CONTRIBUTIONS

TO THE

KNOWLEDGE OF SEEDLINGS

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I. Seedlings of certain woody plants

II Comparative anatomy of hypocotyl and epicotyl in woody plants

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VIII. SEEDLINGS OF CERTAIN WOODY PLANTS.

FRANCIS RAMALEY.

The following observations on seedlings of woody plants were made at the University of Minnesota, during the years 1896, 1897 and 1898. The plants were grown from seed either collected by the writer, or obtained from reliable dealers.

Most of the species studied have not hitherto been investigated. The author has, however, re-examined some plants described by former investigators, especially in cases where the printed descriptions were incomplete or without illustrations.

The measurements given are in all cases based on a considerable number of plants examined. It has been found that the exact lower limit of the hypocotyl is not always readily determined, although, generally it is enough larger in diameter than the root to be exactly located. It has seemed best in giving the length of the hypocotyl to measure its full extent rather than simply that part above the ground.

An attempt has been made to note, as far as possible, whether the seed coat is carried up or remains underground and also how much the cotyledons increase in size after appearing above the ground. These points have not generally been noted by students of seedlings.

In most cases the length of time required for germination of the seeds is given. The figures are for the first seedlings. Oftentimes plants will appear every few days for over a month after the first have come up. Unless otherwise stated it is to be understood that the seeds were planted in the following spring after ripening. The plants studied will be considered in the order of Engler and Prantl.

SALICACEÆ.

Populus deltoides MARSH.

The seed of the "cottonwood" ripens in June and should be planted at once. The young plants appear above ground in a week or sooner.

The cotyledons are petiolate, the blade being ovate-oblong, about 5 mm. in length and 4 mm. broad. The petiole is about 3 mm. long. There is but little increase in size as the plant grows older.

The first two leaves are opposite, lanceolate, short-petiolate, of willow-like shape. They are about 10 mm. long before the epicotyl has developed at all and do not afterward increase in size. The hypocotyl is 10–15 mm. long; the epicotyl reaches a length of 8 or 10 mm.

The third and fourth leaves are nearly opposite; later ones are alternate. The later leaves become broader and longer petioled, gradually assuming the deltoid form characteristic of the species.

ULMACEÆ.

Ulmus americana LINN.

The "white elm" is a native of the eastern and central United States. The seeds ripen in early spring and must be sown at once. They germinate in about a week. Often, but not always, the pericarp is carried up by the growing seedling.

The cotyledons are at first obovate, slightly auriculate, 5 mm. long and 2–3 mm. broad. They are indistinctly reticulately veined. They increase but slightly in size and seldom become more than 7 mm. long. They are short-petioled. The hypocotyl is slender, not enlarged at the base, 25–35 mm. long, but in time it may reach a length of 50 mm. The epicotyl is about 10 mm. in length.

The leaves are petiolate, ovate, coarsely serrate, with distinct veining. The first two are opposite, the third and fourth nearly so. Later leaves are alternate.

Ulmus fulva MICHX.

The "slippery elm," like the previously described species, ripens its seeds early in the spring. These, when planted at once, germinate in about two weeks. The seedling resembles that of *U. Americana* in all essential respects.

Celtis occidentalis LINN.

This is a fine tree native to the central United States and Canada. It is known as the "hackberry." The seeds germinate in from four to six weeks. The seed coat remains under ground.

The cotyledons are at first 10 mm. long, but by the time the first pair of foliage leaves appear they are 30 mm. in length, 17 mm. in width, ovate, entire, notched at the apex. The epicotyl is 10 mm. in length. The figures here given are substantially correct for all the plants examined by the present writer. Lubbock's * figures for seedlings of this species are about one-half those here given.

The epicotyl is at length 20 mm. long. The first two foliage leaves are opposite, the later ones alternate. Leaves of the first year are not at all conspicuously oblique at base as are those of older plants.

MORACEÆ.

Toxylon pomiferum RAF.

This is the well-known "osage orange" of the south-central United States. The seeds germinate in about one month after planting. The seed coat is often carried up by the cotyledons which are thus prevented from opening till they have increased somewhat in size.

When they first appear the cotyledons are 9 mm. long and 5 mm. broad, obovate-oblong, entire, short-petioled. The hypocotyl is stout, 35–50 mm. long.

The cotyledons grow rapidly in size and by the time the first leaves are well developed have increased to 20 mm. in length and 12 mm. in width. The petiole is distinctly margined and 4 mm. long. The veining of the blade is distinct. The epicotyl is 10–15 mm. long. The first two foliage leaves are opposite, narrowly lanceolate, ovate, entire or nearly so, distinctly veined. The later leaves are alternate, often pointed at the base as well as the apex. The seedling of this plant was studied by Lubbock,† but not figured.

Broussonetia papyrifera (LINN.) VENT.

The seeds of this oriental tree, the "paper mulberry," germinate in about three or four weeks after planting. The seed coat is carried up and often remains attached to one of the cotyledons for a time after they have opened.

The hypocotyl is rather slender, 12–15 mm. long. The

* On Seedlings, 2: 493. 1892.
† Op. cit. 2: 498.

cotyledons are oval; when fully open they have a petiole 2 mm. long and blade 8 mm. long and 5 mm. broad, very slightly notched at the apex. When they first emerge from the seed coat the leaves are not over 5 mm. in length.

The first foliage leaves are opposite; they are petiolate, narrowly ovate, serrate, slightly heart-shaped at base and more nearly entire than the later leaves which are alternate, long-petioled, serrate and frequently more or less two- or three-lobed or parted. Usually about the close of the second season the well-known peculiar characteristic leaves make their appearance.

MAGNOLIACEÆ.

Liriodendron tulipifera LINN.

The seeds of the "tulip tree" germinate in from four to six weeks after planting. The wing-like pericarp remains in the soil.

The cotyledons when they first appear are about 7 mm. long and 5 mm. broad, almost sessile, ovate-oblong in shape. Before the first leaf appears each cotyledon has developed a distinct petiole 2 or 3 mm. long, while the blade is about 12 mm. in length.

The foliage leaves are alternate. The first is broadly ovate-oblong, petiolate, emarginate, with entire margin. The second and third resemble the first. The characteristic leaves appear toward the close of the first season or not till the second year. The epicotyl is extremely short, 1–2 mm. long. Succeeding internodes are likewise short.

CALYCANTHACEÆ.

Butneria florida (LINN.) KEARNEY.

This is the familiar "sweet-scented shrub" commonly cultivated in the eastern United States. It is native from Virginia to the Gulf of Mexico. The seeds require a month or more to germinate. The cotyledons are rolled longitudinally about each other in the seed and remain rolled up for two or three days after appearing above ground.

The hypocotyl is stout, 20 mm. long. Cotyledons are thick, dark green, slightly auriculate at base, petiolate, generally somewhat trapezoidal, the apex broadly incurved. They are at

first about 12–15 mm. long and 25 mm. broad. Eventually they may become 20 mm. long and 30 mm. broad with petioles 10 mm. in length. In shape they are often quite asymmetrical.

The foliage leaves are opposite, ovate, pointed, entire. The first do not differ materially from the later ones. The epicotyl is about the same length as the hypocotyl.

Butneria fertilis (WALT.) KEARNEY.

The seedling of this plant does not differ in any important respect from that of the species just described.

CAESALPINACEÆ.

Parkinsonia aculeata LINN.

The seeds of this shrub germinate in about two weeks after planting. The seed coat is usually carried up.

When they first appear the cotyledons are 15 mm. long, 8 mm. broad, ovate-elliptical, sessile, very slightly auriculate at base. The hypocotyl is stout, 30–50 mm. in length. The cotyledons increase in size until they are 25 mm. long.

Foliage leaves are alternate; all are pinnate, the first has five pairs, the second six pairs of leaflets. The epicotyl is 9 mm. long when two leaves have appeared.

Cercis canadensis LINN.

This is the well-known "red bud" or "Judas tree" of the central United States. The seeds germinate in about two weeks. The seed coat is usually carried up, holding the cotyledons together until erect. The veins of the cotyledons are distinct even before the cotyledons have separated.

The cotyledons are broadly ovate, at first 6 mm. long and 4 mm. broad, eventually 15 mm. long and 8 mm. broad. The hypocotyl is stout, 10–30 mm. long. This is of interest since the hypocotyl of *C. siliquastrum* WILLD., as described by Lubbock,* is but 5–6 mm. in length.

The epicotyl is 20–30 mm. long. Foliage leaves are all alternate, entire, cordate, long-petioled.

Gleditsia triacanthos LINN.

The "honey locust," as this plant is called, is a familiar tree of the central United States. The seeds germinate in about one

* Op. cit. 1: 465.

month after sowing. The seed coat is sometimes carried above ground, but it as often remains in the soil.

The hypocotyl is stout, 25–30 mm. in length. The cotyledons are sessile, slightly auriculate, oblong, 18 mm. in length and 9 mm. broad. They do not increase greatly in size.

Leaves are alternate and pinnate. The second appears before the first is fully open. The first leaf usually has eight pairs of leaflets, the second has eleven pairs, the third thirteen pairs. When these leaves have developed the hypocotyl is about 50 mm. long, the epicotyl 20–25 mm.

The first leaves are described by Tubeuf * as having ten pairs of leaflets. In the plants examined by the present writer the first leaf had never more than nine pairs of leaflets.

PAPILIONACEÆ.

Amorpha fruticosa LINN.

This is an ornamental shrub indigenous to North America and frequently cultivated. The seeds germinate in about two weeks after planting.

When the cotyledons first appear they are ovate in shape, about 5 mm. long and 2.5 mm. broad. By the time they are fully open they measure 8 mm. in length. The hypocotyl at this time is 25 mm. long, quite slender, gradually thickened below.

The cotyledons attain a length of 12 mm. They are sessile. The epicotyl is 15 mm. in length. Foliage leaves are alternate. The first five or six are simple, broadly ovate, petiolate. After these the leaves are, for a space, pinnately trifoliate. The terminal leaflet is larger and longer stalked than the lateral ones. Later leaves are pinnate with numerous leaflets.

Amorpha nana NUTT.

The seedlings of this shrub resemble those of *A. fruticosa* save that they are much smaller. The hypocotyl does not become more than 8 or 10 mm. in length and the epicotyl is only about 5 mm. long. Cotyledons are 5 mm. long and 3 mm. broad.

Leaves are alternate. The first six to ten are simple. They are broadly orbicular, emarginate, petiolate, with a distinct midvein. As in the former species the later leaves are pinnately compound.

* Samen, Früchte und Keimlinge, 12°. 1891.

The writer is indebted to Mr. D. M. Andrews, of Boulder, Colo., for seedlings of this plant and of *Acer glabrum*.

Robinia pseudacacia Linn.

The "locust tree" is a native of the middle and southeastern United States. The seeds germinate in about two weeks after planting.

Seedlings of this plant were studied by Lubbock * and by Flot † but the fact is not stated by these writers that the cotyledons are at first somewhat narrowly elliptical or obovate and only at a rather late stage become "oblong-oval." The descriptions hitherto published have not been accompanied by satisfactory figures.

RUTACEÆ.

Ptelea trifoliata Linn.

This is the so-called "hop tree" of the central United States. The seeds germinate in from three to four weeks, the seed coat remaining underground. Almost as soon as the cotyledons get above ground they become erect and then separate.

The cotyledons are nearly sessile, elliptical-oblong, entire, 6 mm. long and 3 mm. broad. They grow for some time and become at length 18 mm. long, 7 mm. broad, minutely serrate, short-petiolate, with midvein distinct. The hypocotyl is rather stout, 15–20 mm. long.

The epicotyl is 20–40 mm. long when the first leaf is fully open. It often elongates somewhat after that time. Leaves are alternate. The first foliage leaf is usually simple, ovate, petiolate, with crenulate margin. Sometimes it is trifoliate, sometimes but partially compound; perhaps one of the side leaflets is separate, but not the other. The second leaf is usually trifoliate, sometimes incompletely so. Later leaves are all trifoliate, the terminal leaflet larger than the lateral ones.

A description of this seedling is given by Lubbock ‡ but there is no figure.

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* Op. cit., 1: 422.

† Flot. Recherches sur la structure comparée de la tige des arbres.—Rev. gen. de Bot. 2: 20. 1890.

‡ Op. cit. 1: 322.

SIMARUBACEÆ.

Ailanthus glandulosa DESF.

This well-known tree is a native of eastern Asia. It is, however, grown extensively in this country. The writer's observations on the seedlings differ somewhat from those previously published.*

The seeds, planted in May, germinated in from two to three weeks. The seed coat and wing sometimes remain in the ground but are quite often carried up by the elongation of the hypocotyl before the cotyledons emerge.

The cotyledons are at first about 6 mm. long. By the time they are fully open they have increased somewhat in size and the hypocotyl has attained its full length, viz. about 40 mm. When the first leaves have opened the cotyledons are broadly obovate, petiolate, with the blade 15 mm. long, 11 mm. broad and the petiole 5 mm. long.

The epicotyl is at length 20 mm. long. The first few leaves are trifoliate. Later leaves are pinnate.

ANACARDIACEÆ.

Schinus molle LINN.

This is the so-called "pepper-tree" sometimes planted in California but a native of tropical America. A description of the germination of the seed is given by Lubbock,† whose account in this case, the present writer only desires to supplement.

The cotyledons are remarkable for their great increase in size; beginning with a length of 5 mm. the blade is finally 20–25 mm. long and broad in proportion. The petiole is about 4 mm. in length.

CELASTRACEÆ.

Celastrus scandens LINN.

This is the "climbing bitter-sweet," a common native liana of the United States. It is frequently cultivated. The seeds ripen in the fall. If planted the following spring they usually require a year to germinate.

The cotyledons are thin, reticulately veined, petiolate, oval-oblong in shape. At first they are 10 mm. long and 5 mm.

* Lubbock op. cit. 1: 327.

† Op. cit. 2: 335.

broad, but grow rapidly and become about twice that size. As they grow older they become broader in proportion to the length. The petiole is finally about 5 mm. long. The hypocotyl tapers gradually to the root so that its exact limit is not easily recognized. It reaches a length of 40 or 50 mm.

The epicotyl is about 15 mm. long. Leaves are all alternate. The first leaves are not different from those formed later.

ACERACEÆ.

Acer negundo LINN.

Seeds of the "box-elder" germinate in from one to two weeks after sowing. The large winged pericarp is brought above ground.

The hypocotyl is 25–35 mm. long when the cotyledons first open and does not grow longer. The cotyledons are strap-shaped, sessile, entire, tri-veined; about 30 mm. long and 5 mm. broad.

The epicotyl becomes 5–8 mm. long. Leaves are opposite. The first two are ovate, acute, serrate, petiolate. Later ones are tri-cleft. Usually the sixth or seventh pair and all later ones are pinnately compound.

Acer glabrum TORR.

The seedling of the "Rocky mountain maple" resembles that of *A. negundo*. The hypocotyl is shorter, 20 mm. long, and the cotyledons about 20 mm. long, 5 mm. broad. Leaves are opposite, long-petioled, ovate-cordate, the second pair somewhat lobed. Later leaves are three- or five-lobed, the lobes more or less acute and sharply serrate.

Acer saccharinum LINN.

The seeds of the "soft maple" germinate in about ten days after planting. The first leaves are well developed when the plant appears above ground. The cotyledons remain in the soil for a time enclosed in the pericarp which eventually decays. Sometimes they do not appear above ground * at all.

The hypocotyl is stout, about 20 mm. long. The cotyledons are somewhat fleshy, asymmetrical, short-petioled, bent around

*Winkler. Kleinere morph. Mittheilungen, in Verhandl. d. Bot. Ver. d. Provinz Brandenburg, 18: 99. 1877.

so that both are on the same side of the stem. They are about 16 mm. long and 8 mm. broad.

The epicotyl often becomes greatly elongated, reaching a length of 50–100 mm. Leaves are all opposite, those of the seedling are the same shape as the later leaves.

RHAMNACEÆ.

Berchemia racemosa SIEB. & ZUCC.

This plant is a shrub with conspicuously veined leaves. It is a native of Asia. The seeds require two or three weeks to germinate. It is often a number of days before the cotyledons get out of the seed coat which is carried above ground.

When the cotyledons first emerge they are sessile, strap-shaped, 8 mm. long and 1½ mm. broad. They remain about the same size for a time after they are fully open. The hypocotyl is slender, about 15 mm. long.

By the time the first foliage leaves are open the hypocotyl is 15–20 mm. long; the epicotyl 5 mm. in length and the cotyledons 10 or 12 mm. long and 1.5–2 mm. broad. The foliage leaves are ovate, petiolate, conspicuously veined; the first two are opposite or nearly so, all others are alternate.

Rhamnus purshiana DC.

This is a handsome tree of Pacific North America sometimes planted in the eastern United States. The bark is the "Cascara Sagrada" of the drug stores. The seeds require a month or more to germinate.

The cotyledons increase but slightly in size after opening. They are obovate, entire, sessile or nearly so, 7 mm. long and 5 mm. broad. The hypocotyl is 25–30 mm. long.

The epicotyl is slender, 15–20 mm. long. Foliage leaves are ovate, pointed, petiolate, alternate. The first two and the third and fourth are, however, nearly opposite. The margin of the leaf is finely serrate; the veining very prominent.

VITACEÆ.

Vitis cordifolia MICHX.

This is one of the commonest wild grapes found in the northern United States. The seeds germinate readily, the cotyle-

dons appearing above ground in about four weeks. Sometimes the seeds do not germinate till the second year.

The cotyledons are ovate, petiolate, veined. When they first appear the blades are about 10 mm. long and 6 mm. broad. They grow to about 18 mm. in length, and a corresponding width before the first leaves appear, after which time they do not increase in size. The petiole is about 8 mm. long. The hypocotyl is stout, from 25–30 mm. long; it does not grow longer.

The leaves are all alternate, ovate-heart-shaped, irregularly dentate, palmately 5-veined. When the first leaf appears the epicotyl is about 8 mm. long. It may eventually reach a length of 10 or 12 mm.

Parthenocissus quinquefolia (Linn.) Planch.

This is the familiar "Virginia creeper," a native of the United States and frequently planted. Seeds germinate in about three weeks.

The hypocotyl is stout, from 20–40 mm. long. The cotyledons are long-petiolate. The blade is cordate, prominently veined, at length 20 mm. long, 20 mm. broad. The petiole is channeled, 20 mm. long. Both hypocotyl and petioles are pink except that part of the hypocotyl which is below ground. The hypocotyl becomes very much thickened toward the end of the season, exhibiting a well-marked "region tigellaire."

The epicotyl is undeveloped, the first leaf arising just above the cotyledons. Leaves are all alternate and quinquefoliate from the beginning. The first do not differ from the later ones.

STERCULIACEÆ.

Sterculia platanifolia Linn.

The seeds of this oriental tree germinate in about a month after planting. A part of the seed coat is often attached to the cotyledons when they first appear above the ground.

The hypocotyl is stout, 40 mm. long at the time the cotyledons open. These are broadly oblong or orbicular, entire, slightly cordate at base, with petioles nearly as long as the blades. The latter are at first about 18 mm. long and 16 mm. broad but become very large, sometimes 40 mm. long and 45 mm. broad. They are palmately five-veined. The midvein forks some distance from the apex.

The epicotyl is about 10 mm. long. Leaves are alternate. The first leaf is broadly heart-shaped, entire, petiolate, palmately five-veined; the midvein runs to the apex of the leaf.

ELÆAGNACEÆ.

Elæagnus umbellata THUNB.

The seeds of this Japanese shrub require about four weeks to germinate. The seed coat is often carried up above ground.

The cotyledons are oblong-ovate, sharply auriculate, short-petiolate. The blades are quite thick. When they first emerge from the seed coat they are 7–8 mm. long but are finally 10 mm. long and 6 mm. broad. The hypocotyl is rather stout, 10–30 mm. long.

The foliage leaves are ovate, entire, petiolate. The first two are opposite or nearly so, later ones are alternate. The epicotyl is short, not usually more than 2 or 3 mm. in length when the first leaves are well developed. It eventually may grow to a length of 4–8 mm.

