DARWIN ON THE MOVEMENTS OF PLANTS.

By ELIZA A. YOUMANS.

SINCE the time of Linnæus, men have wondered and speculated about what are known as the spontaneous movements of plants, and in recent years the causes of these movements have been carefully investigated by botanists. The subject in its various bearings now forms a large part of the science of vegetable physiology. The periodical and irritable motions of plants, and those due to light and gravity, have been closely studied in connection with the mechanical laws of growth, and many of these phenomena have been more or less satisfactorily explained.

But it has been reserved for Mr. Charles Darwin to go deeper into the facts and philosophy of the subject than any of his contemporaries. In 1875 he published a book upon "The Movements and Habits of Climbing Plants"; and he has since extended his inquiries so as to include the movements manifested by the entire vegetable series, except the lowest flowerless plants, and upon these he is now engaged. He has just published an account of these researches in a volume of six hundred pages, uniform with his other works.

One of the movements of plants long ago observed was described by the term *nutation*, which simply means nodding. The motion of a flower in following the apparent movement of the sun from the east in the morning to the west in the evening is an example of nutation, and this kind of motion has been found to be much more extensive in plants than was formerly supposed.

When we observe the growing stem of the hop, after the first two or three joints are formed, we see it bend to one side and travel slowly round toward all points of the compass, and continue these revolutions day and night. This spontaneous gyrating motion of stems and tendrils was first remarked by Palm and Mohl, and Professor Sachs gave it the name of *revolving nutation.*

Mr. Darwin has found that this kind of motion is ever present in the growing parts of plants, so that it must be regarded as a universal property of growing vegetation, and he suggests for it the better term *circumnutation.* He has proved that even the buried stems and rootlets of germinating seeds make this movement so far as the surrounding pressure will permit.

By the most ingenious and delicate contrivances, and his own constant coöperation, Mr. Darwin has made it possible for the circumnutating organs themselves to indicate approximately the direction and extent of their movements. His arrangements for enabling organs to record their motions varied somewhat; but we give his own account of the general process:

"Plants growing in pots were protected wholly from the light, or had light admitted from above, or on one side, as the case might require, and were covered above by a large horizontal sheet of glass, and with another vertical sheet on one side. A glass filament, not thicker than a horse-hair, and from a quarter to three quarters of an inch in length, was affixed to the part to be observed by means of shellac dissolved in alcohol, which was so thick as to set hard in two or three seconds ; and it never injured the most delicate tissues. To the end of the glass filament an excessively minute bead of black sealing-wax was cemented, below or behind which a bit of card with a dot was fixed to a stick driven into the ground. The weight of the filament was so slight that even small leaves were not perceptibly pressed down. The bead and the dot on the card were viewed through the glass plate, and when one exactly covered the other a dot was made on the glass plate with a sharply pointed stick dipped in Indian ink. Other dots were made at short intervals, and they were afterward joined by straight lines. The figures are therefore angular. If the dots had been made every one or two minutes, the lines would have been more curved, as when radicles traced their own courses on smoked-glass plates. When the dot on the card was half an inch from the bead of sealing-wax, and the glass plate (supposing it to have been curved) stood seven inches in front, the tracing represented the movement of the bead magnified fifteen times."

Another, and in some respects better, method was used when it was required to magnify the movement. The dots on the glass plate were copied upon tracing-paper, and joined by ruled lines with arrows to show direction, the first dot being made larger to catch the eye. Night movements are shown by broken lines.

Chapter I is devoted to the circumnutating movements of germinating plants or seedlings. The first experiment relates to the movements of the young rootlet or radicle of a seedling cabbage. In this case fuller details of the process are given, along with the diagram, than in any other, for which reason we reproduce it here.

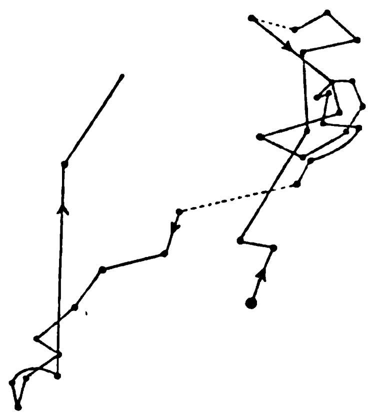


FIG. 1.—BRASSICA OLERACEA: circumnutation of radicle, traced on horizontal glass, from 9 A. M., January 31st, to 9 P. M., February 2d. Movement of bead at end of filament magnified about forty times.

"A seed, with the radicle projecting ·05 inch, was fastened with shellac to a little plate of zinc, so that the radicle stood up vertically; and a fine glass filament was then fixed near its base, close to the seed-coats. The seed was surrounded by bits of wet sponge, and the movement of the bead at the end of the filament was traced (Fig. 1) during sixty hours. In this time the radicle increased in length from ·05 to ·11 inch. Had the filament been attached at first close to the apex of the radicle, and if it could have remained there all the time, the movement exhibited would have been much greater, for at the close of our observations the tip, instead of standing upward, had become bowed downward, through geotropism [gravitation], so as almost to touch the zinc plate. As far as we could roughly ascertain by measurements made with compasses on other seeds, the tip alone, for a length of only $\frac{2}{100}$ to $\frac{3}{100}$ of an inch, is acted on by geotropism. But the tracing shows that the basal part of the radicle continued to circumnutate irregularly during the whole time. The actual extreme amount of movement of the bead at the end of the filament was nearly ·05 inch, but to what extent the movement of the radicle was magnified by the filament, which was nearly three fourths of an inch in length, it was impossible to estimate. . . .

