Fiber, or **Fibre** [from Fr. *fibre* < Lat. *fibra*, fiber, filament]: a delicate, thread-like portion of the tissue of a plant or animal; also a substance composed of such filaments. Man has for ages availed himself of the filamentous character of various parts of plants to make clothing, domestic utensils, parts of instruments of the chase, and shelter for himself and his possessions. The animal kingdom has also been laid under contribution from the earliest times, and even the mineral kingdom contributes, in the substance known as asbestos, a fiber—in the general sense of the word—which has various uses in the arts. The history of the employment of these different materials, their uses, and the details of those processes of manufacture by which they are converted into fabrics for the use of man, belong properly to the different articles in this work in which they are severally described. (See SILK, WOOL, etc.) But the minute characteristics of the principal vegetable fibers, and the points on which their value for particular purposes depends, are most conveniently studied by grouping them under one subject. Anatomically considered, vegetable fibers may be referred to three different sources: viz., (1) plant-hairs, (2) fibro-vascular bundles, or (3) the separate constituents of the latter. (1) The important plant-hairs employed for textile purposes are the long, single cells which are attached to the seeds of certain species of *Gossypium* (cotton). (2) Fibro-vascular bundles are obtained from the stems of monocotyledonous plants, and consist chiefly of long bast-cells, with an admixture of spiral ducts (e. g. Manilla hemp). (3) The principal elements of fibro-vascular bundles of dicotyledons —namely, bast-cells and woody tissue—are used separately as fibers for spinning or for paper-making (e. g. flax and poplar-wood). These structures are cells of different shapes, sizes, and thickness of wall. Although they are derived from sources so different, they possess in common certain chemical and physical properties which must be considered before an examination of individual fibers is undertaken.

Chemical Characters.—The principal material of vegetable tissues consists of cellulose ($C_6H_{10}O_5$, or some higher multiple, $C_{18}H_{30}O_{15}$). This is generally accompanied by an incrusting substance which greatly reduces the flexibility of the fiber. Fibers are freed from this incrusting matter by the careful use of acids, alkalies, and bleaching agents. Cellulose dissolves in an ammoniacal solution of cupric oxide. For an account of other changes produced by chemical agents, see GUNCOTTON, and PAPER.

Physical Properties.—Fibers vary in color, from the snow-white of china-grass (*Böhmeria nivea*) to the grayish black of *Tillandsia*. All vegetable fibers are doubly refringent in polarized light. The conductive power of vegetable fibers for heat appears to be greater in the direction of the length of the fiber than perpendicular to it. The hygroscopic power of fibers is shown in the following table by Wiesner (*Rohstoffe*, § 293):

FIBER.	Percentage of water when air-dry.	Greatest amount of water.
Esparto	6·95	13·32
Belgian flax	5·70	13·90
Cotton	6·66	20·99
Fresh jute	6·00	23·30
Manilla hemp	12·50	about 40·00

Cotton.—Cotton fibers are the hairs which grow upon the seeds of species of *Gossypium*, plants belonging to the mallow family. Five species, now much mixed up, produce most of the cotton of commerce—*G. arboreum, barbadense, herbaceum, hirsutum, religiosum.* In India and China *G. arboreum* and *religiosum* are extensively cultivated; *G. hirsutum* is common in the West Indies; *G. barbadense* and *herbaceum* are those best known in the U. S. The seeds are numerous in the capsule (boll), which splits from the top into three or five parts as the fruit ripens. Each seed is clothed with delicate cells of variable length. Very short hairs are mixed thickly with the longer cells, which are used as fibers. The longer cells vary in length within certain limits in different species; the following measurements by Wiesner are averages:

Gossypium barbadense	3·89–4·05 cm.
" *arboreum*	2·50
" *herbaceum*	1·03–1·82 cm.

