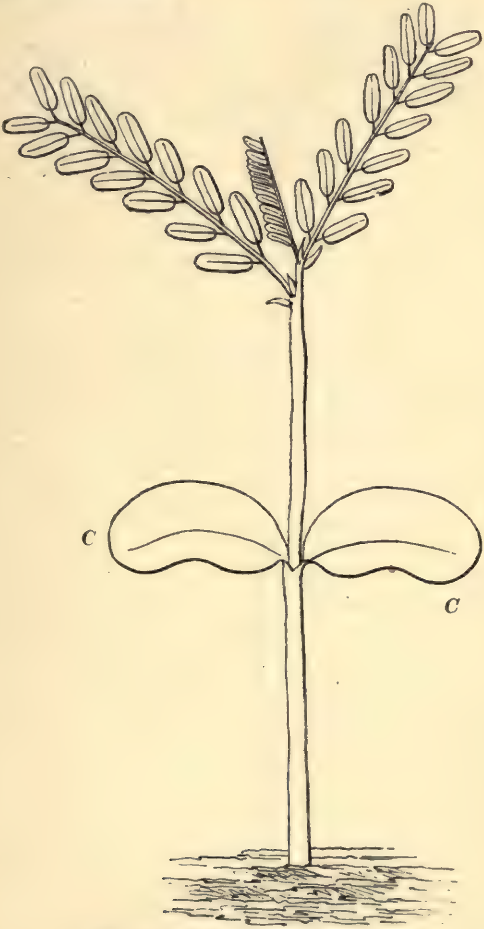


FIG. 266.—*Æschynomene aspera*, × 2.
C, *C*, cotyledons.

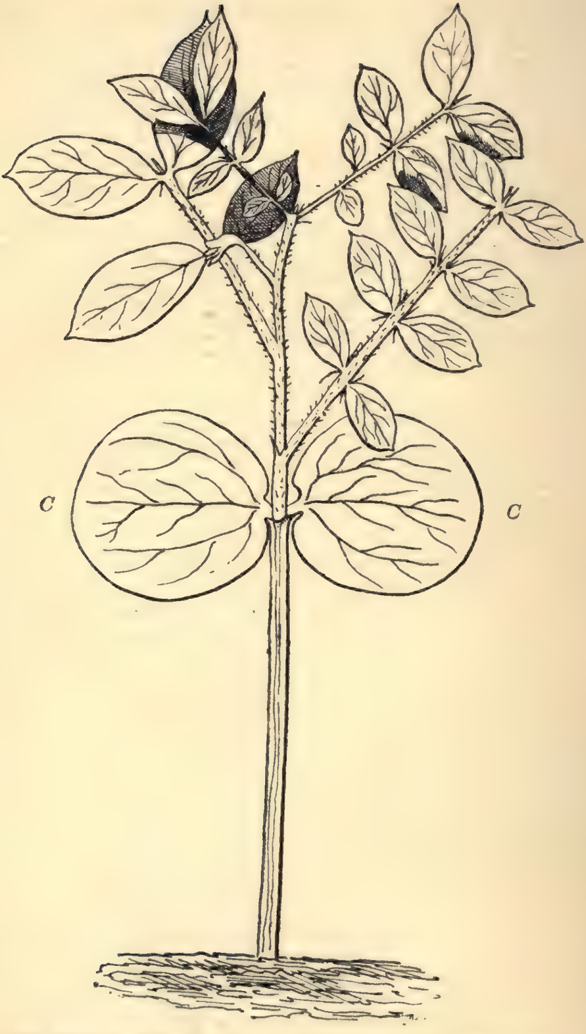


FIG. 267.—*Cæsalpinia tinctoria*. Nat. size. *C, C*, cotyledons.

Ephedra vulgaris (Gnetaceæ) (fig. 269) affords a similar instance of the abrupt passage to a small scale-like leaf.

In most cases, therefore, the first leaves are simpler than those which follow. In species from very dry localities, however, the reverse is often the case. For instance, in Lasiopetalum ferrugineum (Sterculiaceæ) (fig. 270), from Adelaide, the first few leaves are spathulate and more or less lobed, the final ones

Fig. 268.—*Casuarina Cunninghamiana*, × 2. *C*, *C*, cotyledons.