The seedlings of this plant resemble very much those of *E. angustifolia microcarpa** save that in the latter the petioles of the cotyledons are much longer.

MYRTACEÆ.

Eucalyptus globulus LABILL.

This is the well-known "blue gum" tree of Australia. It is planted extensively in California. The seeds germinate in from one to two weeks. The seed coat is often carried up by the cotyledons. These are doubled over each other. One lobe of each is exposed.

The hypocotyl is slender, about 30 mm. long. The cotyledons, when fully opened, are short-petiolate, 3 mm. long and generally twice as broad, two-lobed, the sinus shallow. When first out of the seed coat the cotyledons are about one-half the size here named. No distinct venation was observed, although Lubbock† states that they are tri-nerved.

The epicotyl is about 10 mm. long. The foliage leaves are opposite, lanceolate and entire, those higher on the stem be-

*Lubbock, op. cit. 2: 465.

†Op. cit. 1: 530.

coming gradually broader. Higher internodes of the stem are quadrangular.

Eucalyptus citriodora Hook.

The mode of germination and the seedling of the "lemon-scented gum" resemble the species just described. There are some important points, however, to be noted.

The hypocotyl is 20 mm. long and quite slender. The cotyledons are petiolate. The blade is broadly orbicular, entire, indistinctly 3-veined; at length 6–9 mm. broad, 4–7 mm. long, green above, red to purple below. The petiole is 3–4 mm. in length. The cotyledons are persistent for a considerable time; often remaining till ten or more nodes of the stem are developed.

Eucalyptus corymbosa Sm.

This plant, also a native of Australia, is called "blood-wood." Seeds germinate in two or three weeks. The hypocotyl is 20 mm. long and quite slender. The cotyledons are short-petiolate. The blade is reniform, deeply cordate at base, at first 2–3 mm. long and 5–6 mm. broad. It finally grows about twice this size and is indistinctly 3-veined.

CORNACEÆ.

Cornus amomum Mill.

The seeds of the common "dogwood" germinate in two or three weeks after planting, but sometimes not till the following year.

The hypocotyl is rather slender and quite long, usually 50 mm. or more in length. The epicotyl also is greatly elongated, reaching a length of 40 mm. The cotyledons are oblong-elliptical, entire, short-petiolate. At first they are 10 mm. long and 5 mm. broad. The blades become 20 mm. long and 10 mm. broad, the petioles 4 mm. long.

Leaves are all opposite, ovate, acute, petiolate. The first are like the later ones.

Cornus stolonifera Michx.

Seedlings of this plant resemble those of the previous species in all essential respects.

Cornus florida LINN.

Seedlings of the "flowering dogwood" resemble those of *C. amomum*.

STYRACACEÆ.

Mohrodendron carolinum (LINN.) BRITT.

Seeds of this plant, the "snow-drop tree," planted in the spring of the year following their ripening lie dormant an entire year before germinating.

The cotyledons are thin, oval-oblong in outline, rather short-petiolate. The blades are at first 20 mm. long and 8 mm. broad. They do not increase much in size. The hypocotyl is stout, from 25–35 mm. long.

The epicotyl is about 20 mm. long. The leaves are all alternate, ovate-acute, serrate, petiolate. Save in size there is no difference between the first and the later leaves.

BIGNONIACEÆ.

Tecoma radicans (LINN.) DC.

This is a woody climber, the "trumpet creeper," indigenous to eastern North America and frequently cultivated. The seeds germinate in about ten days. The large flat wing of the seed is sometimes, though not usually, carried up.

The cotyledons are broadly orbicular and deeply notched at the apex. They are almost sessile. When first above ground they are 5 mm. wide, but when fully open are 9 mm. wide. They do not increase in size after that time. The hypocotyl is 20–30 mm. long, green or pale, sometimes pinkish.

The epicotyl is at first quite short, but lengthens, when the foliage leaves open, to about 15 mm. The first leaves are simple, ovate, dentate, petiolate, distinctly veined. The next leaves are tri-foliate. Leaves at length are pinnately compound.

Catalpa speciosa WARDER.

This large tree is a native of the southern United States. Seeds germinate in from one to two weeks. The flat winged seedcoat is sometimes carried up, but more usually remains in the soil.

The cotyledons are face to face. They are dark green,

deeply bifid, the lobes more or less obovate, 5–6 mm. long and 3–4 mm. broad. They increase rapidly to nearly twice their original size. The hypocotyl is stout, 30 mm. long.

The epicotyl is 8–12 mm. long. Foliage leaves are opposite, entire, pointed, ovate to cordate, petiolate with distinct veining.

Seedlings of this plant have been previously* described, but without measurements or illustrations.

RUBIACEÆ.

Cephalanthus occidentalis LINN.

The "button bush" is a low shrub indigenous throughout most of North America. The seed germinates in about three weeks. The seed coat remains in the ground.

The cotyledons are ovate, acute, short-petiolate, 3 mm. long and 1 mm. broad when they first appear; at length they become about twice or three times that size. The hypocotyl is slender, 15–30 mm. in length.

When the first foliage leaves are open the epicotyl is from 4–8 mm. long. Leaves are opposite, ovate, acute, entire, long-petioled, distinctly veined.

CAPRIFOLIACEÆ.

Sambucus pubens MICHX.

This is the "red-berried elder" of the northern United States. The seeds ripen in June. If sown at once they germinate in about one month. Some of the seeds, however, do not come up until the following spring.

The hypocotyl, which passes gradually into the root, is about 10 or 15 mm. long. The cotyledons are petiolate. When they first appear they are 3 mm. long and 2 mm. broad. The cotyledons become longer petioled and the blades more ovate as they grow older. By the time two pairs of foliage leaves have appeared they are 10–15 mm. in length with petiole 8 mm. long.

The epicotyl is very short as are also the succeeding internodes. Leaves are opposite; the first two pairs cordate, serrate, with petioles as long as the blades. The next leaves are generally trifoliate; later ones are pinnately multifoliate.

*Lubbock, op. cit. 2:335.

General Observations on the Facts Recorded in the Preceding Pages.

Without any attempt at ecological explanations of the phenomena of the growth and development of seedlings such as given by Goebel* a few generalizations may be made from the plants at present examined. Some of the features to which attention is called have been previously discussed by Klebs† and Lubbock‡ so that what follows will not be so much a consideration of such points but rather a classification of the plants studied with regard to their special peculiarities.

A knowledge of the shape and general structure of the cotyledons does not help one to predict the character of the foliage leaves. Sometimes there is a certain resemblance between cotyledons and the first foliage leaves or even the later ones. The resemblance is, however, chiefly in cases where the cotyledons are ovate or oblong. This is a very common form for foliage leaves as well. Thus in *Toxylon pomiferum* and *Cephalanthus occidentalis* the cotyledons and foliage leaves are much alike. That the two kinds of leaves are of the same general shape, may be a mere coincidence and of no great significance.

Where the general shape of cotyledons and first foliage leaves is much the same, the former may have entire margins and the latter be variously toothed or lobed, *e. g.*, *Vitis cordifolia*, *Ptelea trifoliata*. While, as has been said, there is no absolute agreement in the shape of cotyledons in a given genus or family, nevertheless, there are, as is well known, many families in which certain types of cotyledons prevail. The first foliage leaves, however, are more frequently alike, *e. g.*, *Acer* spp.

In cases where leaves of old plants are pinnately compound the first few foliage leaves are often simple, *e. g.*, *Acer negundo*, *Amorpha* spp., *Ptelea trifoliata*, *Schinus molle*, *Robinia pseudacacia*, *Sambucus* spp. In all these cases the transition to the compound form is gradual. Thus in *Ptelea trifoliata* the first leaf is simple, the second leaf usually has but one lateral leaflet. In *Robinia pseudacacia* the second leaf is trifoliate while later leaves are more and more multifoliate.

Occasionally even the first foliage leaf is compound, as in

* Organographie der Pflanzen, 1898.

† Beiträge zur Morph. und Biol. der Keimung. Pfeffer's Untersuchungen aus dem Botan. Inst. zu Tübingen 1: 536. 1885.

‡ Op. cit.

Parthenocissus quinquefolia. In *Ailanthus glandulosa*, however, the first few leaves are merely trifoliate while later ones are pinnate. *Parkinsonia* and *Gleditsia* produce pinnate foliage leaves at once, although the earlier leaves have fewer leaflets than those that come afterward.

If the later-formed leaves are not compound but merely lobed or cleft there may be traced a more or less gradual transition to that shape from the entire or more nearly entire first leaves, *e. g.*, *Broussonetia papyrifera*, *Liriodendron tulipifera*.

In nearly all cases where the first two leaves are opposite and the later ones alternate, it is to be noted that the third and fourth are nearly opposite, the fifth and sixth are closer together on the stem than the fourth and fifth or than the sixth and seventh; *e. g.*, *Rhamnus purshiana*, *Eucalyptus* spp., *Ulmus* spp. In other words, the transition from the opposite to the alternate arrangement is usually gradual.

The cotyledons of many species increase considerably in size after they escape from the seed coat; this is particularly noticeable in *Schinus molle*, *Cercis canadensis*, and some others. In other species there is very little increase in the size of the cotyledons after they first appear, *e. g.*, *Rhamnus purshiana*, *Ailanthus glandulosa*.

Cotyledons of rather remarkable shape were noted in the following species: *Celtis occidentalis*, *Catalpa speciosa*, *Eucalyptus globulus*, *Tecoma radicans*, *Acer negundo*, *Berchemia racemosa*, *Butneria florida* and *fertilis*. The first four named have the cotyledons bifid or variously notched or retuse.

Catalpa and *Tecoma*, both Bignoniaceous plants, have very similar cotyledons. The peculiar asymmetrical cotyledons of *Butneria florida* are reproduced exactly in *B. fertilis*. *Eucalyptus globulus*, on the other hand, does not agree at all, in the shape of its cotyledons, with *E. citriodora* and *E. corymbosa*. These have rotund-orbicular cotyledons. The long, narrow cotyledons of *Acer negundo* are quite different from those of *A. saccharinum*. *Berchemia racemosa* has ligulate cotyledons, while in *Rhamnus purshiana*, the only other plant of the same family investigated, the cotyledons are obovate. The large notched cotyledons of *Celtis occidentalis* do not resemble those of the other Ulmaceæ examined. This, is, however, to be expected from the great difference in the character of the fruit in *Celtis* and *Ulmus*.

From the foregoing it may be concluded that broad generalizations in regard to the shape of cotyledons in plant families, cannot be safely made without a considerable mass of data.

Explanation of Plates.

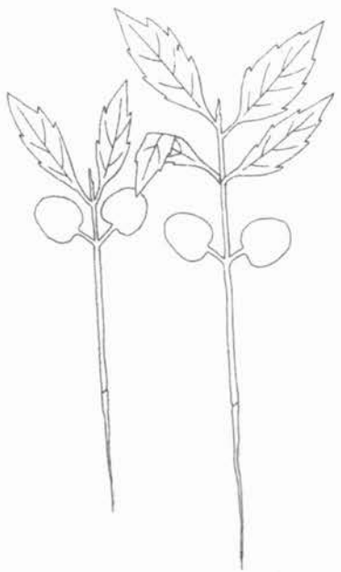
Plate I. Seedlings in various stages of the following plants: *Populus deltoides*, *Ulmus americana*, *Celtis occidentalis*, *Toxylon pomiferum*, *Broussonetia papyrifera*, *Liriodendron tulipifera*, *Butneria florida*, *Parkinsonia aculeata*.

Plate II. Seedlings in various stages of the following plants: *Cercis canadensis*, *Amorpha fruticosa*, *Amorpha nana*, *Robinia pseudacacia*, *Ptelea trifoliata*, *Ailanthus glandulosa*, *Schinus molle*, *Celastrus scandens*.

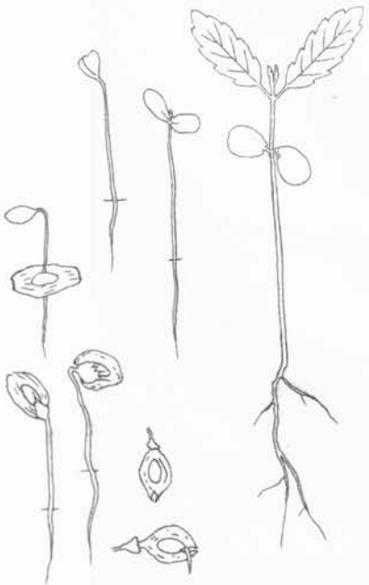
Plate III. Seedlings in various stages of the following plants: *Acer negundo*, *Acer saccharinum*, *Acer glabrum*, *Berchemia racemosa*, *Rhamnus purshiana*, *Vitis cordifolia*, *Parthenocissus quinquefolia*, *Sterculia plantanifolia*.

Plate IV. Seedlings in various stages of the following plants: *Elæagnus umbellata*, *Eucalyptus globulus*, *Eucalyptus citriodora*, *Cornus amomum*, *Mohrodendron carolinum*, *Catalpa speciosa*, *Tecoma radicans*, *Cephalanthus occidentalis*, *Sambucus pubens*.

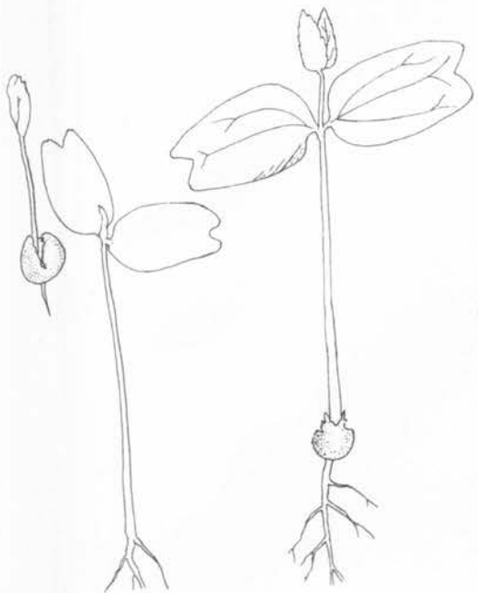
The amount of enlargement or reduction is indicated for each plant.



Populus deltoides x 1½



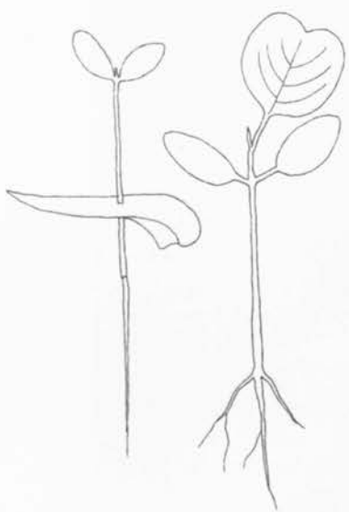
Ulmus americana x ¾



Celtis occidentalis x ¾

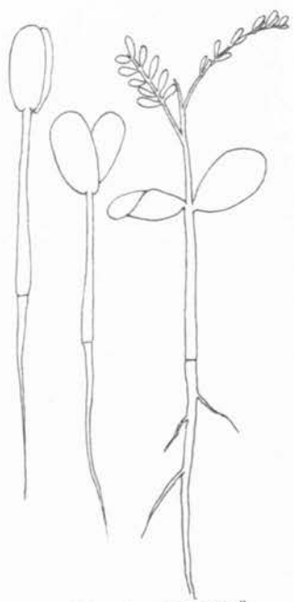
Toxylon pomiferum x ¾

Broussonetia papyrifera x 1½



Liriodendron tulipifera (natural size)

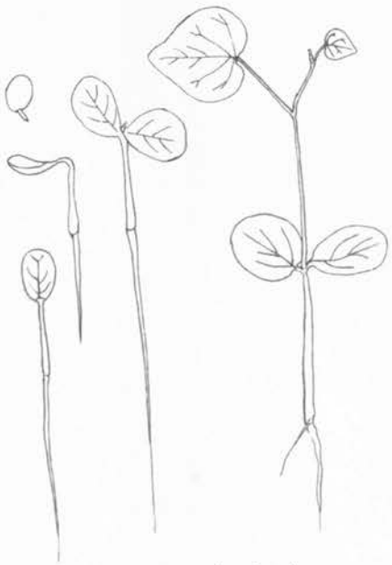
Butneria florida x ¾



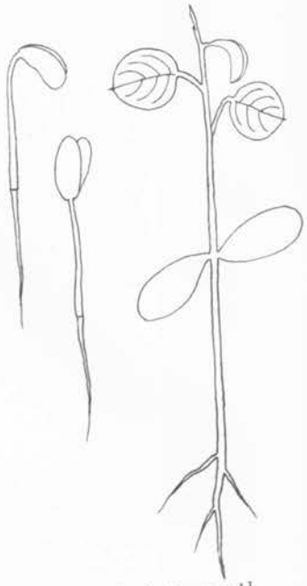
Parkinsonia aculeata x ¾

PLATE I.

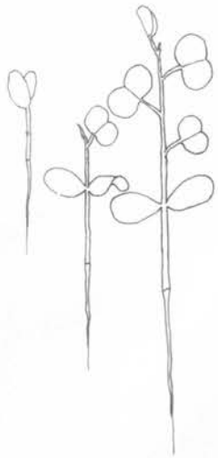
HELIOTYPE PRINTING CO., BOSTON.



Cercis canadensis x $\frac{3}{4}$



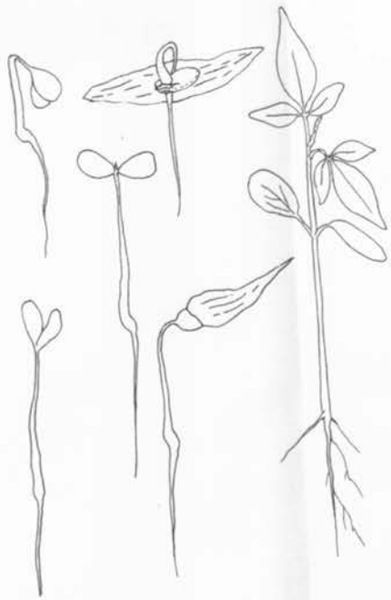
Amorpha fruticosa x $1\frac{1}{2}$



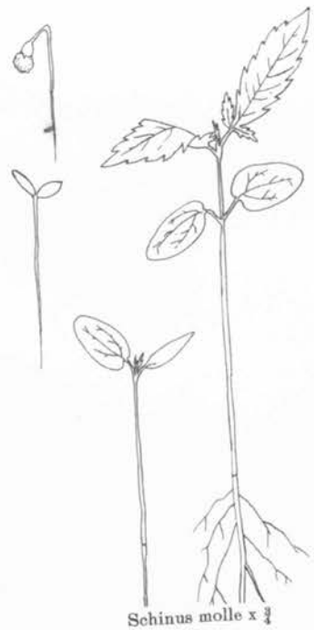
Amorpha nana x $1\frac{1}{2}$

Robinia pseudacacia x $\frac{3}{4}$

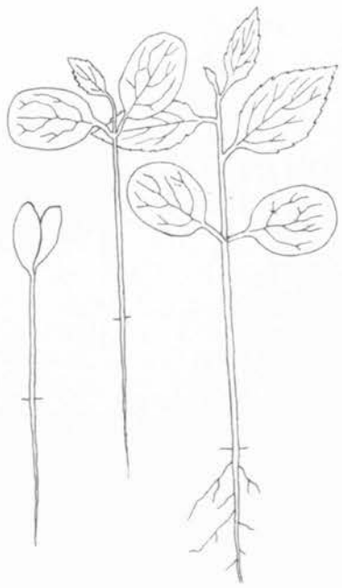
Ptelea trifoliata x $\frac{3}{4}$



Ailanthus glandulosa x $\frac{3}{4}$



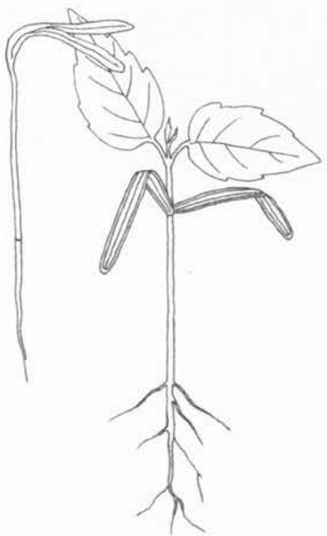
Schinus molle x $\frac{3}{4}$



Celastrus scandens x $\frac{3}{4}$

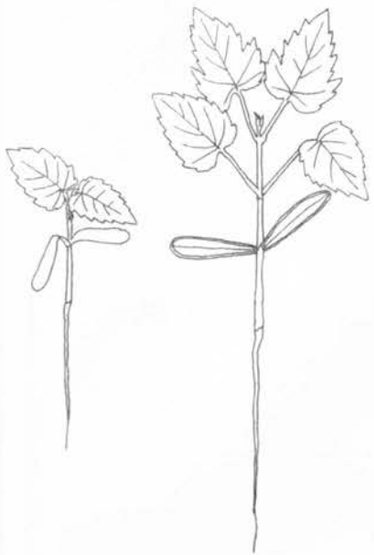
PLATE II.