"Another seed was treated and observed in the same manner, but the radicle in this case protruded ·1 inch, and was not fastened so as to project quite vertically upward. The filament was fixed close to its base. The tracing (Fig. 2, reduced one half) shows the movement

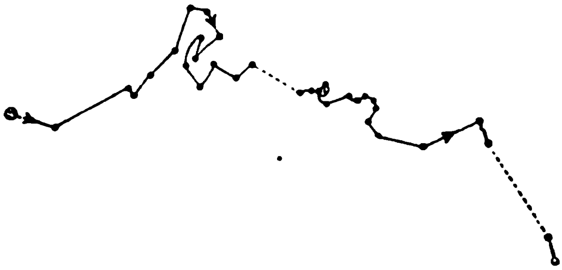


FIG. 2.—BRASSICA OLERACEA: circumnutating and geotropic movement of radicle, traced on horizontal glass during forty-six hours.

from 9 A. M., January 31st, to 7 A. M., February 2d; but it continued to move during the whole of the day in the same general direction and in a similar zigzag manner." The chapter contains fifty-four diagrams, giving the movements of all the parts of the seedlings of all sorts of plants.

Mr. Darwin thinks that these movements of the radicle are useful at least in enabling it to take the line of least resistance, if they do not directly aid it in forming a passage for itself; and he adds: "If, however, a radicle in its downward growth breaks obliquely into any crevice, or a hole left by a decayed root, or one made by the larva of an insect, and more especially by worms, the circumnutating movement of the tip will materially aid its descent; and we have observed that roots commonly run down the old burrows of worms." He says, further, that the force due to longitudinal and transverse growth materially assists the radicle in penetrating the ground. He experimented upon these points, and we give two of these experiments which relate to the force exerted transversely by the radicles of beans. We may say that these radicles have a sharp apex protected by a root-cap, and their growing part is more rigid than the part just above.

A stick cut in the shape of Fig. 3 was purposely split at the short end, the split reaching beyond the hole. As the wood was highly

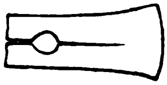


FIG. 3.—OUTLINE OF PIECE OF STICK (reduced to one half natural size), with a hole through which the radicle of a bean grew. Thickness of stick at narrow end, ·08 inch; at broad end, ·16. Depth of hole, ·1 inch.

elastic, the split closed as soon as it was made. The stick and bean were buried in damp sand, the bean being placed so that the radicle in growing would enter this hole. After six days they were dug up, and the radicle was found much enlarged above and beneath the hole. The fissure was open to a width of four millimetres, but as soon as the radicle was removed it closed to two m.m. The stick was then suspended horizontally by a fine wire passing through the hole, and a little saucer was suspended beneath it to receive the weights, and it required eight pounds eight ounces to open the fissure to the width of four m.m.

Again, "holes were bored near the narrow end of two wooden clips or pincers (Fig. 4), kept closed by brass spiral springs. Two radicles in damp sand were allowed to grow through these holes. The pincers rested on glass plates, to lessen the friction from the sand. The holes were a little larger and considerably deeper than in the trials with the sticks, so that a greater length of a rather thicker radicle exerted a transverse strain. After thirteen days they were taken up. The distance of two dots (see Fig. 4) on the longer ends of the pincers was now carefully measured; the radicles were then extracted from the holes, and the pincers of course closed. They were then suspended in the same way as the stick, and a weight of three pounds four ounces was necessary with one of the pincers to open them as much as the radicle had done by transverse growth." This radicle had escaped beyond the hole, and flattened a little, as soon as it had slightly opened the pincers, which had somewhat lessened the strain. As a result of all his observations, he concludes: The radicle "increases in length with a force equal to the pressure of at least a quarter of a pound, and much greater when prevented from bending"; and "it increases in thickness, pushing away the damp earth on all sides with a force of above eight pounds in one case and three pounds in another."

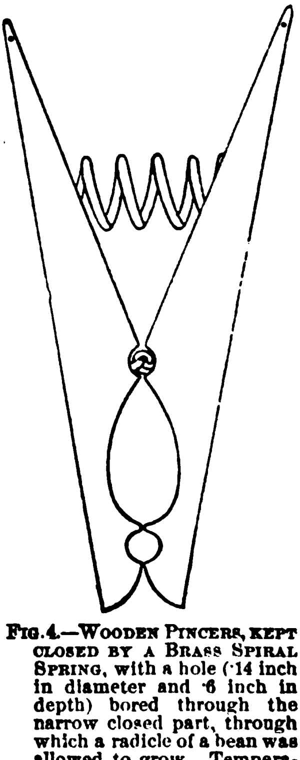


FIG. 4.—WOODEN PINCERS, KEPT CLOSED BY A BRASS SPIRAL SPRING, with a hole (·14 inch in diameter and ·6 inch in depth) bored through the narrow closed part, through which a radicle of a bean was allowed to grow. Temperature, 50°-60° Fahr.