Fig. 269.—*Ephedra vulgaris.* Two-thirds nat. size. *C*, *C*, cotyledons.

linear. Again, in Dodonæa viscosa (Sapindaceæ) (fig. 271), also from Adelaide, the first leaves are lobed, the subsequent ones simple. Heterospermum diversifolium (Compositæ) is another interesting case; here the leaves of the first and second pairs are trifid and pentafid respectively, while those which follow are shallowly serrate and not pinnatifid.

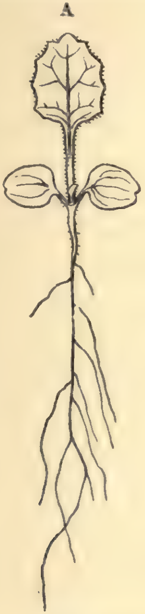
FIG. 270.—Seedling of *Lasiopetalum ferrugineum.* Half nat. size.

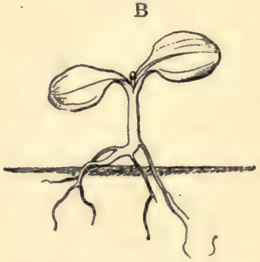
FIG. 271.—*Dodonæa viscosa.* Half nat. size.

ON VARIATIONS OF HABIT AND FORM.

The conditions under which the seedlings are grown naturally exercise some influence on the form of the leaves. For instance, in Mimulus luteus, if the seedlings have sufficient room the first leaves are shortly stalked and deltoid, while the primary nodes are but little developed; on the contrary, if they are more crowded, the internodes and petioles are longer and the leaves are oval.

In the Primrose (fig. 272) we find an arrangement which almost seems as if it were intended to give the seedling some power of locomotion. The hypocotyl is sometimes horizontal, and throws out strong adventitious roots, the upper part, however, becoming vertical as usual.





272.—*Primula vulgaris*. A, grown in sand. Nat. size. B, grown in loam and sand, × 2.

This is due to the primary root behaving differently in different soils. In silver sand a number of specimens examined penetrated the soil perpendicularly. In loam with a mixture of sand the radicle or base of the hypocotyl bends or becomes procumbent in many instances before penetrating the soil. In some cases it soon ceases to elongate and throws out strong lateral rootlets furnished with an abundance of root-hairs.

In Mutisia ilicifolia (fig. 273) the fleshy, pointed cotyledons serve partly as a holdfast for the seedling, as they are recurved, with their points penetrating the ground.

The Mangrove (*Rhizophora Mangle*) supplies an interesting case of very special adaptation. It has a most unusual method of germination,[1] but well adapted to the conditions in which it lives on muddy tropical coasts. The flower has an inferior ovary with two loculi and two ovules in each. Owing to subsequent growth the greater part of the fruit is superior. Generally only one ovule develops to a seed which has a thick spongy seed-coat containing much vascular tissue and is thus

FIG. 273.—*Mutisia ilicifolia.* Half nat. size. *C*, *C*, cotyledons.

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[1] A full account is given by E. Warming in Engler's *Botan. Jahrb.* iv. (1883) p. 519.

adapted for transport of nutriment to the embryo. There is a small amount of albumen which, however, consists of large clear empty cells, and behaves very strangely, growing out of the micropyle and spreading over the lower part of the seed-coat forming an arillode which is subsequently perforated in germination. Warming suggests that it serves as a sucker to absorb and pass on food from the mother-plant to the growing embryo. The seed never leaves the fruit, germination taking place while the latter hangs attached to the mother-plant, the hypocotyl pushing out at its apex.

The embryo consists almost entirely of apparently only one large cotyledon, the hypocotyl and radicle being quite insignificant. The cotyledon is long and subcylindrical in shape, solid above, and covered with a thick layer of absorbent hairs forming a sucker by which the embryo is directly supplied with food. The lower part is hollow and protects the plumule. In germination the hypocotyl grows out of the seed and fruit and forms a long club-shaped structure one, two or even three feet long, terminating in a sharp strong radicle. The plumule is carried out enclosed in the lower portion of the cotyledon; while still connected with the mother-plant it grows to a conical bud of rolled-up leaves and stipules ⅔ inch long. Finally the seedling separates from the cotyledon and drops into the mud where it is rapidly fixed by growth of lateral roots which have already developed in large numbers on the primary root, which remains small, and below it. As soon as a holdfast is secured the plumule unfolds, and the stem elongates.

