PART I.—OF WOOD IN GENERAL.

CHAPTER I.

THE ORIGIN, STRUCTURE, AND DEVELOPMENT OF WOOD AND ITS USE TO THE TREE.

FEW, if any, of the products of nature are of such manifold utility as wood. Though coal has in many lands largely replaced it as fuel, and as a source of tar, though stone, brick, and iron or steel have often been substituted for it as house-building materials, and the metals last mentioned for the construction of ships, new uses are constantly arising for it, such as railway sleepers, pavements, and paper-making, so as to more than make up for the saving effected by these substitutes. In England and the United States, for example, the consumption of wood per head of the population, during the last half century, has more than doubled.

Most people are aware that for these manifold uses a great number of different woods are employed in the various countries of the world—woods that differ in colour, grain, hardness, weight, flexibility, and other properties almost as widely as the trees by which they are produced vary in foliage, flower, or fruit. It is, however, not so generally recognized that the suitability of wood of any kind for some particular purpose depends mainly upon its internal structure. This structure is determined not by man's employment of the material, but by the vital requirements of the tree when growing.

Our present concern is with wood as a material in the arts, and not with any merely botanical interest it may have, or with its cultivation as a crop by the forester. In dealing with the means of recognizing different kinds of wood we shall, therefore, not depend in any way upon characters derived from bark, leaves, flowers, or fruit—the characters, that is, of standing, or of unconverted timber; but only on those of the wood itself as it appears in the timber market. At the same time, if we are to be able to identify woods and determine their suitability for various economic applications, it is absolutely essential that we should know something of their origin, structure, development, and use to the plants that produced them.

Wood does not occur in any plants of a lower grade than ferns; and in the higher plants in which it does occur it is chiefly, but not exclusively in the stem. In the shell of the cocoa-nut or the stone of a peach it probably serves the purpose of checking premature germination of the enclosed seed by excluding damp. In stems, however, the main physiological function of wood is the mechanical one of giving strength to resist the increasing weight of the structure as it grows erect and branches. Submerged aquatic plants, buoyed up, as they are, by the water, do not form wood in their stems, nor, as a rule, do annuals, nor, at first, the succulent, flexible shoots of longer-lived plants. In ferns, even when growing into lofty trees, and in allied plants, the wood, though dense, consists largely of scattered longitudinal strands and often of cells of no great vertical length. Though there are also generally woody layers just below the surface of the stem, giving it considerable strength as a whole, this structure renders tree-ferns useless as timber.

For all practical purposes, therefore, wood is produced only by the highest sub-kingdom of the plant world, the seed-bearing or flowering plants, the *Spermatophýta* or *Phanerogámia* of botanists. This great group of plants is sub-divided, mainly by characters derived from parts other than their stems, into two divisions, the

Gymnospérmæ, or plants the seeds of which are naked, *i.e.* not enclosed in a fruit, and the *Angiospérmæ*, or fruit-bearing plants. The Gymnosperms are all perennial trees and shrubs; but of three "Natural Orders" into which they are divided, two, the *Cycadáceæ* and *Gnetáceæ*, belong almost exclusively to the Southern Hemisphere and are valueless as timber. The third Natural Order is the *Coníferæ*, so named from the general arrangement of its seeds on a series of overlapping scales arranged in a cone, but having also other general characters, one of the most conspicuous of which is the production of numerous, narrow, rigid, undivided leaves, whence they get the familiar name of *needle-leaved trees.* The members of this Order, which includes the Pines, Firs, Larches, Cedars, etc., have much-branched stems, and wood, which, though in many points, such as its arrangement in annual rings of growth, it resembles that of some other, more highly-organized plants, has, as we shall see, many peculiarities. It is, in general, of rapid growth, soft and of even texture, and very commonly abounds in resinous substances. They are, therefore, often spoken of as "*soft woods*" or as "*resinous woods,*" and being, from these characteristics, both easily worked and of considerable durability, are more extensively used than any other class of woods. The Maidenhair-tree of China and Japan (*Gínkgo bilóba*) is exceptional among conifers in having broad leaves: neither this tree nor the Yew can be said to bear cones, though their seeds are naked: the Yew is destitute of resin; and the epithet "soft-wooded" applies to Willow, Poplar, Horse-chestnut, etc., as truly as to conifers.