To determine whether the growing parts of mature plants circumnutate, Mr. Darwin experimented with the representatives of about twenty genera, belonging to widely different families and various countries. Several woody plants were chosen, as being less likely to circumnutate. Plants in pots were kept at a proper temperature, either in darkness or feebly illuminated from above. Diagrams showing the circumnutation in about fifty instances of runners or stolens, flower-stems, leaves young and old, leaflets, fronds, etc., are given, and the volume contains about a hundred and fifty such diagrams, accompanied by explanations and comments bearing upon the argument of the book. The published instances are selected, for one reason and another, from an accumulation of similar material, the result of years of observation. The figures made by stems, which were always growing, are of course somewhat spiral, forming a succession of more or less irregular narrow ellipses, with their longer axes directed to different points of the compass at different times. They show that the course pursued is often interrupted by zigzags, loops, and small triangles. The rate of movement was different at different times and with different plants. Some made but one ellipse a day, and others four or five.

In studying leaves, he experimented with from thirty to forty widely distributed genera of dicotyledons, monocotyledons, and cryptogams. The seat of movement, he found, was generally in the petiole, but sometimes also in the blade. The extent of movement differed greatly. It is chiefly in a vertical plane; but, as the ascending and descending lines never agreed, there was always some lateral motion describing irregular ellipses. These observations were made upon healthy plants growing in pots, illuminated from above, many of them through ground glass, and they were also plants that do not sleep at night. The stem was always secured to a stick close to the base of the leaf under experiment. Besides his general conclusion that all growing parts circumnutate, many other important inferences are drawn by the author from these experiments and observations.

This movement, which in the case of climbing plants was believed to be due to increased growth of the side that for the time became convex, has more recently been proved to result from the circumstance that every part of a plant while it is growing, and in some cases after growth has ceased, has its cells rendered more turgescent and its cell-walls more extensile first on one side and then on another. Why this should be the case is not known, but Darwin suggests that the changes in the cells may require periods of rest, which accords with our knowledge of the rhythmical nature of motion.*

Under the microscope, this movement of circumnutation was seen in a few cases to be made up of sudden small jerks forward for ·002

* For an interesting and extended discussion of this subject, the reader is referred to the chapter on the mechanical laws of growth in Sachs's "Text-Book of Botany."

or ·001 of an inch, and then a slow retreat for part of the distance. No such movement could be detected with a two-inch object-glass, in the case of Drosera, and how far it is general is not known. Mr. Darwin says : "The whole hypocotyl (stem of a cotyledon) of a cabbage or the whole leaf of a Dionæa* could not jerk forward unless a very large number of cells on one side were simultaneously affected. Are we to suppose that these cells steadily become more and more turgescent on one side, until the part suddenly yields and bends, inducing what may be called a microscopically minute earthquake in the plant ; or do the cells on one side suddenly become turgescent in an intermittent manner—each forward movement thus caused being opposed by the elasticity of the tissues ?"

Mr. Darwin has shown the importance of this ever-present movement in successive chapters upon *modified* circumnutation. By this phrase he means that pressure and other irritants, light and gravitation, do not directly cause movement ; they only modify the spontaneous changes in the turgescence of the cells, which are always in progress, and of which circumnutation is a universal consequence. He thinks that, in the case of seedlings, ordinary or unmodified circumnutation is clearly of service, directly or indirectly ; but, in the later stages of growth, it is from various modifications of this constant motion that the plant derives benefit.

More than half the volume is given to the modifications of circumnutation by *epinasty* and *hyponasty* ;† by nyctitropic or sleep-movements ; and by the influence of light and of gravitation : but we can only glance at one of these, which is popularly styled the sleep of leaves, although there is probably no real analogy between the sleep of animals and that of plants.

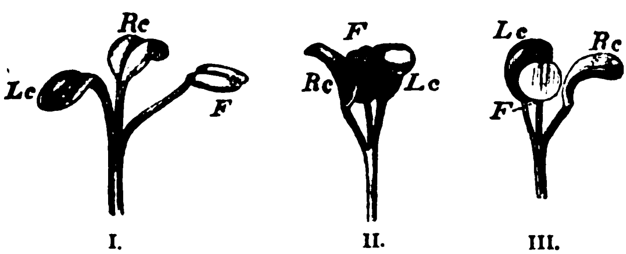


FIG. 5.—TRIFOLIUM STRICTUM : DIURNAL AND NOCTURNAL POSITIONS OF THE TWO COTYLEDONS AND OF THE FIRST LEAF : I. Seedling viewed obliquely from above, during the day : *Rc*, right cotyledon ; *Lc*, left cotyledon ; *F*, first true leaf. II. A rather younger seedling, viewed at night : *Rc*, right cotyledon raised, but its position not otherwise changed ; *Lc*, left cotyledon raised and laterally twisted ; *F*, first leaf raised and twisted so as to face the left twisted cotyledon. III. Same seedling viewed at night from the opposite side. The back of the first leaf, *F*, is here shown instead of the front, as in II.