Sometimes two ovules in one ovary develop and two seedlings grow out from one fruit; in other cases the same results from polyembryony, both plants springing from the same seed.

As a general rule, the first buds produced by the seedlings are in the axils of the leaves, or more rarely of the cotyledons (fig. 274). In some species of Linaria (fig. 275), however, the hypocotyl itself throws out one or more buds which develop into branches. The advantage of this may be that, if the main shoot is cropped or broken almost down to the root, the plant is capable of throwing up another stalk.

We thus find an almost inexhaustible series of beautiful adaptations to purpose. On the other hand, there are not wanting cases in which it would seem that the adaptation is not complete, or that a certain change, which has been of superior importance, has involved a minor evil.

The Oak, Beech, Nut, &c., afford us a very interesting series of species. Fig. 277 represents a diagram of a Nut with the parts somewhat separated from one another, so as to show the relations more clearly. The micropyle (*m*) is at the apex of the seed. The ovule, however, is not straight and orthotropous, which would be, or at any rate seem to be, the simplest arrangement. Quite the contrary, for we find a long placental axis (*pl*) which extends to the apex of the nut, and from which starts

Fig. 274.—*Crucianella ægyptiaca*. Nat. size. With a shoot in the axil of each cotyledon.

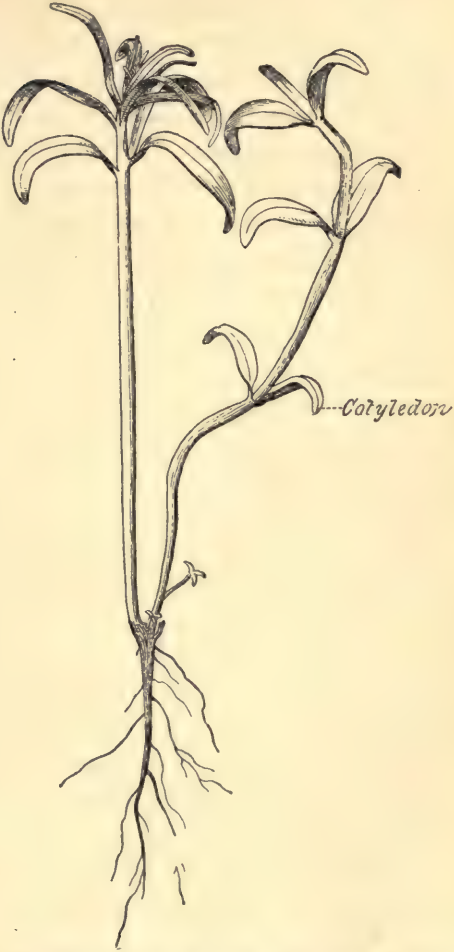

Fig. 275.—*Linaria bipartita*. Nat. size. Bearing a shoot on the hypocotyl.

a raphe (*r*), which returns about half way back again to the place where the true attachment or chalaza (*ch*) is situated. I have in vain endeavoured to discover or imagine any circumstances which would render this complex arrangement specially adapted to present conditions. It would seem as if it would be simpler and give Nature less trouble if the ovule sat directly with its base on the stalk, thus doing away with both the placental axis (*pl*) and the raphe (*r*).

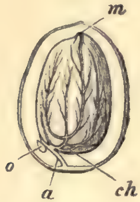

FIG. 276.—Seed of Oak (*Quercus pedunculata*). Nat. size. *o*, abortive ovule.

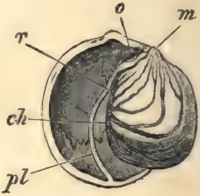

FIG. 277.—Seed of Nut (*Corylus avellana*). Nat. size. *o*, abortive ovule.

This view is strengthened by the fact that such an arrangement has actually been nearly attained by the Oak. The ovule in this genus is theoretically anatropous, but the placental axis and the raphe are both greatly shortened (fig. 276), so that the distance which the nourishment has to traverse is much less, though the actual place of attachment remains the same. The Oak in fact seems to have appreciated the difficulties of the situation, and to have in great measure neutralised them. Is it fanciful to imagine that some ages hence the Oak may be practically orthotropous?