The cells are slender cylinders, with a slight enlargement a little above the base, after which they taper to the summit. The thin walls collapse and twist as the seed ripens, so that the slender, tapering tubes become spiral bands. The breadth of the flattened cells varies in different species. The measurements (from Wiesner) are given in fractions of a millimeter:

G. barbadense,	0·0192–0·0279,	most common	0·0252
G. arboreum,	0·0200–0·0378,	" "	0·0299
G. herbaceum,	0·0119–0·0220,	" "	0·0189
G. religiosum,	0·0255–0·0400,	" "	0·0333

The spiral is irregular, sometimes turning to the right and then abruptly turning in the opposite direction; occasionally there is simply a folding of one edge of the band over the other. These spirals adapt the cells for spinning. Contiguous fibers cling together slightly by interlocking their spirals as they are drawn out, and this slight grasp is strengthened by torsion of the thread at the spindle. Length of fiber is known in the cotton trade as length of "staple."

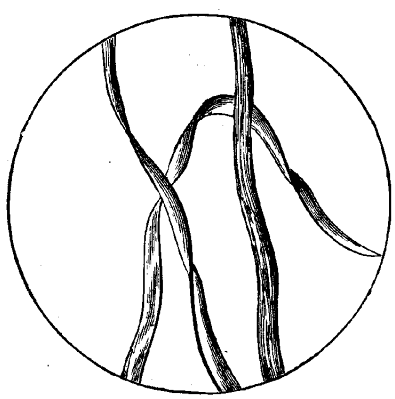

FIG. 1.—Cells of cotton (170 diam.).

Under a magnifying power of 200 diameters the flattened cell, if ripe, exhibits plainly the cell-walls and the space between them, which is filled with air. In exceptional cases the walls are thick, and then the air-space is reduced to a slender dark line. The surface of the wall has a cuticular layer, which may appear unevenly striated, somewhat granular, or nearly smooth. When a cotton fiber is placed in an ammoniacal solution of cupric oxide, the cell-wall dissolves, and leaves the cuticular layer somewhat altered in shape. The same phenomenon is observed in the case of other plant-hairs—for instance, vegetable silk—but never in bast-cells. This use of the solvent serves for the positive discrimination of the textile plant-hairs. The cotton fiber is usually white, but may be tinged yellow (*G. religiosum*). The finer short fibers are frequently colored green (*G. hirsutum*). This becomes rose-red on the addition of dilute acid, but the green color is restored by ammonia. The removal of the cotton fiber from the epidermis of the seed is effected without material injury to the hairs of black-seed cotton by means of the saw-gin. In green-seed cotton the fibers are more closely adherent. The shorter hairs which remain after the ginning are utilized in paper-making. The characters which determine the commercial grade of cotton are length of staple, fineness, and whiteness. In sea-island cotton, always black-seeded (*G. barbadense*), the latter qualities are found combined with great length of staple. The cotton of Louisiana is short-stapled, fine, and white; that from *G. religiosum* (and *G. flavidum*) is short-stapled, fine, and yellow.

Bombax Wool.—The mature seeds of many *Bombaceæ* are packed in their capsules in a mass of silky hairs which have become detached during ripening. These hairs are single cells of brilliant luster and a yellowish-brown color. It can not be spun except when mixed with cotton or other fibers, which it can in no way improve.

Vegetable Silk.—Under this name are grouped the fibers which grow on the seeds of many milkweeds (*Asclepiadaceæ* and the like). The remarkable fineness and luster of these fibers have led to many futile attempts to employ them, either alone or with cotton. The fiber is so weak and brittle that it would be useless for weaving even if it could be spun. A species of *Beaumontia* in India yields a vegetable silk of greater strength and almost pure whiteness. It is used in the manufacture of artificial flowers.

Fibro-vascular Bundles of Monocotyledonous Plants.—New Zealand Flax.—This fiber is obtained from *Phormium tenax*, now extensively cultivated in New South Wales. The leaves yield 22 per cent. of merchantable fiber. The fiber is yellowish, and composed of bast-cells mixed with ducts and cambium-cells. The bast-cells are 0·008–0·0189 mm. broad, and 2·7–5·65 mm. long. These form the raw fiber, which often exceeds a meter in length. New Zealand flax is fitted for cordage by its strength and resistance to the action of water and the atmosphere. According to Labillardière, the absolute strengths of the New Zealand flax, hemp, and flax are in the ratio of 60 : 48 : 34·5 ; silk = 100.