Nyctitropic (*night-turning*) is the word used by Darwin to describe the sleep of leaves and occasionally of flowers, but, as flowers are affected chiefly by changes of temperature instead of light, their

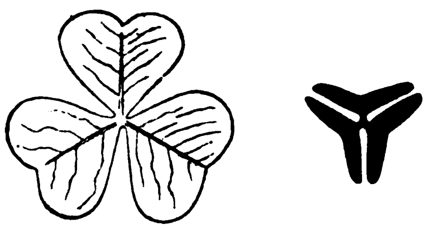
* In these instances the jerking motions were very remarkable.

† The alternately more rapid growth of the upper and under surfaces of organs.

sleep does not so much concern the inquiry. The night-movements of leaves result from circumnutation modified by changes of light and darkness, and also by heredity; and, as Darwin has proved, they are chiefly of use to the plant in diminishing the loss of heat by radiation. Therefore, he says, no movement deserves to be called nyctitropic unless it has been acquired for this purpose. As some leaves and cotyledons bend upward only a little at night, the question arises, At what angle does the diminished radiation warrant the use of this term? He takes an arbitrary limit of 60°, above or below the horizon, as any less angular rise and fall would be of slight significance. Nyctitropic movements are easily affected by surrounding conditions of moisture and temperature, and in many genera it is indispensable that the leaves should be well illuminated during the day. From the very wide list of genera experimented upon, it follows that the habit of sleeping "is common to some few plants throughout the whole vascular series."

Darwin first considers the sleep of cotyledons, having observed the positions during the day and night of the representatives of one hundred and fifty-three genera. Some ten pages are given up to remarks upon this subject. We give his account of the behavior of the cotyledons of *Trifolium strictum* as it is illustrated by a picture of the diurnal and nocturnal positions they assume.

"On the first day after germination, the cotyledons stood at noon horizontally, and at night rose to only about 45° above the horizon. Four days afterward the seedlings were again observed at night, and now the blades stood vertically and were in contact, excepting the tips, which were much deflexed, so that they faced the zenith. At this age the petioles are curved upward, and at night, when the bases of the blades are in contact, the two petioles form a vertical ring around the plumule. The cotyledons continued to act in nearly



A. B.

FIG. 6.—OXALIS ACETOSELLA: A, leaf seen from vertically above; B, diagram of leaf asleep, also seen from vertically above.

the same manner for eight or ten days from the time of germination, but the petioles had become straight and were much lengthened. After twelve or fourteen days the first true leaf was formed, and during the next fortnight a remarkable movement was repeatedly observed. At I, Fig. 5, we have a sketch made in the middle of the day, of a seedling a fortnight old. The two cotyledons, of which

Rc is the right, and *Lc* the left one, stand directly opposite one another, and the first true leaf (*F*) projects at right angles to them. At night (see II and III) the right cotyledon (*Rc*) is greatly raised, but is not otherwise changed in position. The left cotyledon (*Lc*) is likewise raised, but it is also twisted so that its blade, instead of exactly facing the opposite one, now stands at nearly right angles to it. This nocturnal twisting movement is effected by the twisting of the whole length of the petiole. At the same time the true leaf (*F*) rises up vertically, or even inclines inward. It also twists a little, so that the upper surface of its blade fronts the upper surface of the twisted left cotyledon. The whole case is remarkable, as with the cotyledons of no other plant have we seen any nocturnal movement except vertically upward or downward."

The various ways in which the leaves of plants are protected from loss of heat by radiation at night are shown by diagrams and pictures from which we select some of the most striking. A good deal of space is given to an account of the circumnutation and nyctitropic movements of the *Oxalidæ*. In most of the species of oxalis the three leaflets sink vertically down at night. But, as their sub-petioles are short, the blades could not assume this position from want of space, unless they were in some manner rendered narrower, and this is effected by their becoming more or less folded (Fig. 6), so that their lower surfaces are brought near together (see B), as if the object were their protection rather than that of the upper surface. This would form a marked exception to the rule, that the object of sleep is protection of the upper surfaces from radiation, if it had not been found that, in species where the sub-petioles are longer, the leaflets sink without folding together. By thus crowding together at night, a much smaller surface is exposed than during the day.

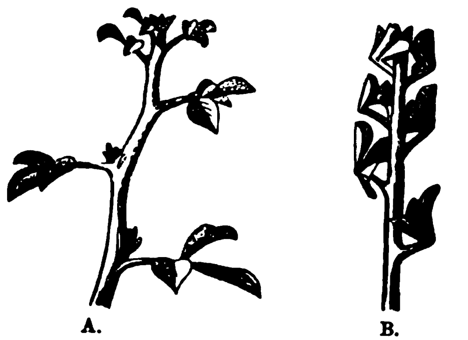


FIG. 7.—MEDICAGO MARINA : A, leaves during the day ; B, leaves asleep at night.