MILLOTYPE PRINTING CO. BOSTON

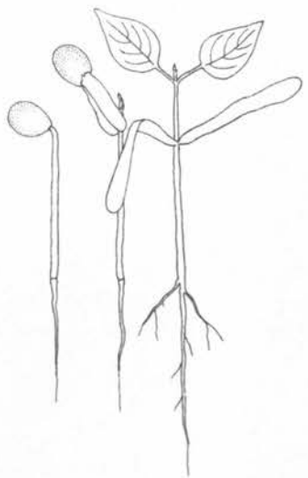


Acer negundo x $\frac{3}{4}$

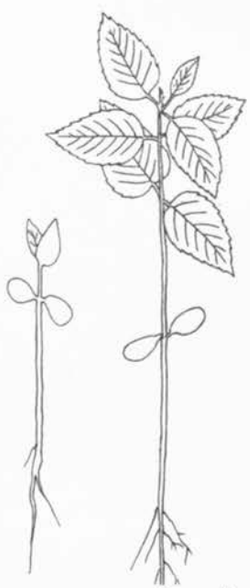
Acer saccharinum x $\frac{3}{4}$



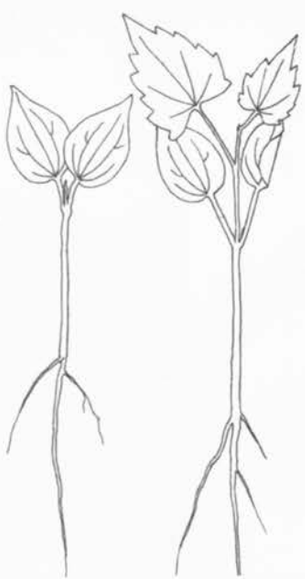
Acer glabrum x $\frac{3}{4}$



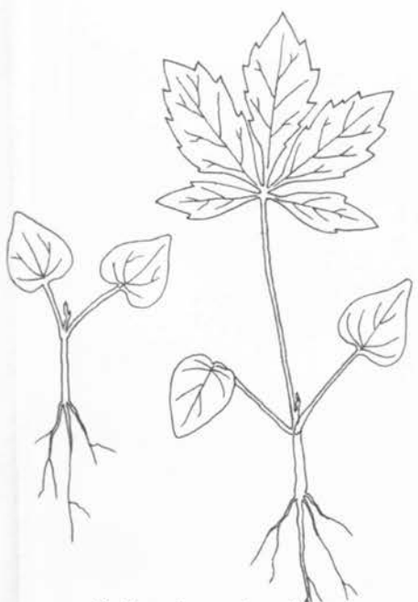
Berchemia racemosa x $1\frac{1}{2}$



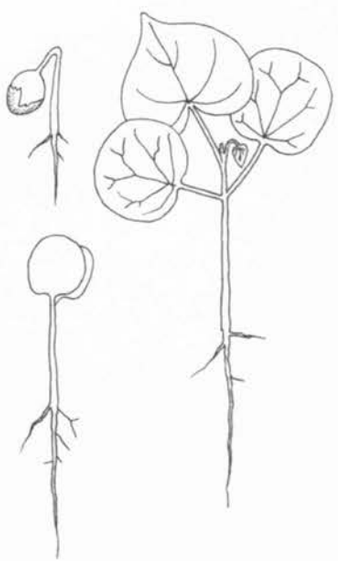
Rhamnus purshiana x $\frac{3}{4}$



Vitis cordifolia x $\frac{3}{4}$



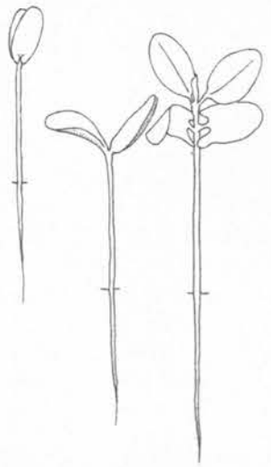
Parthenocissus quinquefolia x $\frac{1}{3}$



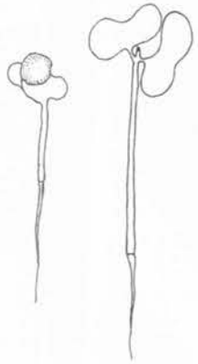
Sterculia platanifolia x $\frac{1}{3}$

PLATE III.

HELIOTYPE PRINTING CO., BOSTON



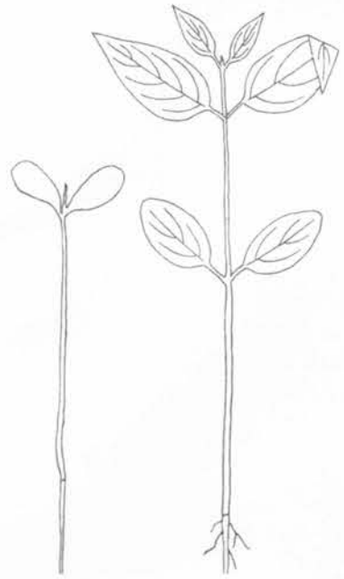
Elaeagnus umbellata x 1½



Eucalyptus globulus
(natural size)

Eucalyptus corymbosa
(natural size)

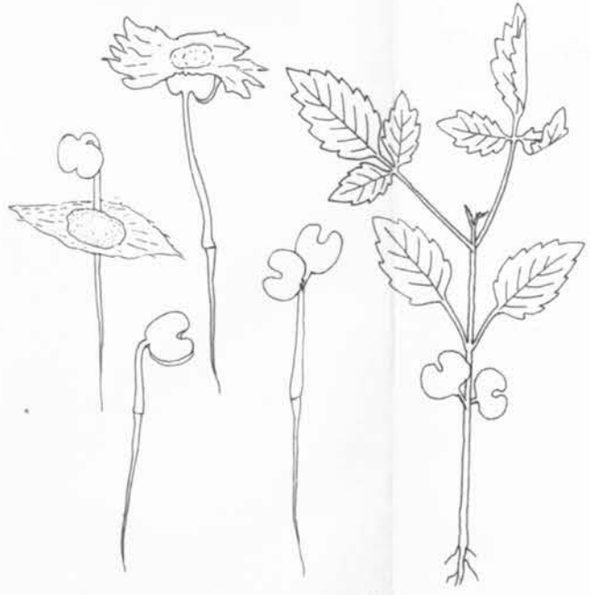
Eucalyptus citriodora
(natural size)



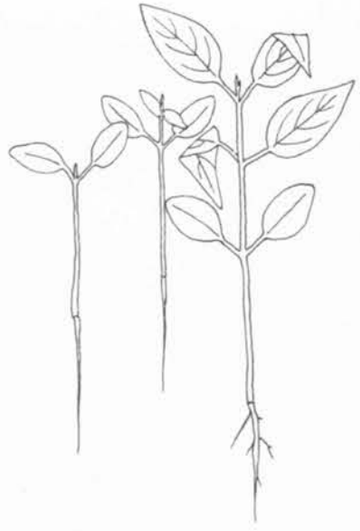
Cornus amomum x ¾

Mohrodendron carolinum x ¾

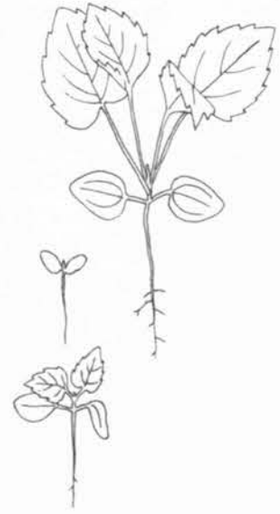
Catalpa speciosa x ¾



Tecoma radicans x ¾



Cephalanthus occidentalis x 1½



Sambucus pubens x ¾

PLATE IV.

MILLIOTYPE PRINTING CO., BOSTON

IX. COMPARATIVE ANATOMY OF HYPOCOTYL AND EPICOTYL IN WOODY PLANTS.

FRANCIS RAMALEY.

The following is an account of the anatomy of seedlings of certain woody dicotyledonous plants. These plants were studied: *Ulmus americana* LINN., *Celtis occidentalis* LINN., *Toxylon pomiferum* RAF., *Broussonetia papyrifera* (LINN.) VENT., *Liriodendron tulipifera* LINN., *Menispermum canadense* LINN., *Butneria florida* (LINN.)KEARNEY, *Parkinsonia aculeata* LINN., *Cercis canadensis* LINN., *Gleditsia triacanthos* LINN., *Amorpha fruticosa* LINN., *Robinia pseudacacia* LINN., *Ptelea trifoliata* LINN., *Ailanthus glandulosa* DESF., *Schinus molle* LINN., *Berchemia racemosa* SIEB. & ZUCC., *Rhamnus purshiana* DC., *Vitis cordifolia* MICHX., *Elaeagnus umbellata* THUNB., *Eucalyptus globulus* LABILL., *Tecoma radicans* (LINN.) DC., *Catalpa speciosa* WARDER, *Cephalanthus occidentalis* LINN. The order in which they are described is that of Engler and Prantl. This order will be followed throughout.

The author is under obligation to Professor Conway MacMillan, who suggested the subject of the investigation and under whose direction the work has been completed.

The seedlings were grown at the University of Minnesota during the years 1896, 1897 and 1898. They were examined at different ages so that the original structure of both hypocotyl and epicotyl could be noted as well as the differences brought about through secondary changes.

For the sake of convenience and uniformity three stages were studied; these may be designated as first, second and third stages. A seedling with the cotyledons expanded but with the epicotyl undeveloped is said to be in the first stage. Obviously only the structure of the hypocotyl was studied in this stage. In the second stage the epicotyl has elongated and the first foliage leaves have appeared. In the third stage a considerable number of foliage leaves have been developed and the anatomical structure has, to a considerable extent, taken on its perma-

nent characters. Sections were also, in many cases, cut from material two years old for purposes of comparison.

Since the structure of the hypocotyl is often materially different in all the three mentioned stages, it has seemed important to make a record of the changes which take place during the first year's growth. Previous investigators have not done this.

A number of investigators who have made a comparative study of root and shoot have incidentally examined the hypocotyl, *e. g.*, Goldsmith [1876] and Gérard [1880 and 1881]. The latter made some careful observations on the course of vascular bundles from the cotyledons to the root. His statement that the characteristic root structure often extends as high as the cotyledons is not, in general, confirmed by the present investigation.

The most important articles* which need to be mentioned at the present time are by Dangeard [1888 and 1889], Van Tieghem [1891], and Flot [1889 and 1890]. Dangeard begins with a study of the structure of roots, of which he distinguishes three types. In the first type the root is diarch; the hypocotyl has four bundles in two pairs which arise as cotyledonary trace bundles by the division of the midrib of each cotyledon. In the second type the root is tetrarch; the hypocotyl has eight bundles in four groups. In the third type the root is octarch, while the hypocotyl has sixteen bundles in eight groups. The first type of structure of the hypocotyl above mentioned is the one commonly found in the plants studied by the present writer who has called it the "typical structure." (See General Conclusions at the close of this paper.)

Flot [1889, 1890] describes the "region tigellaire," a much thickened portion of the axis of certain year-old seedlings. The region extends from the base of the hypocotyl up to the first foliage leaf or to some point between that and the cotyledons. It is noted only in certain species. It is not the same as the "tigelle," which extends only as high as the cotyledons. The "region tigellaire" is characterized by only a slight development of sclerenchyma and of normal phloem, while internal phloem is probably altogether absent. The pericycle, he says, is well developed.

Van Tieghem [1891] divides the hypocotyl into "tigelle" and "rhizelle." The growth of the hypocotyl is produced by the elongation of either the tigelle, as in *Ricinus*, *Acer*, *Cucur-*

* Search has been made, but without success, for a paper by Monal: Rech. sur l'anat. compar. de la tige hypocot. et epicot.

bita, *Tagetes*, *Convolvulus* and *Mirabilis*, or, the rhizelle, as in Ranunculaceæ, Cruciferæ, Caryophyllaceæ, Chenopodiaceæ, Umbelliferæ, Rubiaceæ and Coniferæ, or by a combination of the growth of both as in *Euonymus*.

The designation of certain regions as tigelle, rhizelle and tigellaire does not seem to the present writer a matter of great importance in the plants which he has studied, for in them these regions are by no means sharply differentiated. Further observations and references to the work of Flot mentioned above are given in the pages which follow.

In the special portion of the present work will be found descriptions of the structure of hypocotyl and epicotyl in the various species examined. Accompanying each description is a diagram of the cross section of the hypocotyl when the seedling is in the first stage previously described, and diagrams of both hypocotyl and epicotyl of the second and third stages. In these diagrams stereom is black, xylem is dotted, cortex, phloem, pericycle and the pith are white. The endodermis, when distinct, is indicated by a single line as is also the epidermis and the boundaries between the various zones. In each figure the diagrams of the hypocotyl are at the left, those of the epicotyl at the right.

ULMACEÆ.

Ulmus americana.

Structure of Hypocotyl.

The epidermis is composed of cells which, in cross section, are square or rounded. After secondary growth of the stele has commenced these cells become very much flattened. There is no hypoderma differentiated. The cells of the cortex are large; all are about the same size.

The endodermis is small-celled and is easily recognized in early stages, when it contains very little starch. Afterward starch becomes abundant in the endodermis, pericycle, cortex, phloem and inner xylem.

In the stele there are many small phloem bundles which are confluent into two crescent-shaped areas. There are two xylem bundles of somewhat crescentic appearance in cross section. The xylem and phloem soon form closed rings.

The pericycle, in seedlings which have about two internodes

of the stem developed, is partially sclerenchymatous. At a later time numerous groups of sclerenchyma are found in the phloem and cortex.

The pith becomes quite small. There is a small-celled perimedullary zone.

The formation of cork cambium, as noted by Flot ([1890], p. 29), takes place in the inner cortex.

Structure of Epicotyl.

The cells of the epidermis when seen in cross section, are somewhat rectangular in outline. The tangential diameter is the longer. Numerous hairs are present. No collenchymatous hypoderma is produced. The cortex is rather narrow. The cells are all about the same size.

The endodermis is distinct only in young material. The cells are small. They contain starch. At the end of the season starch is found in the pith and inner xylem and is sparingly distributed in the cortex and phloem.

In the youngest material examined the phloem forms a closed ring surrounding a number of xylem groups. There are usually eight of these. They soon fuse to form a complete ring.

Numerous small groups of thick-walled cells finally make their appearance in cortex, pericycle and phloem.

The pith becomes quite small. The cells have thin unlignified walls. The perimedullary zone is easily distinguished; it consists of from one to three layers of small cells which are often somewhat flattened.

Cork formation, as is well known in this species, begins in the outermost cell layer of the cortex.

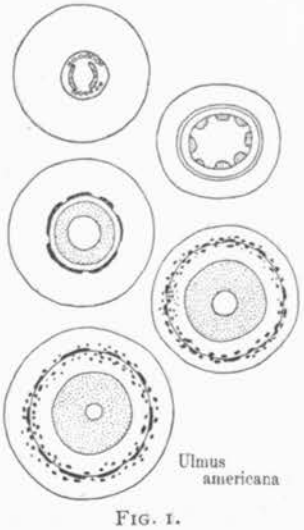


FIG. 1.

Comparison of Structure of Hypocotyl and Epicotyl.

The epidermal cells of the hypocotyl in young material appear radially elongated, those of the epicotyl tangentially elongated. The former region has a thicker cortex, fewer epidermal hairs, sclerenchyma developed earlier in the pericycle.

The stele of the hypocotyl has two xylem bundles and two aggregations of phloem bundles. In the epicotyl the youngest material examined has a complete ring of phloem and about eight xylem bundles. Cork formation in the former region takes place deep in the cortex instead of in the outermost cortical layer.

In their final structure the two regions are practically alike.

Celtis occidentalis.

Structure of Hypocotyl.

The epidermis is composed of thin-walled cells, small, square in cross section. There is no hypoderma. The elements of the cortex are large. There are about twenty layers of cells.

The cells of the endodermis are much smaller than those of the cortex and on this account the endodermis is readily distinguished until considerable secondary growth of vascular tissue has taken place.

Starch is found in the endodermal region from the first; toward the close of the season it is found not only in the pith, phloem and cortex, but very abundantly distributed throughout the xylem. Large isodiametric crystals, long known in the stem of this species (Moeller [1882], p. 74), make their appearance in the cortex some time before the close of the first season.

The stele, which is cylindrical from the first, has originally four xylem bundles and two crescentic masses of phloem. At an early stage the xylem forms a closed ring, while it is not till sometime afterward that the two areas of the phloem become united.

Two interrupted rings of sclerenchyma appear later in the first season, one of these is in the cortex and consists of much larger groups of cells than does the other which is in the outer phloem.

The pith is large-celled. A more or less definite perimedullary zone of small cells is at length developed.

Cork formation begins at a late period in the outermost cell layer of the cortex.

Structure of Epicotyl.

The cells of the epidermis are at first nearly square in cross section but at a later time are considerably flattened. There

are numerous simple curved and pointed hairs; there are also some with bulbous ends.

The cortex is thin. A distinct collenchymatous hypoderma is developed. It usually consists of three or four layers of cells.

The endodermis, which is originally distinct, soon becomes unrecognizable. The cells are about the same size as those of the cortex; they contain starch. Eventually all the parenchymatous elements contain starch.

The stele is originally somewhat elliptical in cross section. The phloem, in the youngest material examined, forms a complete ring. There are generally two large and four small xylem bundles. These soon fuse to form a closed xylem zone.

An interrupted band of sclerenchyma is developed at the outer limit of the xylem.

As in *Celtis australis* (cf. Flot [1893], p. 68) there is a distinct perimedullary zone composed of two or three cell rows.

Cork formation begins, rather late in the season, in the outermost hypodermal layer (cf. Moeller [1882], p. 74).

Comparison of Structure of Hypocotyl and Epicotyl.

A striking difference between hypocotyl and epicotyl is the absence from the former region of the numerous epidermal hairs so abundant in the latter. The hypocotyl is without a hypoderma.

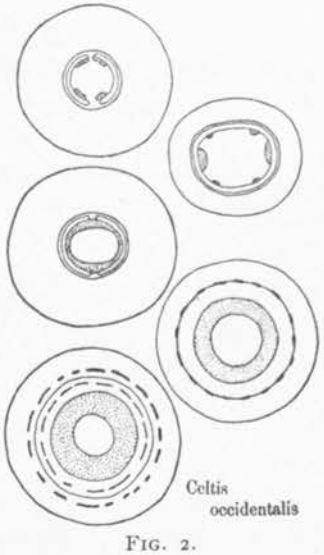


FIG. 2.

The primary stelar structure of the hypocotyl is peculiar, the phloem forming two crescentric masses and not uniting into a closed ring till after the xylem bundles have fused. The epicotyl possesses a ring of phloem and six xylem bundles.

At the end of the season the hypocotyl has two interrupted bands of sclerenchyma instead of one, and a smaller pith. Aside from these differences the two regions are the same in structure.