Aloë Fiber.—This is obtained from tropical species of *Aloë*. The fiber is white, of brilliant luster, and of nearly the same thickness throughout its great length of 20–50 cm. It is made up chiefly of bast-cells 1·3–3·72 mm. long, which do not readily separate from the bundle. The fibers are used in the rough state for cordage. The finest aloë fibers are spun and woven for fine muslins.

Manilla Hemp.—This fiber, known also in commerce under the names plantain fiber, Siam hemp, Menado hemp, and white rope, is obtained from the clasping leaf-stalks of *Musa textilis* of the Philippine islands. The fibers of other species of *Musa* have been employed, notably the plantain and banana. The outer parts yield coarse fibers 7 meters long—the inner, finer, about 2 meters. The fiber consists chiefly of bast-cells 2·7 mm. long and ·029 mm. thick. Manilla hemp is used for cordage.

Agave fiber, from *Agave americana*, now cultivated in many warm climates, is less tough and flexible than Manilla hemp. It is extremely light, and is capable of extensive use in rigging, but it has been more employed as an addition to bristles in the manufacture of brushes. "Sisal hemp" is the commercial name of the fiber of *Agave rigida*.

Cocoanut fiber, from species of *Cocos*, a tropical palm, is known in commerce under the name coir. It consists of the fibro-vascular bundles of the husk of the fruit. It is reddish-brown in color, very strong, and withstands the action of water for a long time. It is regarded by Grothe as the lightest of all fibers which can be used for making cordage. The raw fiber is 15–33 cm. thick, and consists of many structural elements. The bast-cells are the most important. These are from half a millimeter to a millimeter in length, and 0·016 mm. broad. The walls are unequally thickened. Coir is one of the most important vegetable fibers of the tropics. It is used for twine, cordage, tapestry, brushes, coarse paint-brushes, and even machine-belting.

Pineapple Fiber.—The fibers of the leaves of several species of *Bromelia* are employed for textile purposes. *Bromelia karatas*, of South America, yields a whitish, glistening fiber which resembles Manilla hemp, but is coarser, weaker, and less flexible. The fibers are cylindrical and about a meter in length, seldom exceeding 1·2 mm. in thickness. Its constituents are chiefly thin-walled bast-cells, with a few spiral vessels. When carefully prepared the finest fibers can be used for delicate fabrics.

Bast-fibers from Dicotyledonous Plants.—These are the inner layer of the bark. They are long, flexible cells, with thick walls, aggregated with parenchyma in bundles or bands which are separated by very narrow (or in some cases wide) medullary rays.

Flax.—This is the bast-fiber of species of *Linum*, chiefly *L. usitatissimum*, of which there are several varieties. The separation of the bast-fibers of flax, hemp, etc., from their contiguous tissues involves mechanical and chemical manipulations which are elsewhere described in detail. The stems are first subjected in mass to the action of water, either cold or warm. A kind of fermentation ensues, after which the bast-fibers can be separated from the surrounding tissues by mechanical means. The processes are known as "retting" and "scutching." The best results have been reached by what is known as warm-water rotting, followed by the use of a heckling machine, from which, according to the quality of the flax-plant, 15–20 per cent. of pure flax has been obtained. The length of flax fibers thus separated varies from a fifth of a meter to a meter and two-fifths; their width varies from 0·045–0·620 mm. The fibers are made up of regular cylindrical cells which taper toward the ends. The caliber of the cells is very minute, and is often reduced so that it appears a mere dark line. The cells are 2–4 cm. long and from 0·015–0·017 mm. broad. Here and there minute canals are to be detected in the walls, and by crushing the cell-wall exhibits spiral markings. The microscopic appearance of fresh flax bast-cells differs from that presented by manufactured fiber. The thickening layers of the cell-wall are more or less broken, and the cells are covered with dark lines which are nearly parallel to each other, and generally run in the direction of the length of the cell. This appearance is seen under a magnifying power of 200–300 diameters.