"The drawing of *Medicago marina*, awake and asleep (Fig. 7), answers almost as well for *Cytisus fragrans*, which rose at night on one occasion 23° and on another 33°. The three leaflets also bend upward, and at the same time approach each other so that the base of the central leaflet overlaps the bases of the two lateral leaflets. They bend up so much that they press against the stem; and, on looking down on one of these young plants from vertically above, the lower surfaces of the leaflets are visible: and thus their upper surfaces, in accordance with the general rule, are best protected from radiation. While the leaves on this young plant were thus behaving, those on an old bush in full flower did not sleep at night."

Again, "the species of Melilotus sleep in a remarkable manner. The three leaflets of each leaf twist through an angle of 90°, so that their blades stand vertically at night, with one lateral edge presented to the zenith" (Fig. 8). We have no room for the description of the

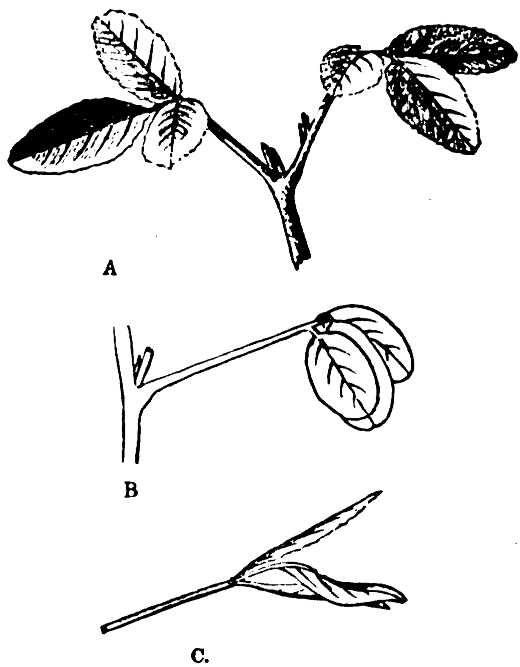
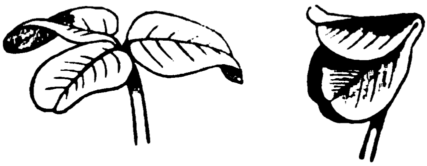


Fig. 8.—Melilotus officinalis: A, leaf during the daytime; B, another leaf asleep; C, a leaf asleep as viewed from vertically above, but in this case the terminal leaflet did not happen to be in such close contact with the lateral one as is usual.

complicated movements performed by these plants. Their petioles and sub-petioles are continually circumnutating during the whole twenty-four hours. Their cotyledons do not sleep.

The nyctitropic movements of eleven species of Trifolium were observed and were found to be closely similar. If we select a leaf of *Trifolium repens* having an upright petiole and with the three leaflets expanded horizontally, the two lateral leaflets will be seen in the evening to twist and approach each other until their upper surfaces come into contact. At the same time they bend downward in a plane at right angles to their former position, until their midribs form an angle of about 45° with the upper part of the petiole. The terminal leaflet merely rises up without any twisting, and bends over until it rests on and forms a roof over the edges of the now vertical and united lateral leaflets, as seen in Fig. 9, with its lower surface fully exposed to the zenith.

The nyctitropic movements of ten species of the lotus tribe were observed and found to be alike. The main petiole rises a little at night, and the three leaflets rise till they become vertical, and at the



A. B.

FIG. 9.—TRIFOLIUM REPENS: A, leaf during the day; B, leaf asleep at night.

same time approach each other. In most of the species the leaflets rise so much as to press against the stem, and not rarely they become inclined a little inward, with their lower surfaces exposed obliquely to the zenith. The young leaves on the summits of the stems close up at night so much as often to resemble large buds. The stipule-like leaflets,

A. B.

FIG. 10.—LOTUS CRETICUS: A, stem with leaves awake during the day; B, with leaves asleep at night; *ss*, stipule-like leaflets.

which are often of large size, rise up like the other leaflets, and press against the stem (see Fig. 10). The circumnutation of a terminal leaflet (with the stem secured) was traced during two days, but the movement was so simple that it is not worth while to give the diagram. The leaflet fell slowly from the early morning till about 1 P. M. It then rose gradually at first, but rapidly late in the evening. It occasionally stood still for some twenty minutes during the day, and sometimes zigzagged a little.