But why should these species be anatropous if it is an advantage to be orthotropous? On this question some light is thrown by the fact that while one seed only comes to maturity, the ovary contains originally several cells each with one or two ovules, though none of the others comes to anything. They can, however, easily be seen, either at the apex of the seed, as in the Nut (fig. 277, *o*) and Beech (*Fagus*), or, as in the Oak (fig. 276, *o*), near the base. Their presence appears to indicate that these species are descended from ancestors the fruit of which was composed of several cells, each with more than one seed—a state of things therefore very unlike the present, and when the anatropous condition would be an advantage. If this view be correct, the structure of the fruit in the Nut, Beech, and others becomes peculiarly interesting, because it represents a case in which the present arrangements are not those in all respects most convenient to the plant, and renders it probable that the same explanation may apply to other cases of difficulty.

The development of the fruit and seed in Viburnum is interesting and unusual (fig. 278). At the time of flowering or immediately after the corolla has dropped, the raphe passes (fig. 278, A) along one side of the ovule, across the lower and apical end, and a little way up the other side to the chalaza, which at this time is a little below the middle of the ovule.

Owing to a localisation of growth in the young seed, the lower and apical end, including the raphe, attains (fig. 278, B, C) great development. The seed being attached at the apex of the cell, is encouraged to grow at its lower end only, in order to completely occupy the cavity of the ovary. The distance between the chalaza and the hilum or micropyle remains unaltered, consequently as growth goes on the raphe seems to creep farther and farther round the seed, whereas it is only the lower part of the seed and the raphe which grow and develope together till the cavity of the ovary is completely filled, when the raphe surrounds nearly the whole of the mature seed.

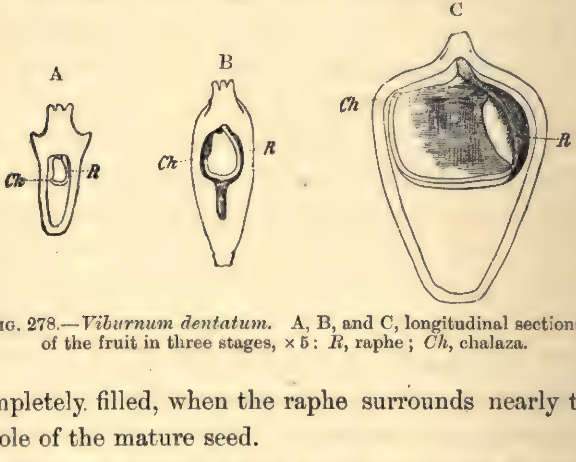

FIG. 278.—*Viburnum dentatum.* A, B, and C, longitudinal sections of the fruit in three stages, × 5: *R*, raphe; *Ch*, chalaza.

We meet indeed with a great many cases in which a larger or smaller number of the ovules, often all but one, fail to become developed. In some of them we may perhaps see a provision to increase the chances of fertilisation. There are others, however, in which this explanation will not hold good. In Ptelea (Rutaceæ), for instance, the ovary contains 2–3 cells, each containing two ovules, one inserted rather above the other, and the inferior ovule constantly fails to develope. In this and other similar cases we can hardly doubt that the existence of this second, and now functionless, ovule carries us back to a time when the ancestors of our present Ptelea habitually produced two seeds.

In Paliurus (Rhamnaceæ) the fruit normally contains three, but sometimes only two, loculi, each with a single seed. Again, in Myagrum (Cruciferæ) the ovary is spuriously 3-celled, but the two outer cells produce no seed. In Hæmanthus (Amaryllideæ) there are three cells, each containing a seed, only one of which, however, comes to maturity. In Convallaria there are three cells, each with two ovules, but only one cf the six is generally developed. In the ovary of Horse Chestnut (*Æsculus Hippocastanum*) each of the three cells is two-ovuled (one ovule being erect and one pendulous). Either one or the other may get fertilised; and each cell matures one seed only. Sometimes only one ovule gets fertilised in the whole ovary, and the cell containing it grows at the expense of the others, which remain small. The seed is large, depresso-globose, or variously flattened by compression, and its shining chestnut-brown testa is thick and leathery. The embryo occupies the whole of the interior, and has thick, conferruminate cotyledons, separable with difficulty when mature.