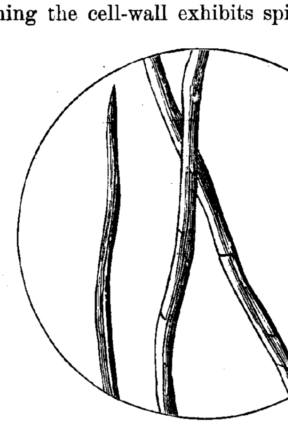

Fig. 2.—Bast-cells of flax (170 diam.).

The best flax fiber is whitish, and this absence of color is secured by the best methods of preparation. Much of the Belgian flax is steel-gray, and that of Egypt is grayish yellow. Flax has a delicate silky luster. The total absence of any luster is an indication that the bast-cells have not been wholly freed from surrounding tissues. Irish, Belgian, and Italian flax is regarded finest. The Irish fiber is very fine, soft to the touch, and strong. Many Belgian varieties are nearly as fine as the Irish, and exceed it in length. The longest fiber comes from Egypt. It is coarse and hard to bleach, but very strong. The use of flax in the manufacture of linen thread and linen fabrics can be traced further back than that of any other textile vegetable fiber. It is spun before bleaching.

Hemp.—This fiber consists of the bast-cells of *Cannabis sativa*, a plant of the nettle family. Hemp fiber is generally longer than flax fiber, sometimes reaching a length of 1 or 2 meters, or even more. Whitish and grayish fibers are best, the greenish come next, and lastly come the yellowish. Hemp fiber, even when finest, contains a mixture of parenchyma with the bast-cells. The latter are not so regular as those of flax. The walls are not always equally thick, but they are in general strongly thickened, and exhibit the canals which have been described under *Flax*. The air-space in the cells equals one-third of the whole breadth of the cell. Wiesner has shown that an ammoniacal solution of cupric oxide serves for the discrimination of hemp from flax. Under the influence of this agent the inner layer separates and becomes much crumpled, while the outer portion of the cell-wall becomes swollen and exhibits a fine parallel marking. Flax and cotton become blue by the action of iodine solution and sulphuric acid, but hemp turns somewhat greenish. The finest hemp is Bolognese, but by far the largest amount comes from Russia. It is not so fine as the hemp from Prussia or Austria. The hemp produced near Strassburg is used for spinning. Hemp is chiefly used for fine and coarse cordage.

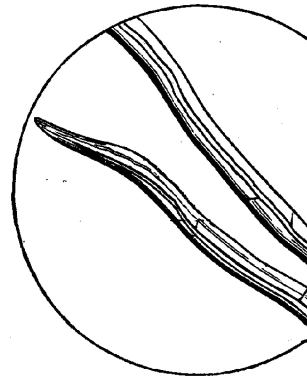

Fig. 3.—Bast-cells of hemp (170 diam.).

Mallow Hemp.—Several plants of the mallow family yield fibers which may be treated of in this place.

Hibiscus cannabinus of India, now cultivated in the West Indies, where it is called *ambaree*, has fibers of unequal length and differing greatly in their thickness. The bast-cells are 4–6 mm. long and ·020–·041 mm. thick.

Sida retusa and other species of *Sida* are much used in India as sources of fibers, which are coarse or fine according to the mode of preparation. The bast is without luster and of remarkable strength. The fibers consist almost wholly of flattened irregular cells, which in other characters much resemble the bast-cells of flax. Sunn hemp is produced from stems of *Crotolaria*, a plant of the pulse family. It is a fine and very strong fiber, only slightly hygroscopic. It is known in India also as Madras hemp. The flattened fibers are striated, and vary in width from 0·02–0·35 mm. Tercum fiber and Jetee fiber are from the stems of plants of the milkweed family.