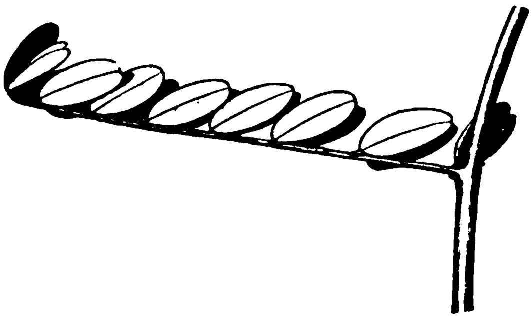
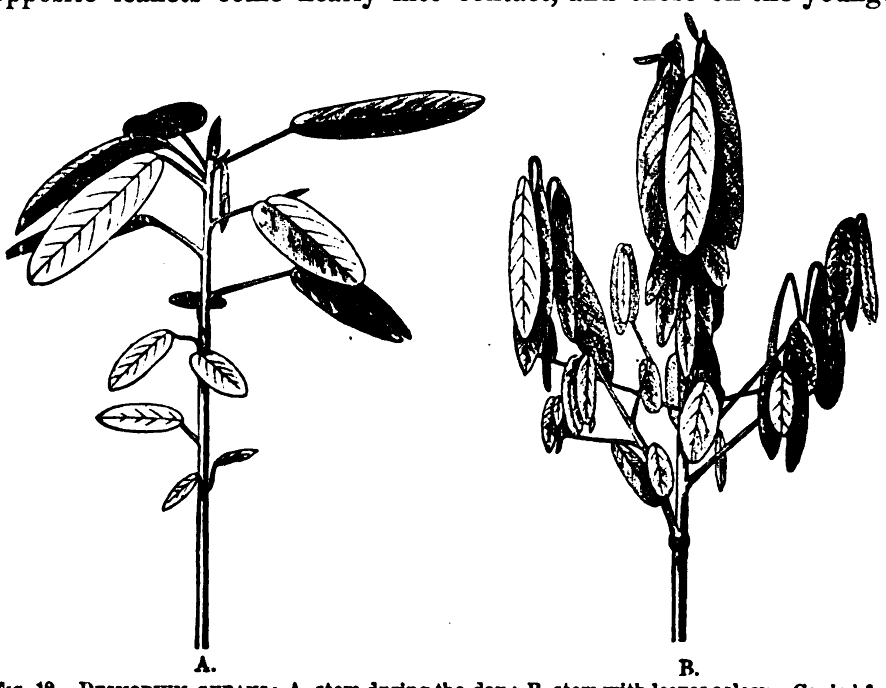


FIG. 11.—CORONILLA ROSEA: Leaf asleep.

The leaves of *Coronilla rosea* bear nine or ten pairs of opposite leaflets, which during the day stand horizontally, with their midribs at right angles with the petiole. At night they rise up, so that the opposite leaflets come nearly into contact, and those on the younger

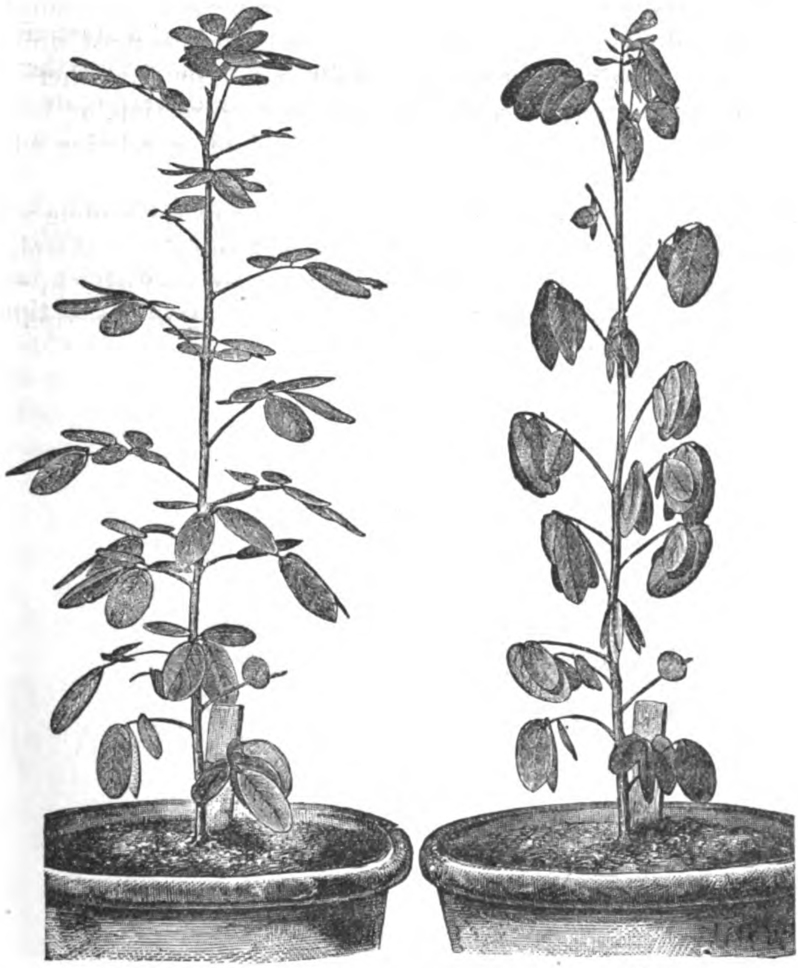


A. B.

FIG. 12.—DESMODIUM GYRANS: A, stem during the day; B, stem with leaves asleep. Copied from a photograph; figures reduced.

leaves into close contact. At the same time they bend back toward the base of the petiole until their midribs form with it angles of from 40° to 50° in a vertical plane (as in Fig. 11).