In Cordia (Boragineæ) the fruits are typically four-celled, but are generally by abortion reduced to one or more fertile or seed-bearing cells, while the others are empty.

In Cordia grandifolia (fig. 279) usually only one cell contains a perfect embryo. The pericarp is crustaceous when dry or subcoriaceous; the endocarp bony, except at the receptacle where a cavity is left filled with rather soft, cortical, pale-coloured tissue, and nearly smooth

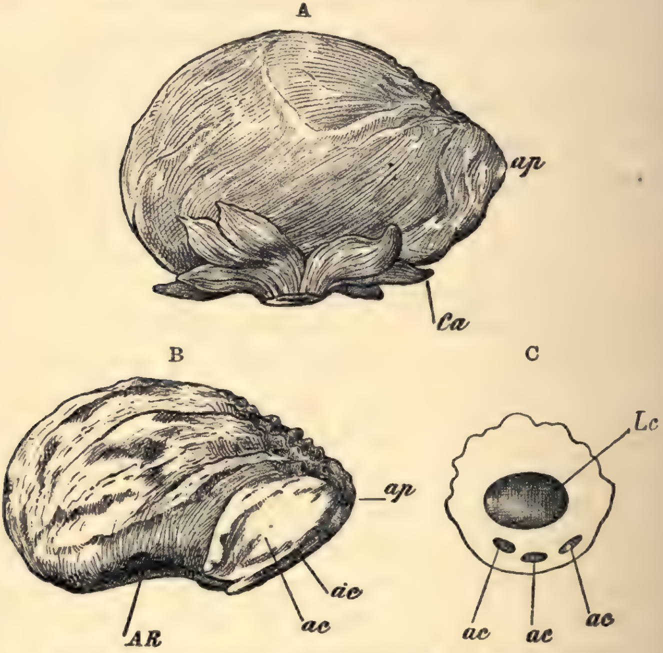

FIG. 279.—*Cordia grandifolia.* A, fruit, × 4: *Ca*, calyx; *ap*, apex of fruit. B, endocarp and seed, or nut, × 4: *AR*, attachment to receptacle; *ap*, apex of nut; *ac*, *ac*, aborted cells of ovary. C, transverse section of nut, × 4: *ac*, *ac*, *ac*, aborted cells of ovary; *Lc*, large cell usually containing a seed, but here empty.

except on the upper side which is raised into numerous tooth-like elevations. On the ventral aspect it is smooth and differently coloured near the top, denoting the presence of the three aborted lobes of the ovary. A transverse section of this part showed one large and three small cavities, the latter of which were empty.

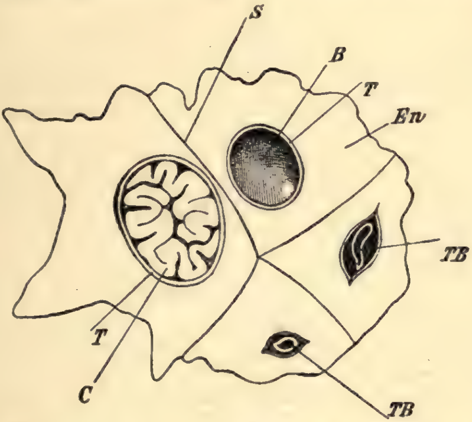

FIG. 280.—*Cordia subcordata.* Transverse section of nut, × 4: *T*, testa; *C*, cotyledon; *TB*, *TB*, testa of barren seeds in empty cells; *En*, endocarp; *B*, barren cell with testa, *T*; *S*, sutural line.

In the fruit of C. subcordata figured (fig. 280) one cell had a perfect embryo or seed, while all the other ovules were aborted and the cells very small.

We meet with similar cases in many Palms where a single seed results from a tricarpellary ovary. The Coco-nut is a familiar illustration.

From the point of view as to the origin of these differences, the variations in seedlings offer great interest.

For example, out of 135 seedlings of Cress (*Lepidium sativum*), which, as already mentioned, differs from the rest of the genus in having tripartite cotyledons, no less than 25, or as much as 18½ per cent., differed from the type, and had this character more or less imperfectly developed. Under cultivation the seedlings of Primula sinensis often have one of the cotyledons deeply bifid; in one lot of seedlings this was the case with, for instance, over 20 per cent. of the plants.