The second and higher division of seed-bearing plants, the Angiospermæ, is divided into two Classes, which, whilst agreeing in having their seeds enclosed in fruits, differ in many characters, and in none more than in the structure of their stems. They are known botanically, from the number of seed-leaves or *cotyledons* of their embryos, as *Monocotylédons* and *Dicotylédons.* The Monocotyledons, with one such seed-leaf, comprise lilies, orchids, bananas, palms, sedges, grasses, etc. Few of these, such as Palms and Bamboos, reach the dimensions of trees, and those which do so have generally unbranched stems which do not as a rule increase in diameter after the very earliest stages of their growth, the wood in them being confined to isolated strands crowded together towards their outer surfaces. Though such stems may occasionally, like those of tree-ferns, be utilized "in the round," and veneers, cut from the outer part of the stem of the Cocoa-nut Palm (*Cócos nucífera*), and known, from the appearance of the dark-coloured woody strands in the lighter ground-tissue, as "Porcupine-wood," are used for inlaying, Monocotyledons may well be ignored as economic sources of wood.

Dicotyledons, so named from having two seed-leaves to the embryo, comprise an immense and varied assemblage of plants,

FIG. 1.—Transverse section of an Oak, 25 years old. After Le Maout and Decaisne, from *The Elements of Botany*, by permission of Mr. Francis Darwin and the Syndicate of the Cambridge University Press.

a very large proportion of which are merely herbaceous, never forming wood. In those perennial members of the Class, however, which acquire the dimensions of trees or shrubs, the stem generally branches freely, has a separable "bark," and increases in girth with age; the wood, though, as we shall see, it differs in several important but not very obvious characters, agreeing with that of conifers in being arranged in rings produced in successive seasons (Fig. 1). These rings, as they appear in a cross-section of a tree, or conically tapering sheaths surrounding the tree, as they in fact are, form on the outside of the wood of previous seasons and beneath the bark; and this type of stem, characteristic of gymnosperms and dicotyledons, is in consequence correctly termed *exógenous*, from the Greek *ex*, outside of, and *gennao*, to produce. The term *endógenous*, still sometimes applied to the structure of the stem of monocotyledons, is less accurate. Dicotyledons are commonly slower of growth than conifers, and their wood, especially that near the centre of the stem, is often much harder. They bear as a rule also broad, net-veined leaves; and are known familiarly, therefore, as "*hardwoods*," or as "*broad-leaved trees*." Such are the Oak, Beech, Ash, Elm, Teak, Willow, Alder, etc.

It is then only with the two classes of exogenous stems, those of gymnosperms or needle-leaved trees, and those of dicotyledons or broad-leaved trees, that we are concerned.

Though, as we have already said, conifers and broad-leaved trees present important differences in the structure and consequent character of their wood, their manner of growth is so nearly identical in its initial stages and broad outlines that we may well treat them at first collectively. It is, perhaps, the many branches and the numerous small leaves exposed by means of those branches to a maximum of air and light in these two groups of plants (as contrasted with the general absence of branching, and the small number and large size of the leaves in ferns and palms) that has determined the production of the progressively-enlarging, solid stem that characterizes them. It must be remembered, however, that the stem of a tree fulfils several very distinct physiological purposes. Besides bearing up the weight of leaves and flowers so as best to obtain the air and light they require, it is the means of communication between the root and the leaves. Through it the water and its dissolved gases and saline substances, taken in by the root from the soil, are conveyed to the leaves, which have been termed the "laboratory of the plant," to be built up in them, with the carbonaceous food-material taken in from the atmosphere, into those complex "*organic*" compounds of which the whole structure of the plant is composed. Furthermore, the stem serves as a reservoir in which some of these organic compounds, the "plastic material" of the plant, are stored up for use in future growth.

Every stem and every branch—and a branch is but a secondary stem, differing only in position—as long as it remains capable of elongation, is terminated, in the groups of trees with which we are concerned, by a bud. A *bud* is a growing-point protected by overlapping rudimentary leaves.