MORACEÆ.

Toxylon pomiferum.

Structure of Hypocotyl.

In cross section the cells of the epidermis appear radially elongated. Eventually they are considerably flattened. The cells of the outer cortex are similar to those of the epidermis. There is no collenchyma developed. The inner cortex is composed of larger cells.

The endodermis is distinct but in material taken at the close of the growing season it was not distinguished. The development of pericycle is remarkable. This region is composed of about six layers of parenchymatous cells resembling, in shape, those of the endodermis.

Starch is found, from the first, in the endodermis and later appears in all the conjunctive tissues.

The stele is slightly four-angled. There are, in the youngest material examined, four xylem bundles and two large crescent-shaped phloem bundles. The phloem soon forms a complete ring as does also the xylem, but the two xylem bundles first fuse in pairs.

About this time four aggregations of small groups of sclerenchyma appear in the pericycle. Eventually a nearly complete sclerenchymatous ring surrounds the phloem.

The pith is large-celled. A small-celled perimedullary zone of three or four layers is present.

Cork formation takes place in the fourth or fifth layer of the cortex.

Structure of Epicotyl.

The epidermis is composed of cells which are, at first, nearly square in cross section but later are very much flattened. According to Moeller [1882] the epidermis is two-layered. Numerous straight epidermal hairs are present; there are also some stalked glandular hairs. The cells of the cortex are rather small, parenchymatous, not at all collenchymatous.

The endodermis is distinguished with difficulty even in very young material. Its cells contain starch. Starch is later found in all the parenchymatous tissues.

There is a variable number of vascular bundles; usually eight to sixteen. These soon fuse to form closed rings of phloem and xylem.

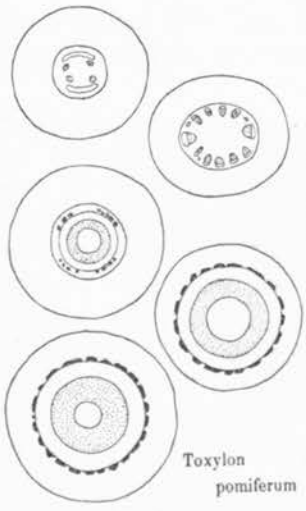
An interrupted sclerenchymatous ring is formed at the outer edge of the phloem; the cells are thick-walled but do not become lignified the first year.

The pith is rather large. There is a small-celled perimedullary zone which is quite definite.

Cork formation in the epicotyl takes place in the outermost cortical layer (cf. Moeller [1882]).

Comparison of Structure of Hypocotyl and Epicotyl.

In the hypocotyl the cortex and pericycle are much better developed than in the epicotyl. The former region is without epidermal hairs. This point of difference was previously noted by Klebs [1885].



Toxylon pomiferum

FIG. 3.

The stele of the hypocotyl has originally four vascular bundles, instead of from eight to sixteen; the pith is small in extent.

The sclerenchyma is first formed in four patches but afterwards forms almost a complete ring. Cork formation in the hypocotyl begins in a deeper layer of the cortex.

At the close of the year the two regions have nearly the same structure, about the only difference being the size of the pith.

Broussonetia papyrifera.

Structure of Hypocotyl.

There is an epidermis of small cells nearly square in outline when seen in cross section. These cells become greatly elongated tangentially as the tissues within increase in thickness. Short, blunt, unicellular epidermal hairs are numerous.

The cortex is composed of about six layers of large, thin-walled parenchymatous elements which, like the epidermal cells, become stretched toward the close of the season.

The endodermis is small-celled. It sometimes remains distinct till nearly the close of the first season. Starch is present in the endodermis, but absent from all other tissues for a long

time. It eventually appears in the pericycle, phloem, medullary rays and inner elements of the xylem.

The stele is originally very small. In the disposition of the vascular tissues this plant differs from all others examined by the writer. In cross section the center of this stele is seen to be occupied by an elongated area of xylem. On each side of this, separated by a small amount of conjunctive tissue, is a crescent-shaped mass of phloem. The xylem soon forms a somewhat four-sided mass, and is surrounded by a ring of phloem. The xylem at length becomes circular, and the surrounding phloem increases greatly in amount.

There is but slight development of stereom, although, toward the close of the first season, numerous isolated sclerenchymatous elements are found in the phloem.

The cork cambium originates in the endodermis or pericycle. The ring of phellogen is sometimes irregular, appearing now in one, now in the other of the regions named.

It may be said that, since the structure of the hypocotyl in this species so much resembles the general type of root structure, it was thought best to examine a large number of plants, lest the peculiarities noted should have been due to teratological development. All the plants were, however, found to be alike. Neither is there any trouble in this species, to determine the lower limit of the hypocotyl, for it is enlarged below and does not gradually shade off into root, as is the case in some seedlings.

Structure of Epicotyl.

The epidermis is small-celled. There are numerous simple, blunt and pointed hairs, and also some with a single stalk cell and a multicellular bulb at the distal end.

A somewhat collenchymatous hypoderma is developed, consisting of two or three layers of cells, which are smaller than the deeper cells of the cortex.

The small-celled endodermis, at first distinct, soon becomes displaced and changed, owing to secondary growth of sub-lying tissues.

Starch is almost entirely absent, except in the endodermal region, till about the close of the first growing season, when it appears in the pith, medullary rays, phloem and, to a slight extent, in the cortex.

The stele is large. There is a circle of twelve to eighteen conjoint vascular bundles. These soon fuse to form a narrow zone each of xylem and phloem.

There is a considerable amount of sclerenchyma at the outer edge of the phloem. The cells are, however, mostly isolated or else occur in small groups.

The pith, which is extensive, is composed of large, parenchymatous elements with thin, slightly lignified walls. According to Flot [1893], there is a perimedullary zone of five or six layers of crushed, thin-walled cells. The same author states that laticiferous tubes are found in the perimedullary region of young twigs of this species.

The cork cambium is formed in the outermost hypodermal layer (cf. Moeller [1882], p. 82).

Comparison of Structure of Hypocotyl and Epicotyl.

Both hypocotyl and epicotyl have simple epidermal hairs, but the former does not have the pointed or the bulbous hairs found in the latter region. The hypocotyl is also without the somewhat collenchymatous hypoderma found in the epicotyl; its endodermis persists for a greater length of time.

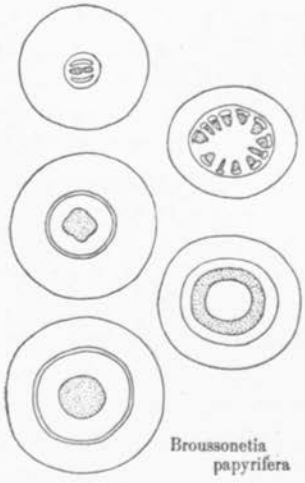


FIG. 4.

The structure of the stele in the hypocotyl is anomalous. A single flat bundle of xylem is flanked by phloem, which eventually surrounds the centrally-lying xylem, the inner cells of which contain starch. There is no pith. The epicotyl, on the other hand, has a large pith, and the vascular bundles are originally numerous. Starch is absent from the xylem.

Cork formation is endodermal or pericyclic in the hypocotyl, but hypodermal in the epicotyl.

MAGNOLIACEÆ.

Liriodendron tulipifera.

Structure of Hypocotyl.

The epidermis consists of cells which are nearly square in cross section; at first they are very much bulged. They never

become flat. The two or three layers of the cortex just below the epidermis are small-celled. The deeper layers are very large-celled.

The endodermis is small-celled and easily distinguished in young material, but is eventually displaced and is not distinguishable. In the young stages starch is entirely absent from the hypocotyl, but later is found sparingly distributed through the various parenchymatous tissues.

The stele, which is originally quadrangular, has four vascular bundles arranged in pairs. By their continued growth zones of xylem and phloem are produced.

About the time that a complete ring of xylem has been formed four masses of sclerenchyma appear in the pericyle. Eventually other groups of pericyclic cells also become sclerotic. The phloem immediately under these groups is better developed than at other places.

The pith is slightly quadrangular. The cells are thin-walled. A definite perimedullary zone was not distinguished.

The cork cambium is produced in the outermost layer of cortical cells.

Structure of Epicotyl.

The cells of the epidermis, when seen in cross section, appear square or tangentially elongated. A narrow collenchymatous hypoderma is developed. The remaining cells of the cortex are all about the same size.

The endodermis is distinct in young material, owing to the presence of starch in its cells. At a later time starch is distributed in small amount in the various parenchymatous tissues.

The number of primary xylem groups in the stele is about six or eight. Groups of phloem are somewhat more numerous. Closed zones of xylem and phloem are produced very early.

The outer phloem has many groups of sclerenchymatous fibers. These groups are close together, separated only by medullary rays. A small amount of sclerenchyma is produced in the cortex.

The pith is rather large, and composed of cells with thin, unlignified walls. No perimedullary zone was distinguished.

Cork is developed in the outermost cell layer of the cortex (cf. Moeller [1882], p. 229).

Comparison of Structure of Hypocotyl and Epicotyl.

The cortex of the hypocotyl is much thicker than that of the epicotyl. The former region has no hypoderma; it has four vascular bundles instead of six or eight or more; the sclerenchyma first appears in only four groups and at no time is as well developed as in the epicotyl.

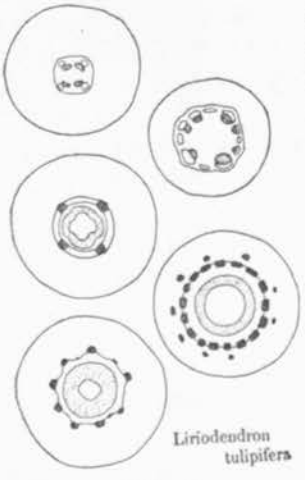


FIG. 5.

The pith of the hypocotyl is smaller than that of the epicotyl; it is somewhat quadrangular in shape.

MENISPERMACEÆ.

Menispermum canadense.

Structure of Hypocotyl.

The epidermis consists of cells which are square or rectangular in cross section. Late in the first season they become flat and tangentially elongated. A very thick, tough cuticle develops at the same time.

There is no hypoderma. There are about twelve layers in the cortex. The cells are large.

The endodermis consists of cells smaller than those of the cortex. It remains distinct a long time, but was not distinguished in material taken at the close of the growing season. The pericycle is peculiar. It is one or two layers in thickness. Usually every second or third cell, when seen in cross section, is without starch, although starch is present in the other cells. Eventually these cells also contain starch.

This plant is somewhat unique in the distribution of starch in its tissues, for in all the different stages examined starch was found in cortex, pith, endodermis and medullary rays and in the pericycle except as just noted.

The stele is quadrangular and has four primary vascular bundles. These increase considerably in size as the plant grows older. At the close of the growing season they are of about the same extent as the medullary rays which are composed of wood parenchyma and are full of starch. There is no phloem produced the first year opposite the medullary rays.

The pith is composed of large cells. There is a rather dis-

tinct smaller-celled perimedullary zone. No cork is formed the first year.

Structure of Epicotyl.

The cells of the epidermis, at first square in cross section, become very much flattened and develop a thick cuticle like that of the hypocotyl. A more or less definite collenchymatous hypoderma is developed. The cortex is composed of about six cell layers.

The endodermis is not easily distinguished even in youngest stages. The pericycle has some cells which in cross section appear empty, while the neighboring cells contain starch. These empty cells at a later time either become filled with starch or else are displaced so that they are not recognized.

Starch is present in the cortex, medullary rays, endodermis, pericycle and pith.

There are originally from nine to fifteen vascular bundles. These usually fuse to some extent so that there come to be only about six or eight. These remain easily distinguishable, since the primary medullary rays are very broad. The growth of the cambium produces no true phloem elements opposite the medullary rays, although there is some thin-walled parenchyma.

A crescent-shaped area of stereom is finally formed at the outer edge of each phloem bundle.

The pith becomes rather small in extent. There is a perimedullary zone of two or three layers of smaller cells. According to Flot [1893] these form at a later time five or six layers of sclerotic parenchyma. The formation of cork was not observed. It does not take place the first year.

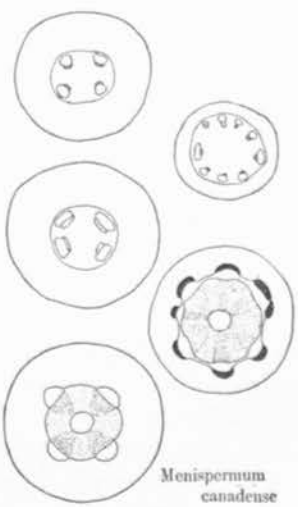


FIG. 6.

Comparison of Structure of Hypocotyl and Epicotyl.

The hypocotyl has a thicker cortex than the epicotyl: it is without a collenchymatous hypoderma. The endodermis is much more distinct in the former region and the peculiar distribution of starch in the pericycle is more pronounced.

Concerning the structure of the stele it is to be noted that in the hypocotyl it is quadrangular; it has but four vascular bundles instead of from eight to twelve and there is no stereom, while in the epicotyl a crescentic mass of stereom borders each phloem bundle.

CALYCANTHACEÆ.

Butneria florida.

Structure of Hypocotyl.

The epidermis consists of cells which are nearly square in cross section. They soon become more or less broken, owing to the early formation of cork. A few short, pointed, unicellular hairs are present.

A true hypoderma becomes differentiated late in the season. About three or four of the sub-epidermal layers of cells become collenchymatous. The cortex has about twenty layers of cells all approximately the same size. Intercellular spaces abound.

The endodermal cells are but slightly smaller than those of the cortex. The endodermis remains more or less distinct until the close of the first year. Starch grains are very small. A few are found in the endodermis, but no starch is present in the other parts of the hypocotyl till late in the season, when it is found in great abundance throughout all the parenchymatous tissues.

The stele is somewhat quadrangular. There are four xylem bundles and four principal phloem bundles. These are situated in the angles of the stele. There are also some small phloem areas. Their location will be seen by reference to the diagram. The phloem and xylem soon form narrow, closed zones. The former is most developed at the original angles of the stele.

It is stated by De Bary [1884], that in the seedlings of Calycanthaceæ a transverse section of the hypocotyl shows six bundles. In the plant under investigation, the present writer found this to be true only for the upper end of the hypocotyl where the cortical bundles, to be mentioned later, are separating and preparing to leave the stele. This appearance is, of course, only seen after the fusion of the primary xylem bundles in pairs, and before complete rings of phloem and xylem are produced.

Toward the upper limit of the hypocotyl there is present a small stereom bundle at each of the four angles of the stele.

These stereom bundles bend outward and accompany the cortical bundles in succeeding internodes.

The pith is rather thick-walled; the cells are about the same size as those of the cortex. A small-celled perimedullary zone of one or two layers is at length clearly distinguishable.

Cork formation begins very early in the outermost sub-epidermal layer of the cells.

Structure of Epicotyl.

The cells of the epidermis when seen in cross section are rectangular with the long diameter parallel to the surface of the section. There are numerous pointed hairs of various lengths.

A collenchymatous hypoderma, four or five layers of cells in thickness, forms the outer part of the cortex, the rest of which is composed of very loose parenchyma.

A definite endodermis was not distinguished. The endodermal region is, however, easily recognized by the presence of starch in many of the cells. Starch is afterward found in great abundance in pith, cortex and medullary rays.

The normal phloem and xylem form closed rings even in the youngest material examined. In the cortex, about half way between the epidermis and phloem are four vascular bundles, ninety degrees apart; each bundle consists of a more or less crescent-shaped mass of lignified sclerenchyma, at whose concave surface is a small area of slightly lignified xylem, consisting usually of five to ten cells. Adjoining this xylem and projecting some distance toward the stele is a lenticular mass of phloem. The general arrangement of the bundle is the same as that carefully described for *Calycanthus* sp. by Woronin [1860] and for *Calycanthus occidentalis* by Williams [1894]. Serial sections showed that in this species these cortical bundles enter the stele about 1 mm. below the insertion of the cotyledons, and not at the middle of the first internode as reported by Herail [1885] for certain other species.

The pith is large. There is a definite perimedullary zone of about three layers of small cells.

The cork cambium is formed very early in the outermost hypodermal layer (cf. Moeller [1882], p. 364).

Comparison of Structure of Hypocotyl and Epicotyl.

The epidermal hairs of the hypocotyl are fewer and shorter

than those of the epicotyl. There is in the former region also a less developed hypoderma.

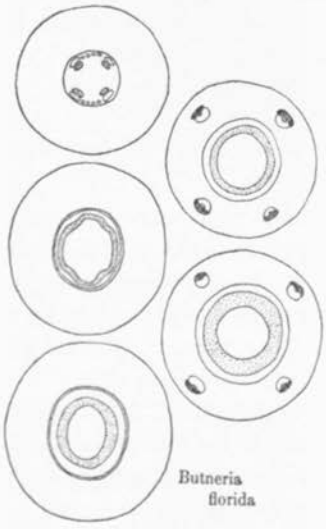


FIG. 7.

The stele of the hypocotyl is originally quadrangular; it is surrounded by a distinct endodermis, and has four xylem bundles and four principal phloem bundles. The stele of the epicotyl is cylindrical, without a distinct endodermis, and even at a very early age, the xylem and phloem form closed rings.

The hypocotyl has no cortical vascular bundles; of these the epicotyl has four.

The presence of true collenchymatous hypoderma in the hypocotyl deserves special mention, as this forms an exception to the general rule that collenchyma is not developed in the hypocotyl.

CÆSALPINACEÆ.

Parkinsonia aculeata.

Structure of Hypocotyl.

The epidermis is composed of cells which are rectangular in cross section. They are, at first, radially elongated. Eventually they become elongated in the other direction.

The cortex is many-layered. There is no hypoderma. The outer cells of the cortex are much smaller than those further down. Very early in the history of the hypocotyl a parenchymatous sheath of small cells is formed in the cortex about midway between epidermis and endodermis. The cells are not arranged in definite rows. The position of this sheath is shown in the last plate accompanying this paper.

The cells of the endodermis are smaller than those of the cortex. They contain starch. The endodermis is quite distinct; it was, however, not definitely distinguished in material collected late in the season. The cortex and pith at a later time also have some starch.

The stele is four-angled. There are originally four phloem

bundles and eight paired xylem bundles. Eventually closed rings of xylem and phloem are formed.

At the corners of the stele in the pericycle groups of sclerenchyma are formed. The cells become very thick-walled and each group quite large.

The pith is large. The cells are rather thick-walled. No definite perimedullary zone was distinguished.

In the material examined cork formation had not commenced.

Structure of Epicotyl.

The epidermal cells are thin-walled, square in cross section, becoming at length much flattened. There is no collenchyma. The cortex is narrow; the cells are about the same size as those of the epidermis.

The endodermis is composed of thin-walled cells. After secondary growth of the stelar tissues it cannot be definitely seen. The cells are about the same size as those of the cortex; they contain starch. Starch is found at a later time in the various parenchymatous tissues.

The number of vascular bundles is variable. Usually there are about twelve. These, at length, fuse to form closed rings of phloem and xylem.

The pericycle develops a sheath of sclerenchyma which almost completely shuts in the phloem. The cells were not very thick-walled in the material examined.

The pith is large, the cells rather thin-walled. A perimedullary zone of small-celled parenchyma at length becomes differentiated.

No material old enough to show cork formation was examined.

Comparison of Structure of Hypocotyl and Epicotyl.

The hypocotyl differs from the epicotyl in having a thicker cortex with a narrow small-celled parenchymatous sheath. The cells of the cortex are also larger.

In its primary stelar structure the differences are very marked. The

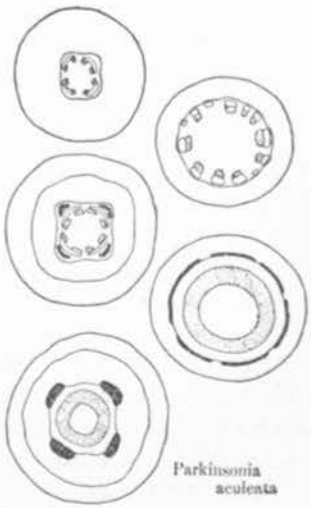


FIG. 8.

hypocotyl has four phloem bundles and eight xylem bundles instead of a large number of conjoint bundles. It has four large groups of stereom instead of a narrow, almost continuous sclerenchymatous sheath.