Fig. 281.
Peucedanum sativum.
Nat. size.

In Ranunculus, occasionally, the petioles of the cotyledons are connate.

In Œnothera the cotyledons are either straight, or one or both involute. Irmisch states that the cotyledons of Clematis recta are usually aerial, but sometimes remain below ground; while the reverse is the case in Melittis, and, according to Winkler, in Dentaria and Mercurialis, for the cotyledons, which are generally fleshy and subterranean, sometimes rise above ground and form small green leaves.

Many species occasionally have one or both cotyledons divided. In Peucedanum sativum, individuals occur very frequently in which one or both (fig. 281) of the cotyledons are bifid, bipartite, or divided to the base, appearing in the last case double, that is, simulating three or four cotyledons, instead of two. Where fission occurs there is a distinct midrib to each lobe of the cotyledon. Opuntia basilaris has sometimes one of the two cotyledons bifid, while occasionally only one is present.

Mr. Guppy records[1] the occurrence of abnormalities in from 2 to 6 per cent. of the seedlings observed in the case of British plants. In *Myriophyllum spicatum* as many as 17 per cent. of the seedlings were apparently monocotyledonous, the cotyledons being more or less completely united into a tube open at the side. In *Limnanthemum nymphoides* and *Samolus Valerandi*, both monocotyledonous and tricotyledonous seedlings were observed, and the latter in *Ranunculus repens* (2 per cent.), *Lythrum Salicaria* (2 per cent.), *Hydrocotyle vulgaris*, *Galium palustre* (1 per cent.), *Scrophularia aquatica* (6 per cent.), *Salicornia herbacea* (4 per cent.), and *Alnus glutinosa* (2 per cent.). In *Caltha palustris*, 6 per cent. were tricotyledonous, 2 per cent. dicotyledonous with one cotyledon cleft, while 1 per cent. had two pairs of cotyledons, each pair arising from a common pedicel.

In cases of polyembryony, as in the Orange and Triphasia, to which we have already referred (p. 130), the number of embryos is very variable.

In Rheum the cotyledons are generally parallel,

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[1] 'Irregularity of some Cotyledons,' *Science Gossip*, 1895, p. 171.

but in some cases one of them is placed more or less obliquely with reference to the other.

In Fagopyrum the position and arrangement of the cotyledons vary greatly. The cotyledons are turned about after striking into an angle of the seed, and then, following the testa, assume very various positions. In Carum Carvi the cotyledons sometimes have their backs to the axis of the fruit, and sometimes their edges, while at others they are oblique.

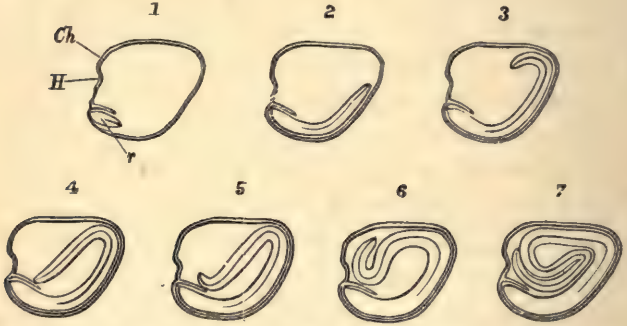

FIG. 282.—*Acer Pseudo-Platanus.* Sections of seed in seven successive stages, showing growth of embryo, × 3.

In Cheiranthus pygmæus the cotyledons are said to be sometimes accumbent, sometimes incumbent, and straight or convolute, even in the same pod.

It would be easy to multiply such cases, but I will only mention one more, in which I will venture to suggest a reason for the variation. In Acer (fig. 282, 1), the embryo originates in a short tubular cavity opposite the micropyle, and is at first straight, with an extremely short turbinate radicle (*r*), and ovate, obtuse, closely adpressed cotyledons. As growth continues the embryo extends itself along the lower side of the seed, and curves with it, becoming gradually lanceolate, or oblong-lanceolate (fig. 282, 2). When the cotyledons have reached the upper, narrow end of the seed, the curvature of the wall turns them down again on themselves (fig. 282, 3). This growth is continued until the tips reach the radicle again, and the ultimate arrangement of the embryo differs according to whether they then curve inwards or outwards. This, again, seems to depend on the exact direction of the growth of the cotyledons. If they strike (fig. 282, 5) against the process which encloses the radicle, then their general direction naturally carries them outwards, until the wall of the seed again turns them upwards, so that they become plicate; if, on the contrary, the tips of the cotyledons pass just within the micropylar process and touch the radicle, then they are compelled to grow in the opposite direction, and they become spirally coiled. In the specimens examined the latter arrangement was exceptional.