In the immediate neighbourhood of this growing-point the stem in this its initial stage is entirely made up of structures which almost completely resemble one another. Whether we cut such a growing-point across or lengthwise it presents under the microscope the appearance of a delicate mesh-work of thin membrane filled in with a viscid semi-fluid substance. These meshes, from their resemblance to honeycomb, were in 1667 named *cells* by Robert Hooke. The delicate membranes which form them, the *cell-walls* as they are termed, are composed of a definite chemical compound known as *cellulose.* It contains the three elements, carbon, hydrogen, and oxygen, in definite proportions, which the chemist represents as $C_6H_{10}O_5$, that is, in a hundred parts by weight 44 are carbon, 6 are hydrogen, and 50 are oxygen. Cellulose, like starch and sugar, belongs to a group of compounds of carbon with hydrogen and oxygen in the proportions in which those two elements occur in water, which are known as *carbo-hydrates.* It has, in fact, the same percentage composition as starch, though differing from it in many properties. It is insoluble in water, flexible, slightly elastic, permeable, but only slightly absorbent, and does not readily undergo fermentation. When treated with acid it passes into the condition of starch, as is evidenced by its then turning blue with iodine, and under certain conditions in the living plant it would seem capable of being formed from, or of passing into, sugar. Cotton-wool consists almost entirely of pure, unaltered cellulose. The viscid, semi-fluid substance contained in the cells is of far more complex chemical composition. It contains not only carbon, hydrogen, and oxygen, but also, though in far smaller proportion, nitrogen, with traces of sulphur, and, perhaps always also, phosphorus and other elements. It is probably a mixture in varying proportions of some of those substances which, from their resemblance to albumen or white of egg, are known as *albuminoid*, and, from the readiness with which they undergo chemical change or decomposition, as *proteids*. Being the substance out of which all plant-structures originate, the sole constituent of the first germs of all living beings, it is known as *protoplasm*, from the Greek *prōtos*, first, *plasma*, formed matter.

Any collection of similar cells or modifications of cells having a common origin and obeying a common law of growth is known as a *tissue*. These young cells at the apex of a stem, of nearly uniform size, and that extremely minute, with their delicate, as yet unaltered, cell-walls filled with protoplasm, form an *embryonic tissue*, one, that is, which will undergo change. Its uniform character causes it to be termed *undifferentiated*, while the various kinds of tissue to which by different changes it gives rise are known in contradistinction as *permanent tissues*. One change to which any cell is liable so long as it contains protoplasm is division into two, a partition wall of cellulose forming across it. The formation of this solid wall from material in solution in the protoplasm, and a correlative power, which, as we shall see, the living plant possesses, of dissolving a cell-wall, illustrate that interchangeability of sugar and cellulose of which we have spoken. A tissue the cells of which undergo division is termed *merismatic* or *meristem*, from the Greek *merisma*, division; so that the embryonic tissue at the apex of a stem is known as *apical meristem*.

Although its cells are all embryonic, they nevertheless at a very early stage commonly present such a degree of differentiation as to make it possible to distinguish three well-defined rudimentary tissue-systems (Fig. 2). First, there is a single layer of cells on the outside of the growing-point, with thickened outer walls and undergoing division only in planes perpendicular to the surface. If we trace this layer backwards down the surface of the shoot below its apex we shall find it continuous with similar cells which have lost their protoplasm and have even thicker outer walls. As this outer layer of permanent tissue is called the *epidérmis*, from the Greek *epi*, upon, *derma*, skin, the embryonic layer in which it originates is termed the *dermátogen* (*derma*, skin, and *gennáo*, to produce). In the middle of the growing-point is a solid column-like mass of cells which are all

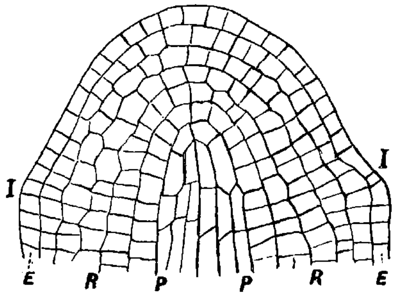

FIG. 2.—Growing-point of stem, showing apical meristem. *P*, plerome; *R*, periblem; *E*, dermatogen; *I*, rudiment of leaf. (After Leunis and Frank.)

somewhat elongated in the direction of the elongation of the stem. This is known as the *plerome* and the central axis of tissues to which it gives rise as the *stele* (Greek for a column)

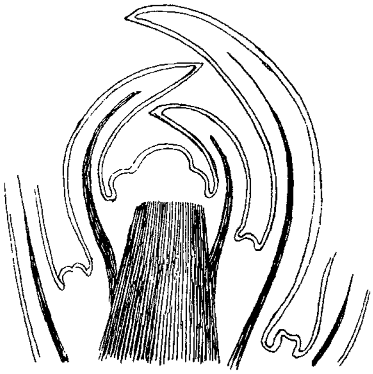

FIG. 3.—Terminal bud, showing growing-point of stem, overlapped by rudimentary leaves with buds in their axils, the whole covered by dermatogen. In the centre is the stele to which descend the midribs of the leaves. (After Prantl.)