Cercis canadensis.

Structure of Hypocotyl.

The epidermal cells are rectangular in cross section; the radial diameter is the longer. These cells never become tangentially elongated. The cells of the outer cortex are smaller than those within. An indefinite sheath of small-celled parenchyma similar to that in *Parkinsonia* can sometimes be recognized.

The endodermis is small-celled; it remains distinct through the first year. Its cells contain starch. Starch is also present toward the close of the year in the pith.

The stele is originally quadrangular. There are four xylem bundles and four phloem bundles. These, at length, develop into closed rings.

Four small groups of sclerenchyma make their appearance in the pericycle at an early time and become, at length, considerably extended.

The pith finally becomes cylindrical. The cells are large and thin-walled. The perimedullary zone is not clearly differentiated.

Cork formation takes place in the cortex either next to or very near the endodermis. It begins sometime before the close of the season.

Structure of Epicotyl.

The epicotyl is somewhat quadrangular in the early stages. The epidermal cells are rectangular in cross section. The tangential diameter is the greater. There is no hypoderma. The cortex is thin. The cells are all about the same size.

The endodermis was not definitely distinguished. In the youngest material examined the phloem forms a closed ring. There are four large primary xylem bundles. There are also some smaller ones. The latter have often only one or two xylem cells. A closed zone of xylem is soon produced.

Nearly all the cells of the pericycle become, at length, sclerotic, thus forming an almost continuous sheath with but few parenchymatous cells.

The pith is large-called. A perimedullary zone was not distinguished.

Cork formation takes place in the second cortical layer as in *Cercis siliquastrum* (fide Moeller [1882]).

Comparison of Structure of Hypocotyl and Epicotyl.

The epidermal cells of the hypocotyl, when seen in cross section, appear radially, not tangentially elongated as in the epicotyl. In the former region the endodermis is distinct, the cortex thicker and the sclerenchyma at first differently disposed.

The stele of the hypocotyl has originally four phloem bundles and four xylem bundles. The youngest material of the epicotyl which was examined has a closed ring of phloem and four large xylem bundles, also a few small groups of xylem.

Cork formation in the hypocotyl takes place in the lower cortex; in the epicotyl it takes place in the second cell layer of the cortex.

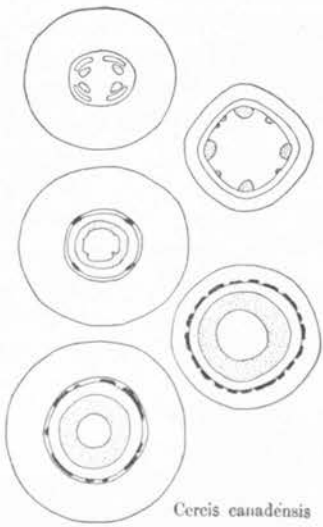


FIG. 9.

Gleditsia triacanthos.

Structure of Hypocotyl.

The epidermis is composed of rather thick-walled cells which are oblong in cross section, the long axis being at right angles to the periphery of the section. These cells are eventually elongated in the tangential direction.

The cortex is very thick. There is no differentiated hypoderma, but three or four of the outer cortical layers are composed of smaller cells than those below.

The endodermis is definite; it is large-celled. In some places it is two layers of cells in thickness. Starch, at first present only in the endodermis, is eventually widely distributed throughout all the parenchymatous tissues.

The stele is cylindrical. There are in the young hypocotyl

eight paired xylem bundles and a large number of groups of phloem. The latter soon grow together, forming a complete ring, while the xylem bundles first fuse in pairs, afterward growing together into a closed zone.

In the pericycle, alternating with the paired xylem bundles there are developed four large bands of sclerenchyma which extend so far around that they nearly touch each other. By the end of the first season these become divided into a number of groups by the intercalation of parenchymatous cells.

The pith, which is eventually of slight extent, is composed of large-celled parenchyma.

Cork formation begins rather early the first season in the third or fourth cell layer of the cortex.

Structure of Epicotyl.

The general shape of the epicotyl is originally somewhat hexagonally prismatic; it soon becomes cylindrical.

The cells of the epidermis are originally nearly square in cross section. There are numerous, long, curved, pointed epidermal hairs. The outer two layers of the cortex become slightly collenchymatous. The other cortical layers are composed of parenchyma.

The endodermis was not distinguished in material taken in the autumn but in the young epicotyl is quite distinct. The cells are rather large, similar to those of the cortical region but packed with starch.

The phloem, in youngest material examined, forms a ring of tissue. There are about six principal xylem bundles which soon fuse.

A broken sclerenchymatous ring is formed which resembles that of the epicotyl. No other stereom is, as a rule, produced the first year.

The pith is large and composed of cells with unlignified walls. There is a small-celled perimedullary zone.

Cork formation takes place in the hypoderma (cf. Moeller [1882], p. 393).

Comparison of Structure of Hypocotyl and Epicotyl.

The hypocotyl differs from the epicotyl in the absence of epidermal hairs and of a collenchymatous hypoderma, in the primary structure of the stele, and in its smaller pith.

In the hypocotyl there are at first four pairs of xylem bundles and a number of phloem bundles. Four large groups of sclerenchyma soon make their appearance in the pericycle. In the epicotyl, on the other hand, a closed ring of phloem surrounds usually about six xylem bundles. No differentiated perimedullary zone was distinguished in the hypocotyl.

The structure of the two regions at the close of the first year differs only in the perimedullary region and pith; the formation of cork having removed the epidermis and hypoderma.

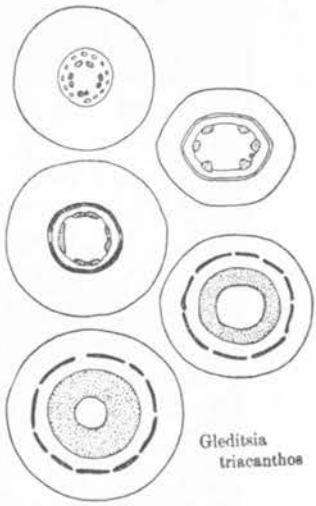


FIG. 10.

PAPILIONACEÆ.

Amorpha fruticosa.

Structure of Hypocotyl.

The epidermis consists of cells rather small, somewhat thick-walled, square or nearly so, in cross section, at length becoming flattened. The cells of the cortex are large; those immediately below the epidermis somewhat smaller, but not forming a definite hypoderma.

The endodermis of thin-walled cells containing starch remains distinct for some time. Toward the close of the first year its exact position cannot be determined, although it can be located approximately. A small amount of starch is scattered throughout the cortex, pith and pericycle as well as the endodermis, even in the youngest stage. This is not the case in most species. Later the phloem and the medullary rays also come to be filled with starch.

The stele is at first quadrangular, and remains so for a considerable length of time. There are four conjoint vascular bundles, and in addition there appear a few small patches of phloem. The bundles soon tend to unite in pairs. Xylem and phloem at length form complete zones. The medullary rays are very numerous; they are one cell in width.

About the time that the epicotyl has reached its full length four small areas of sclerenchyma appear in the pericycle, one adjoining the phloem of each vascular bundle. These increase somewhat in size, and are still visible in two-year-old material. Numerous isolated sclerenchymatous elements are found scattered through the phloem.

The pith is composed of rather large cells with thin walls, which soon become lignified. As the plant grows older the pith becomes almost obliterated. No perimedullary zone was distinguished.

Cork formation takes place in the outer pericycle, at length cutting off all tissues outside, leaving the bundles of sclerenchyma which are at the inner limit of the pericycle.

Structure of Epicotyl.

The epidermis is composed of cells nearly square in cross section. These abut directly upon a large-celled, few-layered cortex. There is no hypoderma.

A definite endodermis was not distinguished at any time although in a very young stage certain starch containing cells were recognized as having the appearance of endodermis; a continuous ring of them was not traced. With the exception of the endodermal and medullary region, starch does not occur until the plant has developed a number of internodes above the epicotyl. The cells of pericycle and phloem are at length filled with starch.

The stele is cylindrical from the first. Owing to fusions the number of vascular bundles is variable. There are, however, generally about five or six bundles. The phloem and xylem eventually form closed rings.

There is a narrow interrupted ring of stereom at the outer edge of the pericycle. Toward the end of the first season numerous small patches of thick-walled fibers appear in the phloem and the pericycle.

The pith is large-celled; it does not decrease appreciably in size as the stem grows older.

In the lower part of the epicotyl cork formation takes place in the pericycle below the ring of stereom mentioned above, thus cutting off the cortex and epidermis which soon die and disappear. In the upper part it takes place in the cortex (cf. Moeller [1882], p. 383). This plant shows a distinct "region tigellaire" in two-year-old material.

Comparison of Structure of Hypocotyl and Epicotyl.

In very young plants the hypocotyl shows a few slightly differentiated layers of smaller cells in the outer cortex. The epicotyl has nothing of the kind.

The endodermis of the hypocotyl is distinct in the early stages, but was not definitely located in the epicotyl. Starch appears earlier in the hypocotyl and the four large groups of stereom are not represented at all in the epicotyl which, however, has an interrupted circle of the same material.

In the former region the stele is at first quadrangular, while always cylindrical in the latter. Cork formation in the hypocotyl is pericyclic, but is cortical in the epicotyl.

The final structure of the two regions is very similar, save in the arrangement of sclerenchyma.

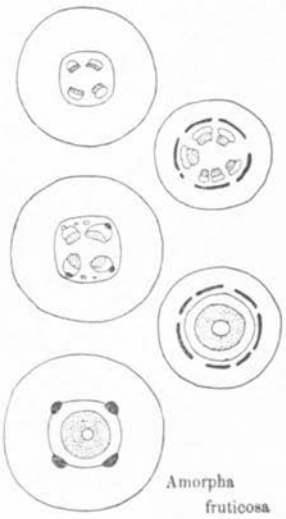


FIG. 11.

Robinia pseudacacia.

Structure of Hypocotyl.

The epidermal cells are oblong in cross section, radially elongated at first, later becoming elongated in the tangential direction. A few straight multicellular hairs are present. There is no differentiated hypoderma. The cells of the cortex are all about the same size.

The endodermis is small-celled and contains starch. It is not easily distinguished in material taken at the close of the growing season. Starch is also found in some of the pericyclic cells in early stages. Later nearly all the parenchymatous tissues have starch.

The stele is originally quadrangular. There are eight phloem bundles and four xylem bundles. These soon produce closed zones.

In the pericycle opposite each of the original xylem bundles a group of stereom appears. These groups, at length, become quite large. In addition to these, at the close of the first year, there are some small patches of stereom irregularly disposed just outside the phloem.

The pith is composed of parenchymatous cells which acquire thick lignified walls. There is a well-differentiated perimedullary zone three or four cells in width. The cells are small and have thick lignified walls.

Cork formation, according to Flot [1890], takes place rather deep in the cortex.

Structure of Epicotyl.

The cells of the epidermis are square or oblong in cross section, and become in time greatly flattened. There are numerous epidermal hairs. A narrow collenchymatous hypoderma is present. The cells of the cortex are about the same size as the epidermal cells.

The endodermis was distinguished only in very young stages. The cells are rather small and closely packed with starch. Starch is found at a later time in the various parenchymatous tissues. Troschel [1879] states that in year-old twigs starch is present in some of the elements of the wood but disappears the next year.

In young material the epicotyl is elliptical in cross section. The stele follows this closely in shape. The phloem forms a closed ring surrounding a variable number of xylem bundles. There are usually more than eight of these bundles. The xylem also soon forms a complete zone in which medullary rays are prominent.

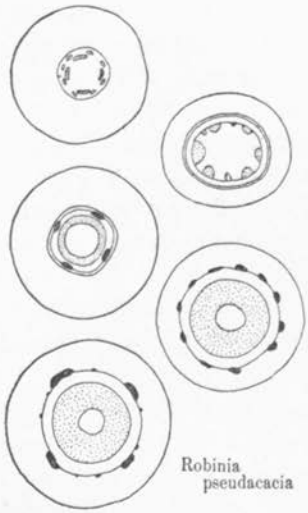


FIG. 12.

The pith cells become, at length, thick-walled. There is a well-defined perimedullary zone.

Cork arises in the fourth, fifth or sixth layer of the cortex (cf. Moeller [1882], p. 384).

Comparison of Structure of Hypocotyl and Epicotyl.

The hypocotyl is without the collenchymatous hypoderma of the epicotyl; it has fewer epidermal hairs; the cortex is thicker; there are four large groups of stereom with some very small ones instead of a broken ring of medium-sized bundles.

In its primary structure the stele of the hypocotyl differs considerably from that of the epicotyl. There are four xylem bundles instead of eight or more and eight phloem bundles instead of a closed ring of phloem.

The cork, although of cortical origin in both regions, arises in the hypocotyl in deeper layers.

RUTACEÆ.

Ptelea trifoliata.

Structure of Hypocotyl.

The cells of the epidermis, when seen in cross section, appear nearly square. They, at length, are flattened. There are a few short, blunt, unicellular hairs. The cortex is large-celled. There is no distinct hypoderma differentiated.

The endodermis is large-celled and contains, at first, very little starch. It later becomes closely packed with starch. The various parenchymatous tissues at length also contain starch in the cell cavities. Numerous lysigenous reservoirs are present in the outer part of the primary cortex.

The stele is originally four-angled. There is one phloem bundle and one xylem bundle in each angle. The phloem soon forms a closed ring surrounding the now greatly enlarged xylem bundles which enclose, at this stage, a somewhat cruciform pith. The xylem bundles also finally fuse.

Four very small groups of sclerenchyma appear, toward the end of the season, in the pericycle. They are equidistant. There are about six cells in each group. Some sections do not show all these groups, as the sclerenchymatous elements do not form continuous strands in the hypocotyl. Some sections show no sclerenchyma at all.

The pith is eventually quite small. The perimedullary zone is not well developed.

The formation of cork begins early in the outermost cortical layer of cells.

Structure of Epicotyl.

The epidermis is composed of cells which appear slightly rectangular in cross section. They are elongated in the tangential direction. Numerous epidermal hairs are present. There is a narrow collenchymatous hypoderma. The cells of the inner cortex are very large.

The endodermis is distinct and can be recognized in year-old material. Starch is present from the first. The various parenchymatous tissues at length have a small amount of starch. Secretion cavities develop in the cortex.

The stele is small; much smaller than is usual in most species. In the youngest material examined the phloem forms a complete ring surrounding a small number of xylem bundles which eventually fuse.

Numerous groups of elements in the pericycle become sclerotic so that they form an interrupted ring of sclerenchyma surrounding the phloem.

The pith is small, unusually so for an epicotyl. There is a definite perimedullary zone of small-celled parenchyma containing starch.

The formation of cork takes place in the outermost layer of hypoderma (cf. Moeller [1882], p. 326).

Comparison of Structure of Hypocotyl and Epicotyl.

The hypocotyl does not have the epidermal hairs and the collenchymatous hypoderma of the epicotyl. The cortex of the former region, though very thick, is but little thicker, in proportion, than that of the epicotyl.

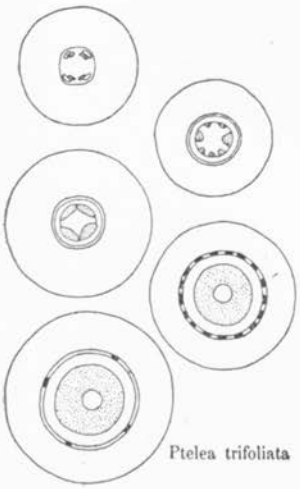


FIG. 13.

In the stele of the hypocotyl there are four phloem bundles and an equal number of xylem bundles, while in the epicotyl, in the youngest material examined, the phloem forms a closed ring surrounding about six xylem strands.

The sclerenchyma of the hypocotyl is in four somewhat irregular columns in the pericycle, while in the epicotyl it forms more nearly a closed sheath. In the former region also the perimedullary zone is poorly developed.

SIMARUBACEÆ.

Ailanthus glandulosa.

Structure of Hypocotyl.

The epidermis consists of small cells, square or nearly so, in cross section, and considerably bulged when young. A few

short, unicellular hairs were seen, but none noted in very young plants. There is a hypoderma of one or two layers of somewhat larger and thicker-walled cells. The rest of the cortex is parenchymatous and large-celled.

The endodermis consists of cells somewhat smaller than those of the adjacent cortical layer. The endodermis was not recognized in older material. Starch is present from the first in the endodermis, pericycle and pith, but does not appear in the cortex till nearly the close of the first season.

The stele is at first quite small. There are four xylem bundles arranged in pairs and four phloem bundles similarly disposed. The phloem soon forms a complete ring, surrounding the now considerably enlarged xylem bundles, which also eventually form a closed ring.

Opposite each of the four original xylem bundles there appears in the pericycle a group of sclerenchymatous cells. These groups become, at length, somewhat divided so that the old hypocotyl may have a considerable number of smaller groups. There are numerous sclerenchymatous fibers scattered in small and large patches through the phloem and pericycle.

The pith is thin-walled; toward the end of the first season it becomes lignified. The perimedullary zone, described by Flot [1893], as an important feature of the stem structure is first definitely noted at this time.

The oleoresin canals described by Trécul [1867] as occurring at the outer border of the pith, and by Van Tieghem [1884] as in the inner xylem of the stem, were not distinguished in the hypocotyl. Crystal rosettes of calcium oxalate occur singly in certain cells of the phloem area. Single oleoresin cells are found here and there in the cortex and phloem.

Cork formation, as noted by Flot [1889 and 1890] takes place in the layer of cells just below the epidermis.

Structure of Epicotyl.

The epidermis resembles that of the hypocotyl, but there are numerous, somewhat long, curved or hooked epidermal hairs. Most of these are unicellular.

The hypoderma is, as previously described for the stem by De Bary ([1884], p. 404), collenchymatous. The cells are small; toward the inside the hypoderma gradually shades into the ordinary cortex.

A definite endodermis was not distinguished at any stage, although, since starch is present in the region of the pericyle and endodermis from the first, those regions can be located approximately. Starch is found later in pith and cortex; also in many of the inner xylem elements.

There are, at first, eight to ten conjoint vascular bundles. Eventually the phloem and xylem form closed rings.

Scattered sclerenchymatous elements are found in the phloem, pericycle and cortex.

The pith is irregular in outline. The first formed xylem elements project into it. The perimedullary zone is not conspicuous the first year, being composed of a few cells with unlignified walls.

The cork cambium is formed in the outermost hypodermal layer (cf. Moeller [1882], p. 327).

Comparison of Structure of Hypocotyl and Epicotyl.

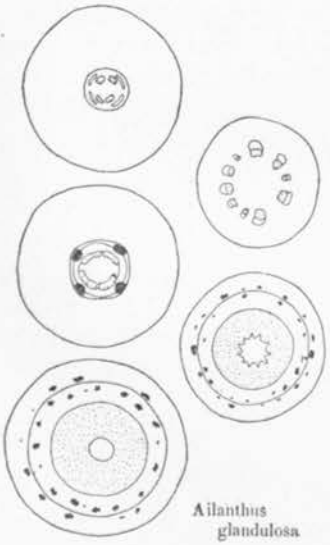


FIG. 14.

The hypocotyl has a few, the epicotyl a considerable number, of epidermal hairs. The hypocotyl does not have the collenchymatous hypoderma found in the epicotyl. The pith is smaller and circular instead of scalloped; the perimedullary zone is better developed.

The endodermis is distinct in the hypocotyl for a considerable time, while in the epicotyl it was not definitely distinguished at all. The hypocotyl has, at first, four xylem and four phloem bundles; the epicotyl eight to ten conjoint bundles.

At the close of the year the only differences are those noted in the medullary and perimedullary regions.

ANACARDIACEÆ.

Schinus molle.