The appearance presented by a sleeping branch of *Desmodium gyrans* and by one in the daytime, copied from two photographs, is shown at A and B (Fig. 12), where the leaves are seen at night crowded together, as if for mutual protection. Not less striking is the contrast between the night and day aspect of *Cassia corymbosa,* as seen in Fig. 13. Here the horizontally extended leaflets sink down vertically at night, and at the same time rotate so that the lower surface faces outward.



A. B.

FIG. 13.—CASSIA CORYMBOSA: A, plant during day; B, same plant at night. Both figures copied from photographs.

As a conclusion from all his experiments, observations, and reflections upon this subject, Mr. Darwin states:

"The great sweeps made by the stems of twining plants, and by the tendrils of other climbers, result from a mere increase in the amplitude of the ordinary movement of circumnutation. The position which young leaves ultimately assume is acquired by the circumnutating movement being increased in some one direction. The leaf-blades of various plants assume a vertical position through modified circumnutation, in order to protect their upper surfaces from being chilled through radiation. The movements of various organs to the light, which are so general throughout the vegetable kingdom, and occasionally from the light, or transversely with respect to it, are all modified forms of circumnutation, as again are the equally prevalent movements of stems, etc., toward the zenith, and of roots toward the center of the earth. In accordance with these conclusions, a considerable difficulty in the way of evolution is in part removed, for it might be asked, How did all their diversified movements for the most different purposes first arise? As the case stands, we know that there is always movement in progress, and its amplitude or direction, or both, have only to be modified for the good of the plant, in relation with internal or external stimuli."

The discovery of the sensitiveness of the apex of the radicle was made by Darwin when he was looking for something else. Wishing to know how the radicles of seedlings passed over obstacles in the ground, he placed germinating beans in such a way that the tips of

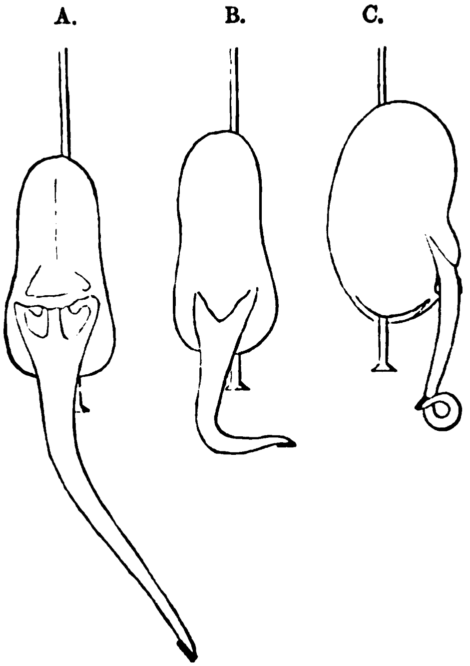
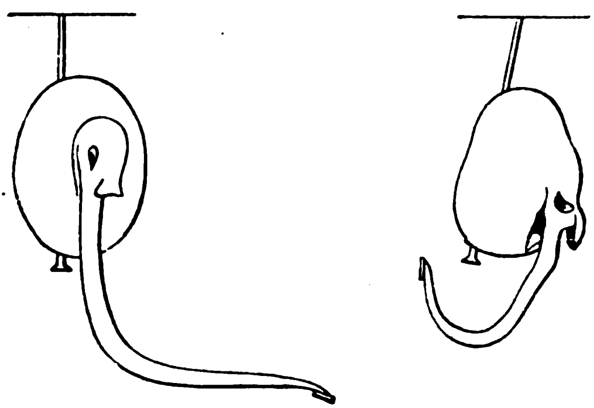


Fig. 14.—Vicia faba: A, radicle beginning to bend from the attached little square of card; B, bent at a rectangle; C, bent into a circle or loop, with the tip beginning to bend downward through the action of geotropism.

the radicles came into contact with opposing surfaces at a high angle. When the root-cap touched such an obstacle it was at first a little flattened, but this flattening soon disappeared, and the apex took a direction at right angles to its former course. Straight lines had been painted along the growing terminal part of some of these radicles before they met the opposing objects, and the lines became sensibly curved in two hours after the apex had come into contact with them. The explanation of this curvature of the growing part could not be mechanical resistance, because it occurred when there was not pressure enough to produce it ; and, besides, Sachs has shown that the growing part is more rigid than the part just above it, which should have yielded first to resistance. Moreover, objects that yield with the greatest ease will deflect a radicle. After various attempts to explain the phenomenon, Darwin was led to suspect that the tip was sensitive to contact, and that it transmitted an effect to the upper part of the radicle, so exciting it to bend away. Such a thing had never been suspected, although Sachs discovered that the radicle is sensitive a little above the apex, and bends, like a tendril, *toward* the touching object.