(Fig. 3). Between the outer dermatogen and the inner plerome there is a layer, or a series of layers, of cells which undergo division both in planes perpendicular to and in planes parallel to the surface of the stem. These are known as the *periblem*. On tracing them backwards down the shoot we find them continuous with tissues which immediately beneath the epidermis are commonly green, and which often have their cells much thickened in the corners in herbaceous plants or shoots, whilst still further back, on older parts of woody shoots, the green layer is often buried under one or more layers of brown cork. These tissues which thus originate in the periblem are known collectively as the *cortex*.

It is with tissues originating from the central plerome or stele that we are mainly concerned. If we cut a young shoot across, a little below its entirely embryonic apex, we shall see that, whilst there is a central whitish mass, which on being magnified exhibits a comparatively wide-meshed structure, there are round this a ring of patches of a greyer, closer tissue. These grey patches may be observed to be roundish or slightly wedge-shaped in outline, their longer diameter lying in one of the radii of the stem, and they are wider across their outer parts. They appear grey on account of the smaller diameter of their cells. Longitudinal sections show these patches to be cross-sections of long strands or bundles of cells, narrower and more elongated than those around them. The central mass of tissue is the *pith* or *medulla*, and these strands are known as *procambium* or *desmogen*.

The pith is relatively large in the stems of herbaceous plants or in young shoots (Fig. 4), but does not increase in bulk as the tree grows older. Its cells are at first full of fluid, and their walls often remain thin. Those of its outer portion, near the procambium strands, are smaller, and all its cells are often two or three times as long in the direction of the elongation of the stem as they are broad. Thus in shape they are short, polygonal, closely-packed prisms. In many cases, as in the Elder, the cells of the pith die, losing their fluid contents, shrivelling, and so completing disorganizing the entire tissue that the stem becomes hollow, or a mere line of dry powder in the centre of the innermost ring of wood marks this structural centre of the stem. In other cases, as in the Oak, the cells of the pith have their walls thickened, and turn from white to brown; but even then its relatively minute width makes it difficult to detect in a stem several years of age.

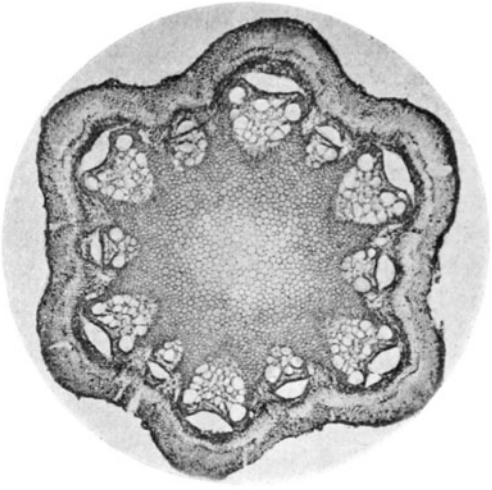

FIG. 4.—Transverse section of the stem of Traveller's Joy (*Clématis Vitálba*), showing relatively large central pith and large vessels.

The *procambium strands* extend from the rudiments of leaves near its apex right through the stem into the root. They get their name from a Latin word, *cambio*, to grow, being in a merely transitory or embryonic condition. In Monocotyledons the whole of their tissue passes into the condition of wood and bast; so that the *bundle*, as the strand in its permanent form is termed, being incapable of any further growth in diameter, is said to be *closed*. It is because it gives rise to a bundle (Greek, *desmos*, a bond) that the procambium is termed *désmogen*. In those trees, however, with which we are concerned, viz. Gymnosperms and Dicotyledons, whilst the inner portion of each strand becomes *wood* or *xylem* (Greek, *xylon*, wood) and the outer part *bast* or *phloem* (Greek, *phloios*, bark), a band between these two parts remains embryonic. This layer is called the *cambium*, or more precisely, for a reason