Structure of Hypocotyl.

The epidermal cells are square or oblong in cross section, becoming, at length, flattened. There are numerous short epi-

dermal hairs. No hypoderma is developed but the cells of three or four outer layers of the cortex are smaller than those of deeper layers.

The endodermis is small-celled and easily recognized in young stages, although at that time the cells are without starch. Later starch appears in small quantities in these cells and in those of the pith and phloem.

The stele is originally four-angled and remains so for some time. In each angle there is a single xylem bundle and two groups of phloem; these form a crescent-shaped mass bordering a group of cells which later develop into a resin duct. After a time secondary vascular bundles are intercalated between the primary bundles. All finally fuse to produce closed zones of phloem and xylem.

A few small groups of sclerenchymatous cells develop at the outer border of the phloem.

The pith remains somewhat four-sided. The four original xylem bundles project into it at the angles. The pith cells have thin, unlignified walls. A perimedullary zone of small cells was distinguished.

Material old enough to show cork formation was not obtained.

Structure of Epicotyl.

The epidermis resembles that of the hypocotyl. Trichome structures seem to be no more abundant. There is no collenchymatous hypoderma developed. The cells of the cortex are all about the same size.

The endodermis is not easily recognized owing to the fact that in young stages it contains no starch. Later when starch is present the cells have been compressed and displaced by pressure from the subjacent tissues.

The stele contains a variable number of vascular bundles. Usually there are about eight. In connection with each bundle is a small resin passage, at first pointed out by Trécul [1867]. In older material these resin passages become quite large and somewhat flattened. The phloem and xylem then form closed zones.

Groups of sclerenchyma, usually consisting of only a few cells, are found at the periphery of the phloem. These are often located near the resin passages.

The pith is nearly circular, not quadrangular, and is com-

posed of large, thin-walled cells. There is a distinct perimedullary zone.

The region of cork formation was not determined.

Comparison of Structure of Hypocotyl and Epicotyl.

In their primary structure the steles of the hypocotyl and epicotyl show important differences. That of the former region is quadrangular; it has four primary vascular bundles and at a later time other secondary bundles are intercalated. These latter do not have resin canals. In the epicotyl there are about eight vascular bundles each with a resin canal.

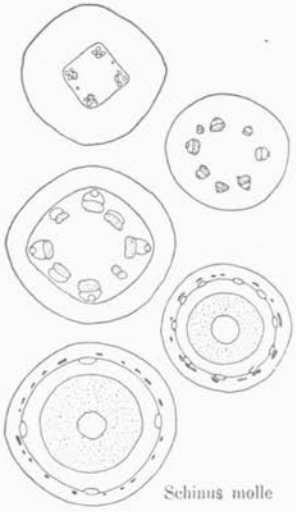


FIG. 15.

The pith of the hypocotyl is four-sided, that of the epicotyl circular in outline, when seen in cross section.

RHAMNACEÆ.

Berchemia racemosa.

Structure of Hypocotyl.

The cells of the epidermis are nearly square in cross section, sometimes radially elongated, but becoming at length considerably flattened. No hypoderma is developed, although the cells of the outermost layer of cortical tissue are considerably smaller than those below. There are about five layers of cells in the cortex. This tissue is extremely loose, having many intercellular spaces.

The endodermis is quite distinct until nearly the time that cork formation begins. The cells are smaller than those of the cortex but larger than the pericyclic elements.

Starch is present in the endodermis from the first, but does not appear in the cortex at all, nor in the pith and phloem till about the close of the season.

The stele is originally four-angled. There are four xylem and four phloem bundles. These are paired. They soon fuse so that there are two crescent-shaped bundles, and by further growth closed rings of xylem and phloem are produced.

While the bundles are in the crescent form four small groups

of sclerenchyma appear in the pericycle, one opposite each of the original xylem groups.

The pith is composed of large cells, whose thin walls become, at length, somewhat lignified. A perimedullary zone of about two layers may be distinguished but is not always continuous the whole way around the pith.

The cork has its origin in the inner cortex or in the endodermis. Some of the layers of cork carry a brown pigment.

Structure of Epicotyl.

The epidermis, composed originally of small cells, square or pentagonal in cross section, eventually becomes strongly cuticularized and the separate elements very much flattened.

There is no hypoderma developed. The cortex is rather large-celled, but very narrow, being only three or four layers of cells in thickness. During the second year the walls of these cells become conspicuously pitted. Many large crystals, chiefly cubical in form, are found in this region.

The endodermis, composed of flat cells containing starch is distinct till near the close of the first season. Except in the endodermis starch is absent until about the end of the first year's growth, when it appears in the pith and medullary rays.

Even in very young stages the phloem forms a closed zone surrounding a ring of from six to ten, but generally about eight, xylem bundles. These soon become fused. A narrow band of sclerenchyma, for the most part only one cell wide, is found at the outer limit of the phloem; it does not form a closed ring, but is more or less irregular and broken. Small patches of sclerenchyma are found in the phloem of two-year-old seedlings.

The pith is large-celled; the walls are thin but slightly lignified. No perimedullary zone was distinguished.

The region of cork formation was not distinguished. Two-year-old material was examined, but the cork cambium had not begun to form.

Comparison of the Structure of Hypocotyl and Epicotyl.

The epidermis of the hypocotyl remains thinner-walled and exhibits less cuticularization than that of the epicotyl. This is to be expected, since in the former region cork is produced the first year, while in the latter not till a later period.

The hypocotyl has at first four xylem and four phloem bundles, the epicotyl a closed ring of phloem and about eight xylem bundles. In the former area there are but four groups of sclerenchyma, while in the latter there is an interrupted circle of thick-walled elements just outside the phloem.

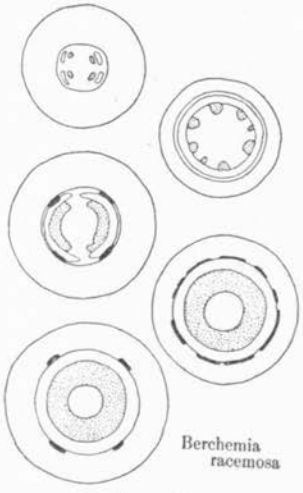


FIG. 16.

The pith of the hypocotyl is smaller than that of the epicotyl.

Rhamnus purshiana.

Structure of Hypocotyl.

The cells of the epidermis are originally square or pentagonal in cross section. They become, at length, much flattened. The cortex is thick and very large-celled. No hypoderma is differentiated.

The endodermis consists of small, thin-walled cells containing starch. It remains distinct until cork formation takes place. Starch is found, late in the season, in the perimedullary zone and phloem, but not in the cortex.

The stele is originally somewhat four sided and has four vascular bundles which soon fuse and produce closed zones.

The pith is composed of very large cells. The perimedullary zone is rather ill-defined. It is one or two cells in width. The cells are small and contain starch.

The cork is of endodermal origin. Its formation begins toward the close of the growing season.

Structure of Epicotyl.

The epidermal cells, at first square or pentagonal in cross section, become at length, considerably flattened. There are numerous short, curved and pointed hairs. A poorly developed hypoderma is present in year-old material. The cells of the cortex are all about the same size.

The endodermis was distinguished only in young material. The cells are small and contain starch. The perimedullary zone, cortex and phloem have at a later time, small amounts of starch.

The phloem, in the youngest material examined, forms a complete ring. There are about six xylem bundles. These soon fuse.

Considerable masses of stereom develop at the periphery of the phloem forming a broken sheath.

The pith is large-celled. There is present a definite perimedullary zone of small cells containing starch. The cell walls are lignified.

Cork is produced in the outermost hypodermal layer as in other species of *Rhamnus* (cf. Moeller [1882], pp. 292 et seq.).

Comparison of Structure of Hypocotyl and Epicotyl.

The hypocotyl has a thicker cortex than the epicotyl; it does not have a hypoderma; epidermal hairs are absent; the sclerenchymatous ring found in the epicotyl is here absent.

The endodermis of the hypocotyl remains distinct for a greater time than that of the epicotyl. The former region has originally four vascular bundles; the latter has, in the youngest material examined, a zone of phloem and about six xylem bundles. Cork formation in the hypocotyl is endodermal while in the epicotyl it is hypodermal.

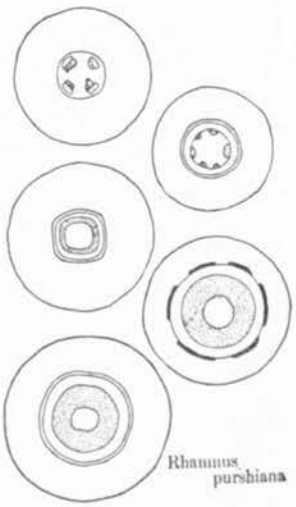


FIG. 17.

VITACEÆ.

Vitis cordifolia.

Structure of Hypocotyl.

The cells of the epidermis are nearly square in cross section, but become at length considerably flattened. Many of them are somewhat prolonged, forming short, blunt papillæ. A thick cuticle is present. In cross section it appears minutely notched.

Three or four of the outer layers of the cortex are small-celled, but not collenchymatous. The cells of deeper layers are larger and all about the same size.

The endodermis is small-celled, and is for a long time readily distinguished because it contains starch. Starch is generally absent from the other tissues, but, at a later time, appears in the pith.

There are four primary vascular bundles. Other secondary bundles soon become intercalated and finally complete rings of phloem and xylem are produced.

A single group of sclerenchymatous elements is formed at the outer edge of each primary vascular bundle. By the end of the season other smaller groups are also present.

The pith finally becomes very small. Sometimes, by the projection into it of two of the vascular bundles, a line of xylem extends nearly across it. There is no perimedullary zone.

The cork cambium, as in other species of *Vitis* (cf. Flot [1889]), is formed about the close of the first season in the pericycle.

Structure of Epicotyl.

The epidermal cells are square in cross section, becoming at length flattened. The cuticle is like that of the hypocotyl. A well-differentiated collenchymatous hypoderma is present. The other cells of the cortex are parenchymatous.

The endodermis contains starch and is, therefore, easily distinguished. Toward the end of the season starch is also found in the pith. The number of primary vascular bundles is variable. Usually there are more than eight. At an early time closed zones of phloem and xylem are produced.

A broken ring of sclerenchyma is developed toward the end of the first year in the pericycle.

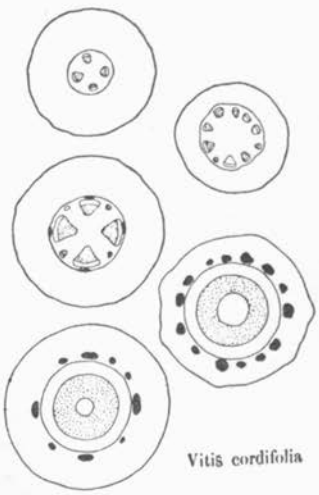


FIG. 18.

The pith is thin-walled and large-celled. A definite perimedullary zone was not distinguished.

The cork, as in the hypocotyl, is of pericyclic origin (cf. Moeller [1882], p. 207).

Comparison of Structure of Hypocotyl and Epicotyl.

The hypocotyl has a thicker cortex than has the epicotyl. It has but four primary vascular bundles instead of eight or more. It has four large masses of sclerenchyma in the pericycle and a few smaller ones instead of a more nearly continuous sclerenchymatous ring.

The pith of the hypocotyl becomes, at length, nearly obliterated.

ELÆAGNACEÆ.

Elæagnus umbellata.

Structure of Hypocotyl.

The cells of the epidermis are more or less oblong in cross section. There are no epidermal hairs. The outermost layer of the cortex becomes somewhat thick-walled but not collenchymatous. The cortex has about six cell rows.

The endodermis is small-celled. It remains distinct for a time, but in sections of material gathered at the end of the season it was not distinguished. Very little starch is found in any of the tissues save in the endodermis.

The stele is originally four-angled. A single phloem bundle and two xylem bundles are placed in each of the angles. The phloem soon forms a closed ring while the xylem bundles fuse in pairs and increase in size. This leaves a cruciform pith. The continued growth of the xylem produces a complete zone surrounding, at length, a circular pith. Secretion cells in the phloem are numerous.

At the outer edge of the xylem, in old material, are a few patches of sclerenchyma forming a very much interrupted ring.

The pith is of considerable extent and is surrounded by a perimedullary zone of small cells containing starch.

Cork formation takes place far down in the cortex.

Structure of Epicotyl.

The epidermis consists of cells which are oblong in cross section with the tangential about twice the radial diameter even in very young material. The peculiar stellate trichome structures, well known in this genus, are abundant.

The outer cortical cells are nearly circular in outline, when seen in cross section. They are somewhat smaller than the cells of the epidermis. The inner cortex is composed of large cells which eventually are very much flattened owing to pressure of the growing parts within.

The endodermis is small-celled and contains starch. In old material it was not recognized.

The stele is circular from the first. In the youngest material examined the phloem forms a complete ring surrounding about

six xylem groups. The xylem bundles soon fuse producing at the end of the season quite a thick zone.

An interrupted sclerenchymatous ring is developed in the pericycle.

The pith, which is composed of large thin-walled elements, is surrounded by a narrow small-celled perimedullary zone containing starch.

The cork is formed rather late in the season in the outermost cortical layer as in other species of *Elaeagnus* (cf. Moeller [1882], p. 117).

Comparison of Structure of Hypocotyl and Epicotyl.

The hypocotyl is without the trichome structures so noticeable in the epicotyl; the stele is at first four-angled instead of cylindrical; there are four phloem bundles and eight xylem bundles instead of a ring of phloem and six xylem bundles.

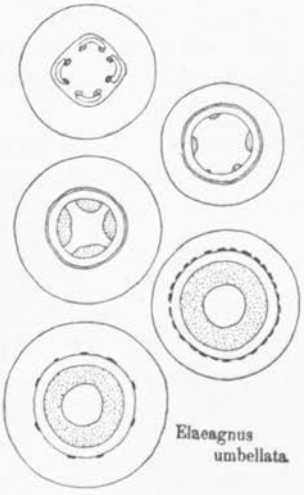


FIG. 19.

At the end of the season the vascular tissue is alike in the two regions but the pericyclic sclerenchyma of the hypocotyl is less abundant. Cork is developed in the inner cortex of the hypocotyl and in the outermost layer of cortex in the epicotyl.

MYRTACEÆ.

Eucalyptus globulus.

Structure of Hypocotyl.

The epidermal cells, at first oblong, radially elongated, become at length in cross section nearly square. The cuticle, which is covered with elevations, appears, when young, in cross section minutely serrate.

There is no hypoderma differentiated, but the outermost layer of the cortex is smaller-celled than the layers below. The cortical cells are large. They become flattened toward the end of the season by the growth of the internal tissues.

The endodermis is composed of small cells containing starch; it at length becomes indistinguishable. Starch is for the most part absent from other tissues. Lysigenous secretion reservoirs are found in the conjunctive tissue.

The stele is four-sided. The general shape of the hypocotyl sometimes follows that of the stele (cf. Irmisch [1876]). There are originally four narrow curved phloem bundles and the same number of small xylem bundles. The phloem soon forms a closed ring; the xylem bundles increase in size, leaving for a time a cruciform pith; but eventually the xylem also forms a complete ring and the pith is cylindrical.

Four small groups of sclerotic cells make their appearance in the pericycle about the time that the phloem ring is first formed. These groups eventually become somewhat broken up and numerous groups of fibers appear in the phloem arranged in three or more interrupted circles.

The pith is large-celled. It is small in amount even from the first. No definite perimedullary zone was distinguished.

Cork formation, according to Flot [1890], is cortical or pericyclic.

Structure of Epicotyl.

The cells of the epidermis are at first more nearly square in cross section than those of the hypocotyl. They at length become very much elongated in a tangential direction.

The cortex is large-celled; the cells of the outer layer are rather small. No hypoderma is differentiated. Numerous lysigenous secretion sacs are present.

The endodermis is thin-walled; the cells are small and contain starch.

The stele is at first somewhat quadrangular and becomes at length elliptical, in cross section. In the youngest material examined the phloem forms a closed ring. The number of xylem bundles is somewhat variable; these are so disposed that the pith is generally at first somewhat cruciform.

The pericycle becomes, at length, largely sclerenchymatous; numerous interrupted rings of bast fibers begin to appear but are only slightly thickened the first year.

The pith, at first cruciform, becomes somewhat quadrangular. There is a perimedullary zone (*fide* Flot [1893]). An internal cambium produces a ring of phloem just outside the pith. This is mentioned by DeBary [1884]. A few sclerotic cells were noted at the inner limit of the internal phloem.

According to Flot [1890] cork formation is sub-epidermal.

Comparison of Structure of Hypocotyl and Epicotyl.

The hypocotyl is more nearly cylindrical than the epicotyl; its epidermis less flat, its stereom is better developed the first year. Stem internodes above the epicotyl are square.

The primary structure of the hypocotyl is like that of *Tecoma*. There are four xylem bundles and four phloem bundles. In the youngest epicotyl examined the phloem forms a complete ring and there is a variable number of xylem bundles.

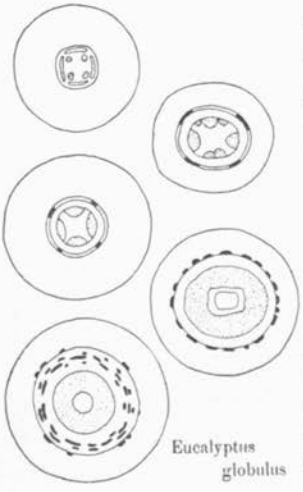


FIG. 20.

No internal phloem was recognized in the hypocotyl although it is quite distinct in the epicotyl. The cork of the former region is pericyclic or cortical in origin, that of the latter subepidermal.

BIGNONIACEÆ.

Tecoma radicans.

Structure of Hypocotyl.

The epidermal cells are rectangular in outline when seen in cross section. From being originally radially elongated they are, at length, nearly square. The cuticle in cross section appears minutely serrate. There are a few short, simple, epidermal hairs.

The cortex is of loose parenchyma, generally about six layers in thickness. There is no differentiated hypoderma.

The endodermal cells are smaller than the cells of the cortex. Originally they are irregularly hexagonal in outline, but toward the end of the year they become elliptical and have slightly thickened walls. Starch is entirely absent, except in the endodermal region until nearly the close of the first year, when it appears especially in the pith.

The stele is originally very small and somewhat four-sided, containing four xylem bundles and four phloem bundles. The latter are next the pericycle. They alternate with the xylem bundles. These are presumably the four "principal bundles" found, according to Hovelacque [1888], in all Bignoniaceous stems. At quite an early stage the phloem and xylem form closed rings.

About the time that this is apparent four small groups of sclerenchyma make their appearance in the pericycle just outside the original xylem bundles. Each of these is composed of only six to ten cells with extremely thick walls. Later numerous isolated, lignified sclerenchymatous cells appear in the outermost layer of the cortex; a few also are found in the phloem area.

The pith is large-celled and thin-walled. The formation of a cambium layer in the small-celled perimedullary region begins some time before the close of the year. This will be further noticed in the description of the epicotyl.

Cork formation takes place in the second cortical layer, *i. e.*, in the cell layer immediately below the sclerenchyma which is thus eventually lost.

Structure of Epicotyl.

The epidermis has a well-marked cuticle which, in cross section, appears minutely notched. The cells seen in cross section are about square, but become tangentially elongated toward the end of the season. There are occasional short epidermal hairs.

The cells of the outermost layer of the cortex are somewhat smaller than those of deeper layers. These are considerably flattened. Although at first of about even thickness throughout, the cortex soon grows in thickness at four equidistant points giving the epicotyl a quadrangular prismatic shape.

The endodermis, which in young stages is distinct, at length becomes indistinguishable owing to displacement and crowding of the cells caused by growth in the lower layers. Starch, though present in the endodermal region, is found only in very small amount in the cortex and pith until the close of the season. Even then the cells are not closely packed with it.

Even in the youngest stage examined, *i. e.*, second stage of our arbitrary division, the phloem and xylem form complete rings.