China-grass and Ramie.—These are from plants of the nettle family—the first from *Böhmeria nivea*, and the second from *B. tenacissima*. China-grass is cultivated in India and Southern China. The bast is very tough, and can be finely divided into minute fibers, which are known as cottonized fiber. It is whiter and more lustrous than ramie fiber, but in other respects does not differ widely from it. *Ramie* is cultivated in China and Japan and in some parts of America. By the "cottonizing" process the fibers are broken up into the bast-cells, which are themselves sometimes broken. It is frequently possible to detect under the microscope traces of the mechanical injuries which they have received in the process. From the coarser fibers cordage is made, but from the finer the so-called *grass-cloth* or *grass-linen* is woven. The manufacture was long confined to India and China, but it has been undertaken in Germany as well.

Jute is the fiber of several Indian species of *Corchorus*, a plant of the linden family. *Corchorus capsularis* is the species most commonly employed in cultivation. In warm countries the culture of jute presents few difficulties. The seed is sown in April or May; in June or July the plant is in flower; in September or October the fruit is ripe. The strength and flexibility of this fiber, like those of flax, hemp, and ramie, diminish at the time the fruit matures. The bast-cells at that time become woody and more brittle, so that it is always desirable to cut the stems before the ripening of the fruit. The yield of jute is said to be from two to five times as great as that of hemp or flax. The stalk is 3 to 4 meters high. The fiber of jute is very silky, slightly colored, and composed almost wholly of bast-cells, which are cylindrical, somewhat flattened, or prismatic. The cells are 0·8–4·1 mm. long, and 0·016 mm. thick. The most striking peculiarity of its microscopic structure is the total lack of parallelism between the inner and outer surfaces of the wall. At many points the cell-wall is much thickened, while in others it is as thin as in vegetable silk. The same unevenness is seen in a few other fibers, but not in flax or hemp. Jute in its finest state has such a brilliancy of luster, and takes colors so well, that it has been much used to mix with silk. Much has been employed as a substitute for human hair in the manufacture of chignons, etc. Of late it has found an extensive use in papermaking. Jute is extensively exported from Calcutta, and is used chiefly in the manufacture of bagging. The term *gunny bagging* (*goni*, a Madras word) was applied not only to this, but to coarse fabrics made out of sunn, *Crotolaria juncea*. Much jute is brought into the market in the form of jute butts, in which state it is taken by the papermakers. A fiber much like jute, and frequently mixed with it, is obtained from *Abelmoschus* (*Hibiscus*) *tetraphyllos*, a plant of the mallow family from India. The bast-cells are 1–1·6 mm. long, and about 0·016 thick. See JUTE.

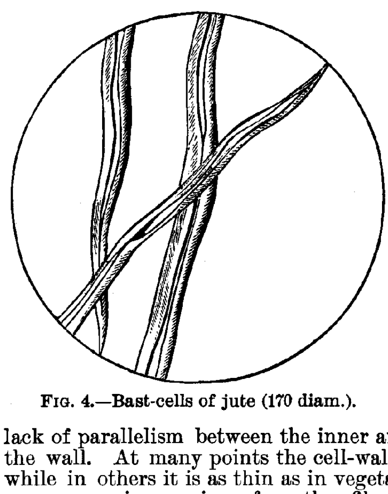

FIG. 4.—Bast-cells of jute (170 diam.).

Esparto Fiber.—This is obtained from the stems and leaves of *Macrochloa tenacissima*, a grass of Southwestern Europe. The fiber has been employed in the manufacture of coarse twine, but is now used wholly for papermaking.

Any of the fibers which have been spoken of can be used in the manufacture of paper, but only a few of them can be economically employed for this purpose at first hand. The fibers first serve in cordage or in woven fabrics, and then are turned over in the form of rags to the papermaker. Fibers for paper must be waste products or very cheap raw material (for instance, wood-tissue) which can be economically worked. *Zizania* (wild rice), *Phragmites* (reed), and the straw of cereals are used in the manufacture of different grades of paper.

Paper Mulberry.—This plant, which belongs to the fig family, furnishes the fibers of which the tapa cloth of Polynesia and the common paper of Japan are made. The inner bark is beaten to a pulp and spread out in thin layers. Much of the Japanese paper contains some vegetable mucilage by which the texture is rendered firmer, but in general the tissues cohere without the addition of any size.