RELATION OF THE SEEDLING TO THE SEED.

The question of course arises whether the embryo conforms to the seed, or whether the shape of the seed is determined with reference to the form of the cotyledons. The seeds, however, are evidently constructed with reference to the habits, conditions, &c., of the plant. I have elsewhere dealt with the structure of the seed, and must content myself here with the simple statement that we have no reason to suppose that it is influenced by the form of the embryo. On the other hand, it seems equally clear that the form of the embryo, and especially of the cotyledons, is essentially influenced by that of the seed.

The Tea (*Thea*), for instance, presents us with a very interesting case, in which the cotyledons vary greatly in shape, following that of the seed, and depending on the number of ovules which develope; the seeds are contained in a woody capsule, and are variously compressed. In Citrus also the cotyledons are unequal and irregular, several embryos being contained in each seed, and sometimes squeezed together in the utmost confusion.

In several other cases among those which have been already referred to, we can hardly doubt, I think, that the form of the cotyledon has been affected by the seed and not *vice versâ*.

Let me, in conclusion, take one other illustration. The cotyledons of the Sycamore (fig. 16) are long, narrow, and strap-like; those of the Beech (fig. 15) are short, very broad, and fan-like. Both species are exalbuminous, the embryo occupying the whole interior of the seed.

Now in the Sycamore the seed is more or less an oblate spheroid, and the long ribbon-like cotyledons, being rolled up into a ball, fit it closely, the inner cotyledon being often somewhat shorter than the other. On the other hand, the nuts of the Beech are more or less triangular: an arrangement like that of the Sycamore would therefore be utterly unsuitable, as it would necessarily leave great gaps. The cotyledons, however, are folded up like a fan, but with more complication, and in such a manner that they fit beautifully into the triangular nut.

Can we, however, carry the argument one stage further? Why should the seed of the Sycamore be globular, and that of the Beech triangular? Is it clear that the cotyledons are constituted so as to suit the seed? May it not be that it is the seed which is adapted to the cotyledons? In answer to this we must examine the fruit, and we shall find that in both cases the cavity of the fruit is approximately spherical. That of the Sycamore, however, is comparatively small, say $\frac{1}{5}$ inch in diameter, and contains one seed, which exactly conforms to the cavity in which it lies. In the Beech, on the contrary, the involucre is at least twice the diameter, and contains from two to four fruits, which consequently, in order to occupy the space, are compelled (to give a familiar illustration, like the segments of an orange) to take on a more or less triangular form.

Thus, then, in these cases, starting with the form of the fruit, we see that it governs that of the seed, and that of the seed again determines that of the cotyledons. But though the cotyledons often follow the form of the seed, this is not invariably the case; other factors must also be taken into consideration. When this is done, we can, I venture to think, throw much light on the varied forms which seedlings assume.

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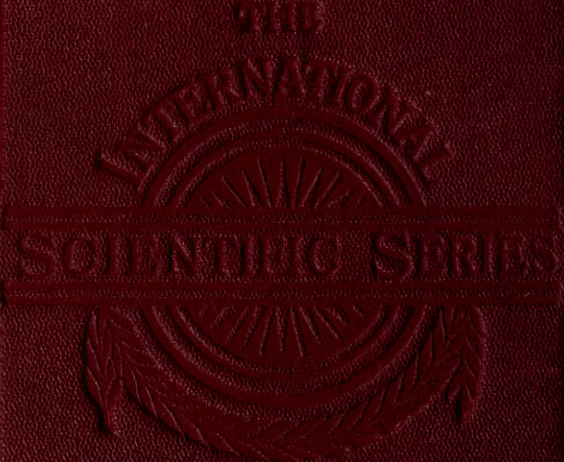
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