The outermost cortical layer toward the end of the season becomes largely sclerenchymatous, although here and there are cells with but slightly thickened walls. Certain cells of the pericycle, at first but slightly differentiated, form, at length, groups of very thick-walled cells.

The pith is composed of large cells with thin, unlignified

walls. It is found to be practically in the center of the section, though Pedicino [1876] found that when the plant climbs the pith is eccentric. About the time that the seedling has developed one internode above the epicotyl a medullary cambium has begun to form in the epicotyl. This produces xylem without and phloem next the pith. Considerable masses of phloem may thus be formed. This peculiar cambium in *Tecoma* was noted by Sanio in 1864 and fully described later by De Bary [1884]. Young branches of the plant were studied by these investigators who did not examine seedlings.

Cork formation, as previously described by Moeller [1882] for young branches, takes place in the second layer of the cortex. The cork cells are nearly square in cross section.

Comparison of the Structure of Hypocotyl and Epicotyl.

Although both hypocotyl and epicotyl are originally cylindrical, only the former remains so, the latter developing four thickened areas which make it somewhat quadrangular.

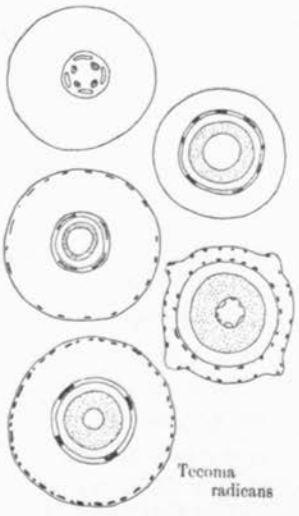


FIG. 21.

The four small groups of sclerenchyma in the pericycle of the hypocotyl are represented in the other region by a considerable number of smaller groups forming an interrupted ring.

The endodermis remains distinct in the hypocotyl for a longer time than in the epicotyl. The medullary cambium is formed later and is less active.

Catalpa speciosa.

Structure of Hypocotyl.

The epidermis consists of small cells, square in cross section. Short, blunt epidermal hairs are rather numerous. No hypoderma is developed; all the cortical cells are thin-walled.

The endodermis remains distinct for a long time. It consists of thin-walled cells which are but slightly smaller than the cells of the cortex. Starch is present, from the first, in the endodermis and toward the close of the season appears sparingly distributed in medullary rays and cortex; it is apparently absent from the pith.

The stele is small; in cross section it is circular. There are at first six, seven or eight conjoint vascular bundles arranged in a circle. Eight is probably the original number, but fusions often take place between adjoining bundles. Complete zones of xylem and phloem are formed at an early stage. About this time four small groups of sclerenchyma appear in the pericycle; they are equidistant. These eventually become somewhat divided, and other cells of the pericycle become sclerotic, so that a number of small groups of stereom are found in this area.

The pith is small in amount. The cells are large, with thin, slightly lignified walls. There is a perimedullary zone of small cells containing starch.

Cork formation takes place in the outermost layer of cortical cells.

Structure of Epicotyl.

The epidermal cells at first are oblong in cross section; the long axis is at right angles to the periphery of the section. Later the shape is more nearly square. There are many straight, blunt epidermal hairs.

The first two or three cell layers of the cortex are collenchymatous. The other layers are rather small-celled parenchyma.

The endodermis, though at first distinct on account of the presence of starch in its cells, was not recognized in older material. Starch is absent from the other tissues in the early stages, but is at length found in the cortex, phloem, medullary rays and perimedullary zone.

Toward the end of the first year a narrow, much interrupted ring of sclerenchyma appears at the outer edge of the phloem. The cells are small with very narrow lumen.

The number of vascular bundles is somewhat variable. About twenty is the usual number. These soon unite to form zones of xylem and phloem.

The pith is large, the cells thin-walled parenchyma. There is a perimedullary zone of small cells containing starch.

Cork arises in the outermost hypodermal layer, as it does in the stem of *Catalpa catalpa* (cf. Moeller [1882], p. 184).

Comparison of Structure of Hypocotyl and Epicotyl.

The epidermis of the hypocotyl has fewer and shorter hairs than that of the epicotyl. The former region has no hypo-

derma, though in the epicotyl a distinct collenchymatous zone is developed.

The endodermis of the hypocotyl remains distinct for a much longer time than that of the epicotyl; the stele has about eight vascular bundles, instead of twenty or more; sclerenchyma is first disposed in four groups instead of a considerable number.

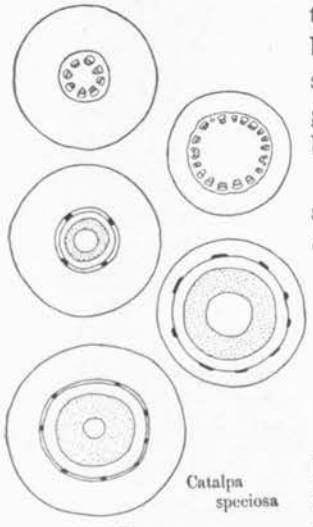


FIG. 22.

The pith of the hypocotyl is much smaller in amount than that of the epicotyl.

RUBIACEÆ.

Cephalanthus occidentalis.

Structure of Hypocotyl.

The cells of the epidermis are oblong or somewhat hexagonal in cross section. About every fifth or sixth cell is elongated radially and pointed, projecting somewhat beyond the general line of cells. These might be described as extremely short hairs. This characteristic feature continues for a considerable length of time.

No distinct hypoderma is formed. The cells of the two or three outer layers of the cortex are rather thick-walled but not collenchymatous. The cortex is loose with numerous large intercellular spaces.

The endodermis is large-celled. It remains distinct through the first year although the cells become at length very much flattened. They contain starch. Starch is later found in the various parenchymatous tissues.

The stele is circular in cross section. There are originally four phloem bundles and an equal number of xylem bundles; they are grouped in pairs. The xylem and phloem soon form closed zones, the xylem encroaching upon the pith which, at the close of the first season is almost entirely obliterated. The hypocotyl thus assumes a root-like structure—" rhizelle " of Van Tieghem [1891].

The cork is of epidermal origin.

Structure of Epicotyl.

The epidermal cells are rectangular in cross section. The radial is the long diameter at first but eventually the two diameters are nearly equal. Many of the cells are prolonged to form pointed hairs which are about three times as long as the ordinary cells of the epidermis.

A narrow collenchymatous hypoderma is developed; this shades off gradually into the ordinary cortex, which is quite extensive.

The endodermis is rather large-celled, the cells resembling those of the cortex but containing starch. The endodermis remains distinct throughout the first year. Starch, which is at first absent from the other tissues, becomes, at length, distributed through all the parenchymatous elements.

The stele, originally elliptical in cross section, follows the general shape of the epicotyl. Eventually the epicotyl becomes cylindrical as does also the stele. In the youngest material examined, the phloem forms a complete zone surrounding a ring of about six xylem bundles, which soon fuse to form a closed ring.

A few of the cells of the pericycle become sclerotic after a time. These are generally isolated; not aggregated in groups.

The pith becomes quite small; it is surrounded by a well-developed small-celled perimedullary zone whose elements contain starch.

The cork, like that of the hypocotyl, arises in the epidermis.

Comparison of Structure of Hypocotyl and Epicotyl.

The hypocotyl differs from the epicotyl in its shorter epidermal hairs, in the absence of a true hypoderma and in the much looser parenchyma of its cortex.

The structure of the stele is also very different, the hypocotyl having originally four phloem bundles and four xylem bundles, while in the epicotyl the phloem, even in the youngest

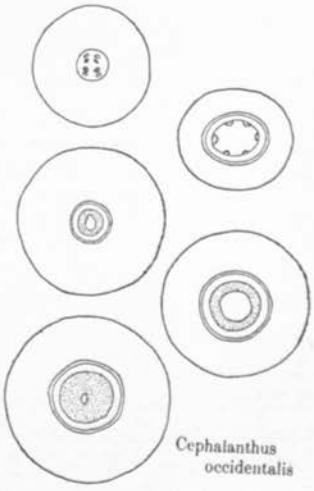


FIG. 23.

stage examined, forms a closed ring surrounding six xylem bundles.

At the end of the first year the structure of the two regions is essentially the same except that the hypocotyl is without pith or differentiated hypoderma.

GENERAL CONCLUSIONS.

The following summary and conclusions are based on the facts shown in the foregoing pages. It is not intended to repeat here all the points which are there given, but merely to bring together under appropriate headings the most important facts of structure of the hypocotyl and epicotyl in the plants studied.

General Shape of Hypocotyl and Epicotyl.—In cross section the hypocotyl is usually circular in outline, the epicotyl is, however, not infrequently hexagonal in outline and somewhat flattened. The hypocotyl has usually in early stages much the greater diameter.

Comparison of the Epidermis of Hypocotyl and Epicotyl.—The epidermal cells of both regions when seen in cross section appear at first square or radially elongated. After a time, however, they became elongated tangentially, being stretched by the growth of the stelar tissues and not continuing to divide. In quite young stages some plants have in the epicotyledonary region, epidermal cells which, in cross section, appear tangentially elongated, viz.: *Ulmus americana*, *Liriodendron tulipifera*, *Butneria florida*, *Cercis canadensis*. Trichome structures are usually fewer and less complex in the hypocotyledonary region, *e. g.*, *Ulmus americana*, *Broussonetia papyrifera*, *Butneria florida*, *Robinia pseudacacia*, *Ailanthus glandulosa*, *Catalpa speciosa*, *Cephalanthus occidentalis*. In the following species the epicotyl has trichome structures but they are absent from the hypocotyl: *Celtis occidentalis*, *Toxylon pomiferum*, *Gleditsia triacanthos*, *Ptelea trifoliata*, *Rhamnus purshiana*, *Elæagnus umbellata*, *Tecoma radicans*.

Hypoderma in the Hypocotyl and Epicotyl.—Only one of the species examined has a definite collenchymatous hypoderma in both regions. This is *Butneria florida*. The following plants have a hypoderma in the epicotyl, but not in the hypocotyl: *Celtis*

occidentalis, *Broussonetia papyrifera*, *Liriodendron tulipifera*, *Menispermum canadense*, *Gleditsia triacanthos*, *Robinia pseudacacia*, *Ptelea trifoliata*, *Ailanthus glandulosa*, *Rhamnus purshiana*, *Catalpa speciosa*, *Cephalanthus occidentalis*.

Comparison of Cortex of Hypocotyl and Epicotyl.—The cortical cells of the hypocotyl are nearly always much larger than those of the epicotyl. This is so commonly the case that various species need not here be specially mentioned; a good example is *Parkinsonia aculeata*. The cortex of the hypocotyl is thicker than that of the epicotyl.

Comparison of Endodermis and Pericycle in Hypocotyl and Epicotyl.—The endodermis in the hypocotyl is, as a rule, more distinct and persists longer than that of the epicotyl. Its cells contain starch. Pericycle is well developed in the hypocotyl, usually consisting of two or more layers of small cells.

Typical Structure of the Stele of the Hypocotyl. The stele is usually somewhat quadrangular. As a rule there are four phloem bundles and four xylem bundles. The phloem and xylem may be in contact or they may be separated by a small amount of undifferentiated parenchyma. In the latter case each phloem area is either directly outside of a xylem area (when the phloem may be spoken of as opposite the xylem), or the phloem bundles are removed from the xylem by greater or less angular distances (alternate arrangement). Using the foregoing terminology the arrangement of bundles may be described as opposite in the following: *Liriodendron tulipifera*, *Menispermum canadense*, *Butneria florida*, *Cercis canadensis*, *Amorpha fruticosa*, *Ptelea trifoliata*, *Ailanthus glandulosa*, *Schinus molle*, *Berchemia racemosa*, *Rhamnus purshiana*, *Vitis cordifolia*, *Cephalanthus occidentalis*. It is alternate in *Eucalyptus globulus* and *Tecoma radicans*.

Certain modifications of the more usual type just described would best be noted separately. There are four xylem bundles and eight phloem bundles in *Robinia pseudacacia*. In *Parkinsonia aculeata*, *Gleditsia triacanthos* and *Elæagnus umbellata* there are eight xylem bundles and four phloem bundles. The xylem bundles soon fuse together in pairs in the last two named species. In *Celtis occidentalis* and *Toxylon pomiferum*, the phloem forms two crescent-shaped areas while the arrangement of the xylem is normal.

Unusual Structure of the Stele of the Hypocotyl.—In certain

species the stele of the hypocotyl does not have the typical structure just mentioned, the number and arrangement of vascular bundles being different. *Ulmus americana* has two xylem crescents and numerous small phloem bundles; *Broussonetia papyrifera* has a root-like structure; in *Catalpa speciosa* there are about eight vascular bundles.

Primary Structure of the Stele of the Epicotyl.—In shape the stele of the epicotyl is often originally somewhat hexagonal, though, as in the case of the hypocotyl, becoming at length cylindrical. As is well known there are usually from six to very many vascular bundles. Sometimes the phloem is completely fused into a closed zone even in very young stages.

Arrangement of Sclerenchyma in the Hypocotyl. The sclerenchyma of the hypocotyl first appears as four masses in the pericycle in *Toxlyon pomiferum*, *Liriodendron tulipifera*, *Cercis canadensis*, *Gleditsia triacanthos*, *Robinia pseudacacia*, *Ailanthus glandulosa*, *Vitis cordifolia*, *Eucalyptus globulus*, *Tecoma radicans* and *Catalpa speciosa*. In the plants just named this original disposition of the sclerenchyma becomes altered either by the intercalation of parenchymatous elements in the areas of sclerenchyma or by the development of sclerenchyma at other points. In the following plants, however, there is practically no change in the sclerenchyma during the first year and the four original masses remain to the end of the season: *Parkinsonia aculeata*, *Amorpha fruticosa*, *Ptelea trifoliata*, *Berchemia racemosa*.

Comparison of the Hypocotyl and Epicotyl with Reference to the Distribution of Sclerenchyma. Commonly the sclerenchyma in the two regions becomes, at the close of the first growing season, equally well developed and similarly arranged. Exceptions to this rule will now be noted. Sclerenchyma is absent from the hypocotyl of *Menispermum canadense*, *Butneria florida* and *Rhamnus purshiana* although present in the epicotyl. In *Ptelea trifoliata* and *Berchemia racemosa* at the close of the first year there is a greater development of sclerenchyma in the epicotyl than in the hypocotyl. The reverse of this condition obtains in *Celtis occidentalis* and *Eucalyptus globulus*. Only scattered sclerenchyma in small amount was recognized in either region in year-old material of *Broussonetia papyrifera;* in *Cephalanthus occidentalis* a few only of the pericyclic cells of the epicotyl become sclerotic.

Cork Formation in Hypocotyl and Epicotyl. The cork cambium is developed in the layer of cells next below the epidermis in both hypocotyl and epicotyl of *Celtis occidentalis*, *Liriodendron tulipifera*, *Butneria florida*, *Ptelea trifoliata*, *Ailanthus glandulosa*, *Catalpa speciosa*. In *Cephalanthus occidentalis* it is of epidermal origin in both regions. In the following species cork formation is sub-epidermal in the epicotyl but the cork is produced in deeper cell layers of the hypocotyl: *Ulmus americana*, *Toxylon pomiferum*, *Broussonetia papyrifera*, *Rhamnus purshiana*, *Elæagnus umbellata*, *Eucalyptus globulus*. In *Cercis canadensis*, *Gleditsia triacanthos*, *Amorpha fruticosa*, *Robinia pseudacacia*, *Vitis cordifolia* and *Tecoma radicans* cork formation in the epicotyl is cortical, while in the hypocotyl it takes place in some cases in the same cell layer, in other cases in deeper layers. Details are given in the previous descriptions for the separate species.

Pith and Perimedullary Zone of Hypocotyl and Epicotyl. The pith of the hypocotyl is smaller than that of the epicotyl, sometimes it becomes nearly obliterated, *e. g.*, *Cephalanthus occidentalis*. The perimedullary zone is sometimes not distinguished in the hypocotyl though present in the epicotyl, *e. g.*, *Parkinsonia aculeata*, *Gleditsia triacanthos*, *Eucalyptus globulus*. The opposite condition is found in *Cercis canadensis* and *Berchemia racemosa*. More often where a perimedullary zone is recognized it is equally developed in both hypocotyl and epicotyl.

Structure of Hypocotyl and Epicotyl at the close of the first year's growth.—Owing to secondary changes the two regions, though at first quite dissimilar in structure, may come to be very much alike. The xylem and phloem always form closed rings; the endodermis often becomes indistinguishable; the cells of the cortex become flattened. The differences of pith, perimedullary zone and sclerenchyma have already been given.

Condensed Summary.

Although secondary changes may cause a great resemblance in the structure of hypocotyl and epicotyl, the two regions are, in their primary structure, essentially dissimilar.

The epidermis of the hypocotyl is more often without trichome structures, the cortex is thicker and composed of larger cells,

the endodermis is more distinct and persists for a greater length of time, the pith is smaller, sclerenchyma is often less well-developed and differently arranged and a hypoderma, so common in the epicotyl, is nearly always absent. Cork formation in the hypocotyl begins either in the same cell-layer that it does in the epicotyl or in a deeper layer, never in a more superficial one.

Starch is, as a rule, distributed in the same way in both regions. It is usually present in the endodermis in the early stages but does not appear in other tissues until the plant has developed foliage leaves, in considerable number.

As to the structure of the stele it may be said that in the hypocotyl there are usually four primary vascular bundles. The exact disposition of the phloem and xylem elements is subject to some variation. Occasionally there are more than four bundles. In the epicotyl the vascular bundles are from six to eight or very many.

The hypocotyl does not have a root-like structure.

Explanation of Plates.

Plate V. Drawings of cross sections to show the primary stelar structure of the hypocotyl of *Ulmus americana*, *Celtis occidentalis*, *Toxylon pomiferum* and *Broussonetia papyrifera*.

Plate VI. Drawings of cross sections to show the primary stelar structure of the hypocotyl of *Menispermum canadense*, *Butneria florida*, *Amorpha fruticosa*, *Robinia pseudacacia* and *Ptelea trifoliata*.

Plate VII. Drawings of cross sections to show the primary stelar structure of the hypocotyl of *Ailanthus glandulosa*, *Schinus molle*, *Berchemia racemosa*, *Eucalyptus globulus*, *Catalpa speciosa* and *Cephalanthus occidentalis*.

Plate VIII. Photographs of cross sections to show the primary structure of the hypocotyl. 1. *Ulmus americana*, 2. *Liriodendron tulipifera*, 3. *Parkinsonia aculeata*, 4. *Cercis canadensis*, 5. *Berchemia racemosa*, 6. *Vitis cordifolia*, 7. *Eucalyptus globulus*, 8. *Tecoma radicans*.

The drawings were all outlined with the aid of a camera lucida. The magnification used was about five hundred diameters. For publication the drawings have been reduced to one-half their original size. The magnification used in making the photographs was from fifty to eighty diameters. They have been slightly reduced. All drawings and photographs were made by the author from his own preparations.