Bast Tissue.—The bast of the linden and some other exogenous plants may be separated from the stem in broad and thick bands, which can be split up into thin ribbons. From these thin bands the coarse Russia matting is made.

Bast of the Linden (*Tilia parvifolia* and *T. grandifolia*).—Stems 30 to 40 cm. high are best for the purpose. From these stems strips 6 to 7 cm. broad can be taken. Their ultimate bast-cells are very thick-walled, and sometimes much widened in the middle. Cuba bast, used for tying up packages of cigars, is from *Paritium tiliaceum* and *elatum*, plants which may be referred to the genus *Hibiscus*, of the mallow family. *Lagetta lintearia*, the lace-bark tree, yields a delicate but strong white bast which has open meshes like coarse lace. *Daphne cannabina*, another plant of the same family (*Thymelaceæ*), has a tough, fibrous bast, which is employed in India for the manufacture of cordage and paper.

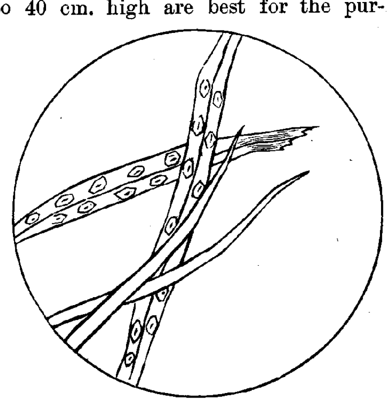

FIG. 5.—Spruce fibers (170 diam.).

Woody Fibers.—These are not used for spinning, but they are finding extensive application in papermaking, and their characters should now receive attention. Two important woods are selected, poplar and spruce, both of which are disintegrated either by mechanical means or by chemicals. In some mills the wood is boiled under pressure, with or without the presence of alkalies, after which it is easily broken down into its cells. In the Voelter process the wood is simply ground upon a rough surface, and the fibers are sufficiently fine for papermaking. The processes will be described in the article PAPER.

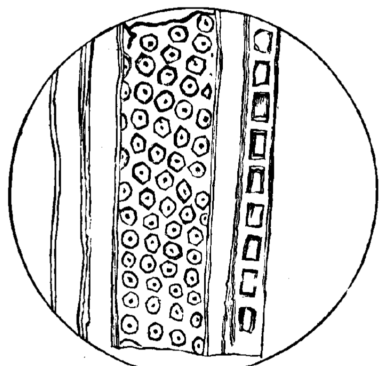

FIG. 6.—Poplar fibers and pitted vessel (170 diam.).

Chemical Tests for Vegetable Fibers.—*A. Iodine in solution, followed by sulphuric acid.* 1. Blue color: cotton; raw flax; cottonized china-grass and ramie (sometimes reddish to blue); raw hemp, greenish blue to pure blue. 2.

Yellow to brown: raw jute; raw esparto; bromelia; aloë and New Zealand flax.

B. Ammoniacal solution of cupric oxide. 1. Dissolves the cellulose: cotton, the cuticular layer remaining; cottonized china-grass and ramie; raw flax; hemp; sunn. 2. Colors the fiber blue, and causes it to swell up: raw jute; New Zealand flax; aloë; bromelia. 3. Simply colors the fibers: vegetable silk, blue; esparto, green.

C. Sulphate of aniline. Almost without effect on cotton, raw and cottonized china-grass and ramie; raw flax and New Zealand flax. Produces change of color in raw jute (gold yellow), raw hemp (light yellow), esparto (bright yellow), aloë and bromelia (gold yellow).

Microscopical Discrimination of Fibers as used.—Fibers of a single cell: cotton, vegetable silk, bombax wool (plant-hairs), cottonized ramie and china-grass (isolated bast-cells). Groups of cells chiefly bast: raw jute, flax, aloë. Groups of cells chiefly bast, with traces of parenchyma of the bast: raw sida, abelmoschus, and hemp. Groups of bast-cells mixed with ducts; New Zealand flax, Manilla hemp, esparto, coir. E. M. SCHAEFFER.