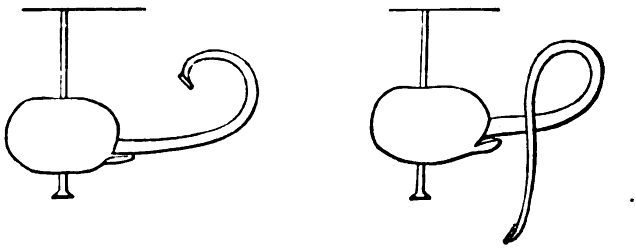
Full details are given of the experiments by which this suspicion was verified. We can only say, briefly, that "germinating beans were pinned hilum downward inside the well-moistened cork lids of glass vessels which were half filled with water, and the light excluded. When the protruding radicles were the tenth of an inch or more long, bits of card about one twentieth of an inch square, or bits of sandpaper, were affixed to the sloping sides of their tips by means of thick gum-water, which by itself had no effect. To avoid confusion from the bending known as Sachs's curvature, the bits were never put in front." That the reader may have a clear idea of the kind of movement excited by the bits of card, we give, Fig. 14, sketches of three beans thus treated, which show the gradations in the degree of curvature. Out of fifty-five beans experimented upon, fifty-two were considerably bent away from the object attached, and the remaining three seemed to become sickly. As the radicle of the pea



A. B.

FIG. 15.—PISUM SATIVUM: Deflection produced within twenty-four hours in the growth of vertically dependent radicles, by little squares of card affixed with shellac to one side of the apex: A, bent at right angles ; B, hooked.

was found to be rather more sensitive at a point above the apex than that of the bean, he experimented with twenty-eight peas which had been soaked for twenty-four hours, and then left to germinate in damp sand. He tried them first with bits of card above the apex for Sachs's curvature, and thirteen of them bent toward the card, the greatest curvature being 62°. Bits of card were then fastened to one side of the tips of eleven radicles within the same jars, and five of them became plainly curved away from this side. In the former case the bend was abrupt, as shown in Fig. 15; in the latter a greater length of radicle

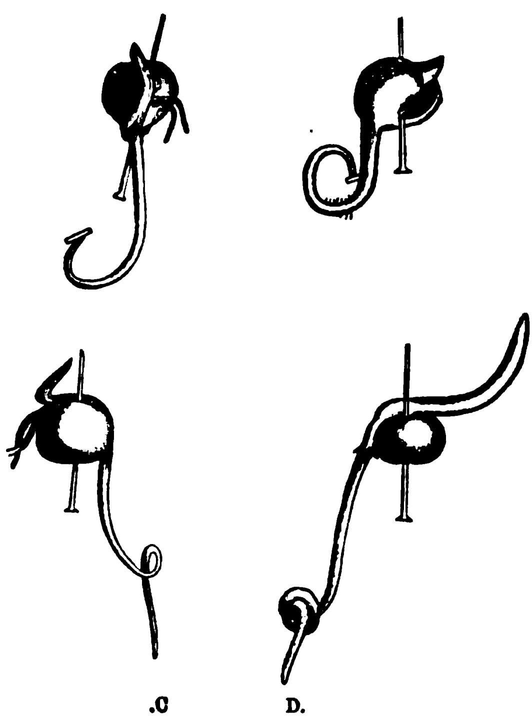


A. B.

FIG. 16.—PISUM SATIVUM.—A radicle extended horizontally in damp air with a little square of card affixed to the lower side of its tip, causing it to bend upward in opposition to geotropism. The deflection of the radicle after twenty-one hours is shown at A, and of the same radicle after forty-five hours at B, now forming a loop.

seemed to be affected and the curve was symmetrical, as seen in Fig. 16. He says, "It was a striking spectacle, showing the difference in the sensitiveness of the radicle in different parts, to behold in the same

A. B.



C. D.

FIG. 17.—ZEA MAYS: Radicles excited to bend away from the little squares of card attached to one side of their tips.

jar one set of radicles curved away from the squares on their tips, and another set curved toward the squares attached a little higher up."

His experiments upon the radicles of dicotyledons were numerous and varied in every way; but the seeds of Indian corn were the only monocotyledonous ones which he observed. Omitting particulars, the cuts (Fig. 17) will show the effects produced in four instances.

In the case of A, the apex of the radicle is so much bent away from the square as to form a hook. At B, the irritation of the card, aided, perhaps, by geotropism, has formed a circle. At C, the tip in forming a loop has rubbed off the attached bit, and the circle has contracted, while at D, the apex, in making a second turn, passed through the first loop and so rubbed off the card, and, growing downward, tied itself into a knot.

Mr. Darwin believes that the tips of all radicles are similarly sensitive, and transmit an influence causing the upper part to bend. Moreover, the tip distinguishes between harder and softer objects, and between moisture and dryness. It is also sensitive to light and gravitation, and the course of the radicle in the ground is determined by the tip. The volume concludes with the following sentence: "It is hardly an exaggeration to say that the tip of the radicle thus endowed, and having the power of directing the movements of the adjoining parts, acts like the brain of one of the lower animals; the brain, being seated within the anterior end of the body, receiving impressions from the sense-organs and directing the several movements."