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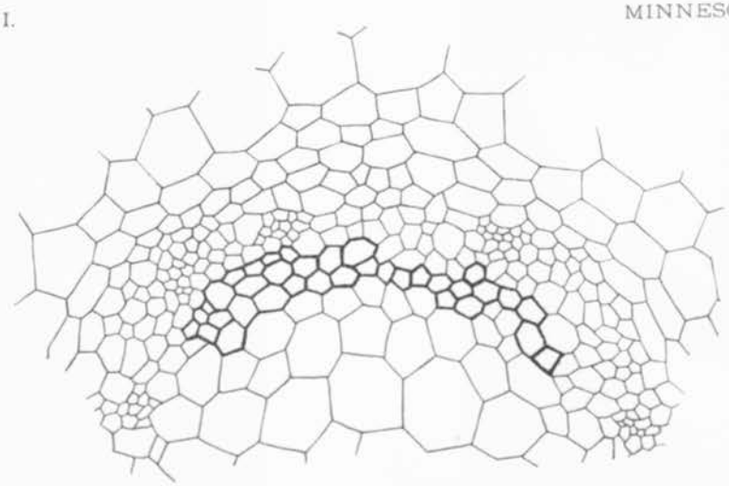
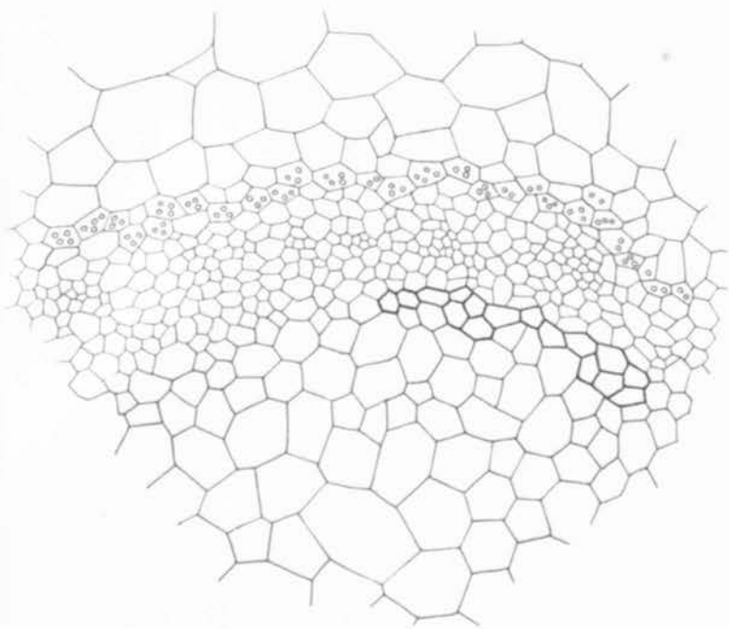
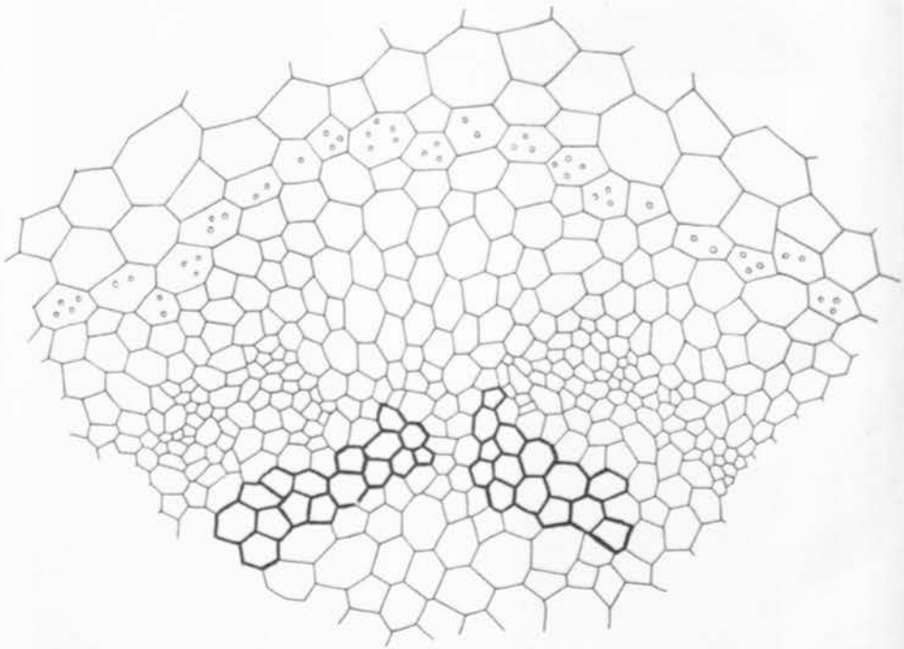


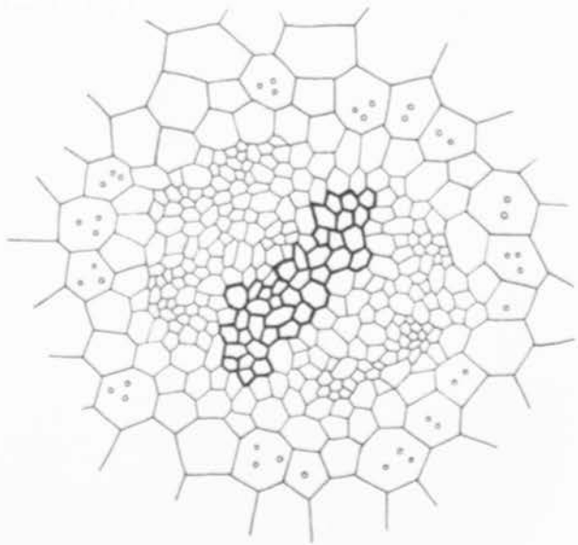
Ulmus americana



Celtis occidentalis

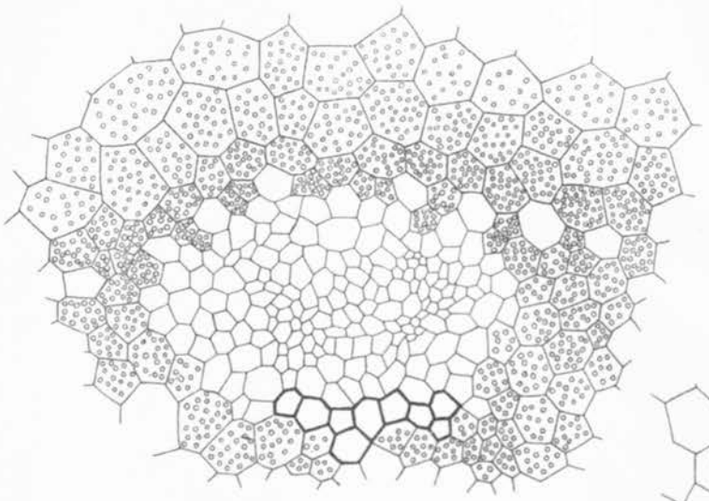


Toxylon pomiferum

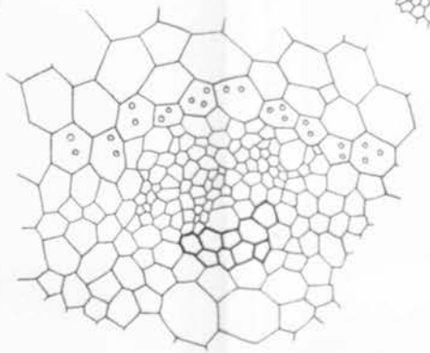


Broussonetia papyrifera

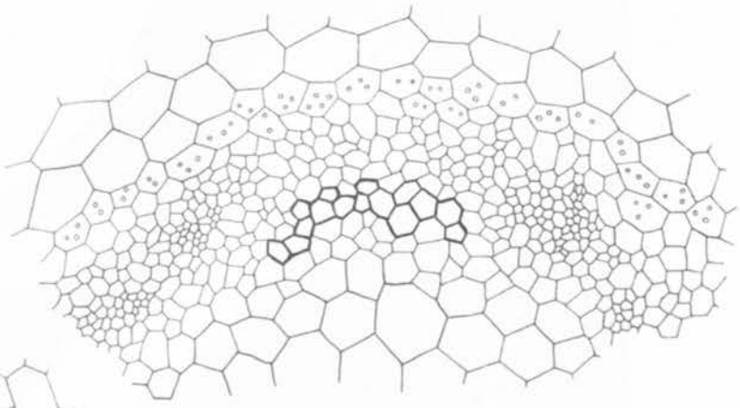
PLATE V.



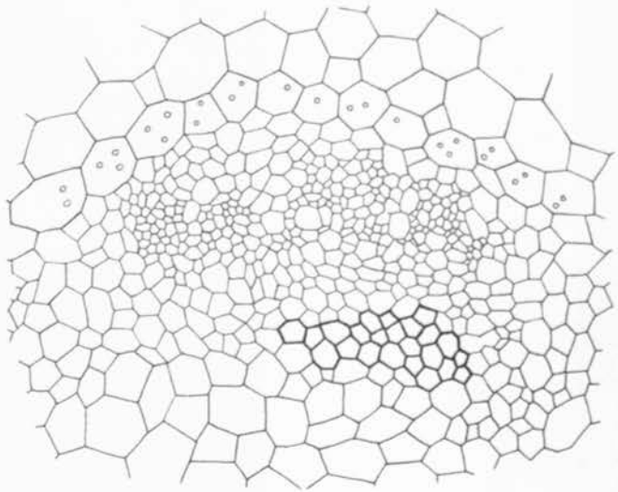
Menispermum canadense



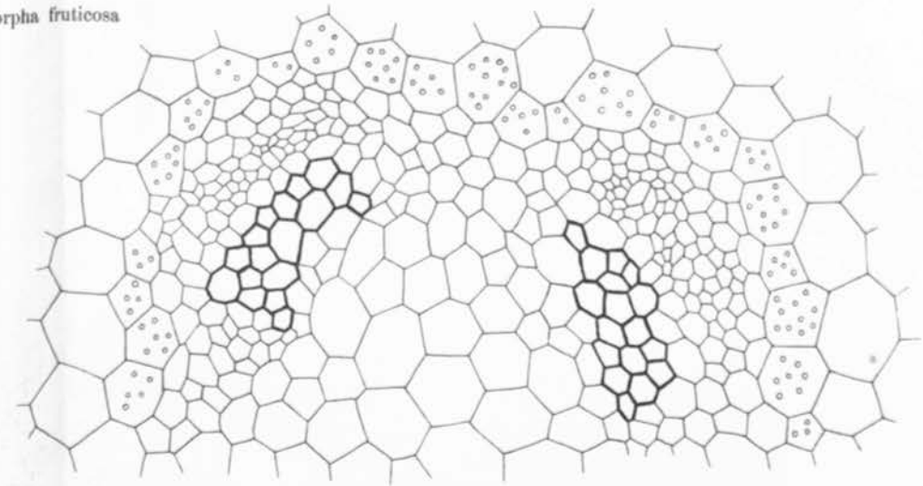
Amorpha fruticosa



Robinia pseudacacia



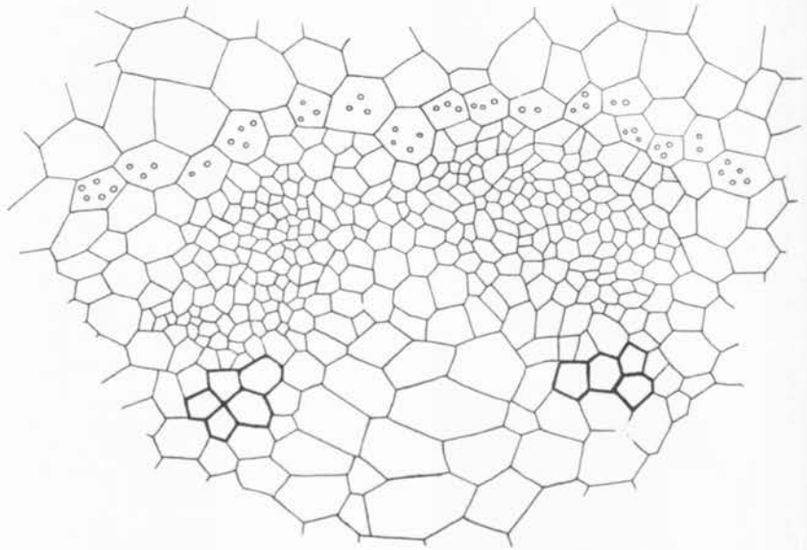
Butneria florida



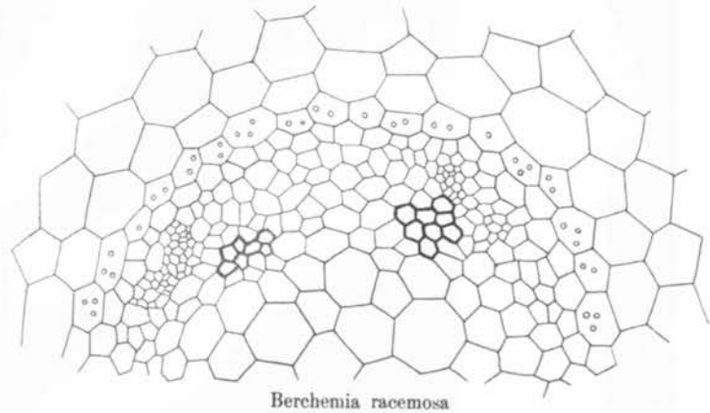
Ptelea trifoliata

PLATE VI.

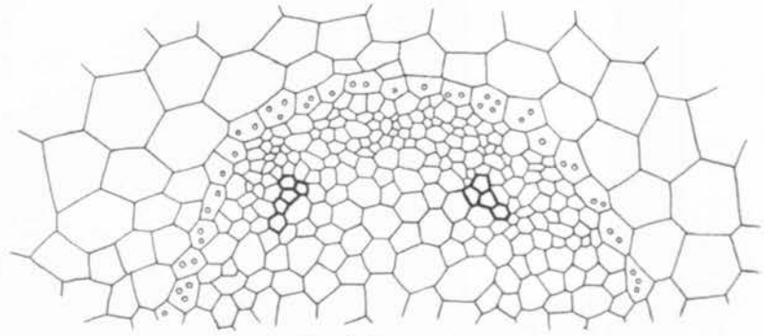
BELLSTYPE PRINTING CO., BOSTON



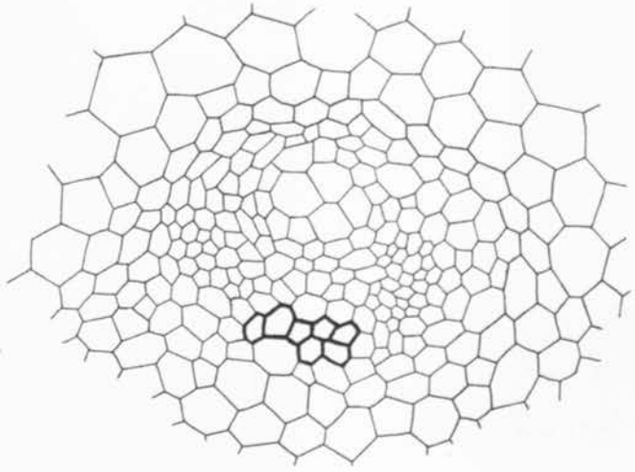
Ailanthus glandulosa



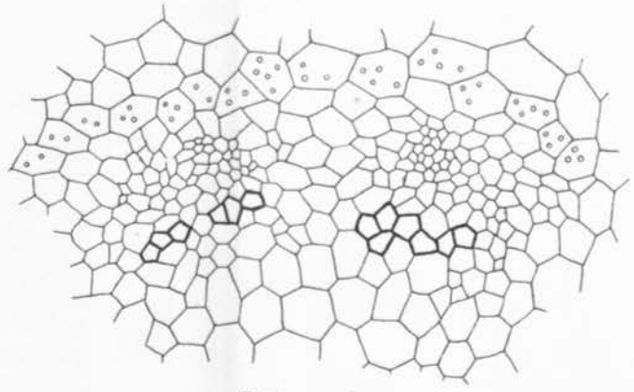
Berchemia racemosa



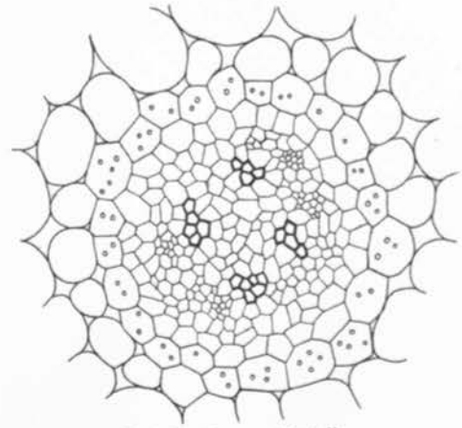
Eucalyptus globulus



Schinus molle



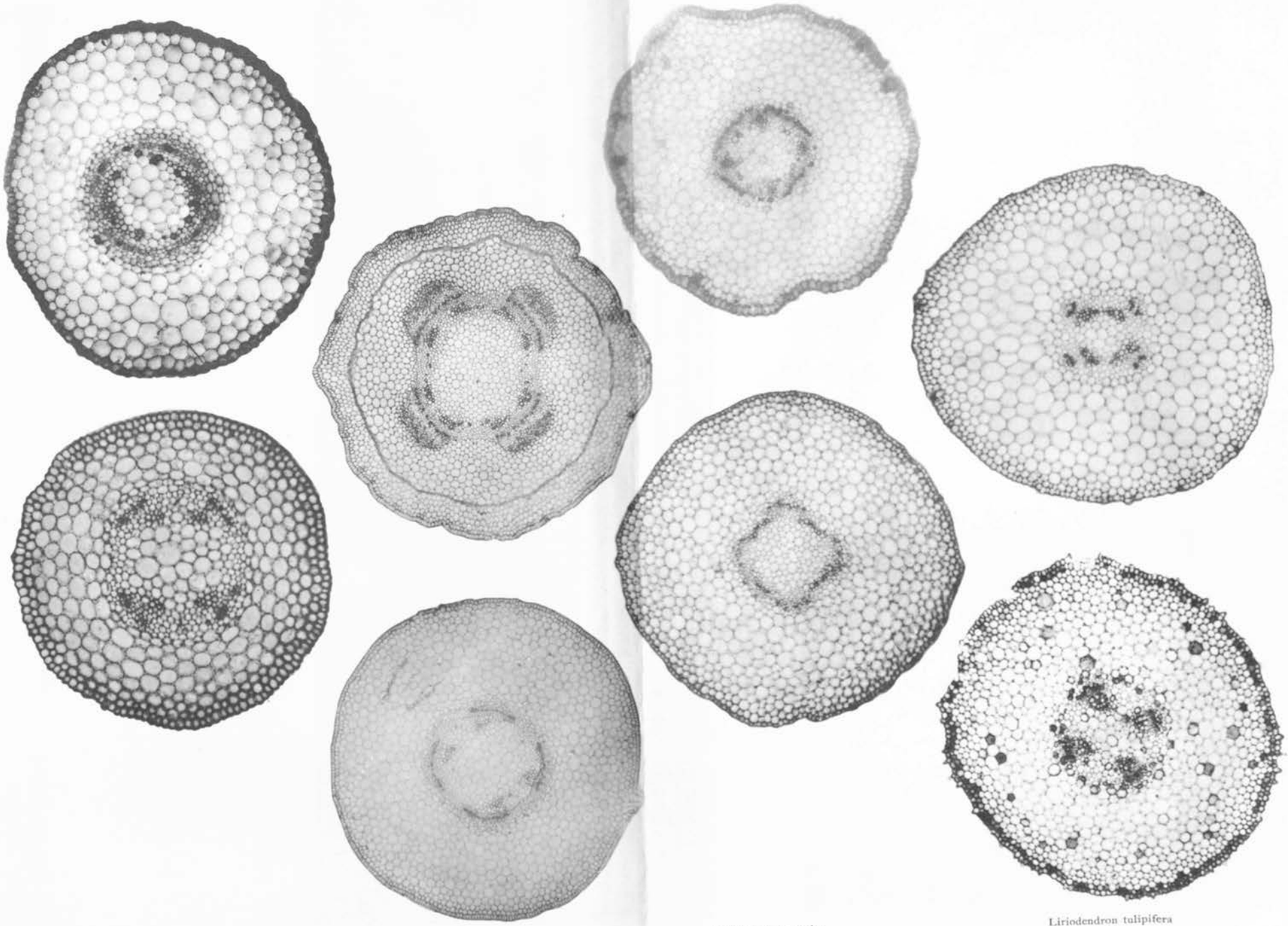
Catalpa speciosa



Cephalanthus occidentalis

PLATE VII.

HELIOTYPE PRINTING CO., BOSTON



Ulmus americana
Berchemia racemosa

Parkinsonia aculeata
Cercio canadensis

Eucalyptus globulus
Tecoma radicans

Liriodendron tulipifera
Vitis cordifolia

PLATE VIII.

THE HELIOTYPE PRINTING CO. BOSTON