HOW CROPS GROW:

A TREATISE ON THE
CHEMICAL COMPOSITION, STRUCTURE, AND LIFE OF THE PLANT,

FOR

Agricultural Students.

WITH ILLUSTRATIONS AND TABLES OF ANALYSES.

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PREFACE.

IN the following pages a picture is drawn of the chemical, structural, and physiological History of a Plant. The plant is the agent by which, through its use of the solar forces, the dead inorganic matter of the earth, water, and air is wrought into living organic forms, to be then used as food for the animal. Thus it becomes necessary, in order that a complete view of the subject may be offered, to describe in detail the elementary substances which, in various combinations, occur in plants; the compounds on which plants feed, and the special nature and distribution within their organs of the several kinds of matter of which they consist. The modes in which plants absorb their food are but partially discussed in the present volume. This subject would in fact have involved the study of soils and manures, and consequently an extension of the idea of the work.

The Plant is here regarded both from a chemical and a botanical point of view. As some chemical chapters are given to render intelligible the results of the chemical analysis or pulling to pieces of the plant, so botanical facts are inserted also, that the more important forms of vegetable structure may become familiar to the student—that the physiological dissection or analysis of the plant may be understood. For by this latter analysis is disclosed the very seat of those chemical actions on which the growth of the plant depends, and by which its distinctive products are elaborated.

The author of this work "has endeavoured to lay out "a groundwork of facts sufficiently complete to reflect a "true and well-proportioned image of the nature and needs "of the plant, and to serve the student of agriculture for "thoroughly preparing himself to comprehend the whole "subject of vegetable nutrition, and to estimate accurately "how and to what extent the Crop depends upon the "atmosphere on the one hand, and the soil on the other, "for the elements of its growth."

The Chemistry of Plant-life is here treated with very considerable fulness. Numerous results of investigations and detailed Tables of Analyses are given, in order that all the more important data whence the conclusions of the scientific agriculturist must be drawn, may be before the student. The laborious researches of many English and continental chemists have been freely quoted; the results recently obtained by German experimenters having furnished more particularly the substance of several important chapters. The experiments at the agricultural stations of the Continent have led to such valuable discoveries, that it is to be regretted that so little regular work of the same kind is carried on in Great Britain. With the exception of the few farmers who carry on careful experiments for the Highland and Agricultural Society, and for local Societies; of Messrs. Lawes and Gilbert, whose elaborate and extensive researches are beyond all praise; and of the Royal Agricultural College of Cirencester, the officials of which have tried systematic experiments in agricultural chemistry for twenty years, we have little work of the kind we are now speaking of going on in this country. Agricultural education is, however, attracting attention at last, and its spread will be duly followed, it is to be hoped, by the establishment of experimental stations in every part of Great Britain.

Many of the results to be found in the following pages may not appear at first sight to have any bearings upon the arts of agriculture, horticulture, or arboriculture. But, as our author remarks: "It must not, however, be forgotten, that a valuable principle is often arrived at from "the study of facts, which, considered singly, have no "visible connexion with a practical result. Statements "are made which may appear far more curious than useful, "and that have, at present, a simply speculative interest, "no mode being apparent by which the farmer can increase his crops or diminish his labours by help of his "acquaintance with them. Such facts are not, however, "for this reason to be ignored, or refused a place in our "treatise, nor do they render our book less practical or less "valuable. It is just such curious and seemingly useless "facts that are often the seeds of vast advances in industry and the arts.

"For those who have not enjoyed the advantages of "scientific training, the author has sought to unfold his "subjects by such regular and simple steps, that any one "may easily master them. It has also been attempted "to adapt the work in form and contents to the wants "of the class-room by a strictly systematic arrangement "of topics, and by division of the matter into convenient "paragraphs."

In order that this book may be complete in itself, so far as its special scope is concerned, not only have the rudiments of Chemistry and structural Botany been introduced, but a series of Experiments has been described, by which the student who has access to chemical apparatus and tests, may become conversant with the most salient properties of the elements, and of those of their chief natural compounds, which constitute the food or the materials of plants.

A few words on the chemical nomenclature of this book. Throughout the volume, the chemical formulæ and names are, almost without exception, those adopted by Roscoe in his "Lessons on Elementary Chemistry." In order to avoid prolixity, the words "lime," "magnesia," "potash," "soda," "silica," are used instead of "calcium oxide," "magnesium oxide," &c. &c. When sulphuric *trioxide* is spoken of as existing in a plant or its ashes, there is no intention of conveying the impression that this compound exists as such in the materials named: it is considered that the expression "sulphuric acid" is less correct, and that the word "sulphates," which might be legitimately employed, does not correspond with the actual results of analysis, in which, from our ignorance of the forms of combination in which the various ingredients actually occur, we calculate our sulphates, phosphates, silicates, &c., into their respective anhydrides or oxides, and the metals of these salts into their respective common oxides.

This English edition of Professor Johnson's work has been very carefully corrected throughout: numerous additions have been made to it, and in some parts it has been entirely re-written. It is hoped that it will prove a useful text-book, full of scientific as well as technical information, for both student and teacher, on the *Life of the Plant.*

A. H. C.
W. T. T. D.

May 1869.

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INTRODUCTION.

INTRO-DUCTION.

The objects of agriculture are the production of certain plants and certain animals which are employed to feed and clothe the human race. The first aim, in all cases, is the production of plants.

Nature has made the most extensive provision for the spontaneous growth of an immense variety of vegetation; but in those climates where civilization most certainly attains its fullest development, man is obliged to employ art to provide himself with the kinds and quantities of vegetable produce which his necessities or luxuries demand. In this defect, or, rather, neglect of nature, agriculture has its origin.

The *art* of agriculture consists in certain practices and operations which have gradually grown out of an observation and imitation of the best efforts of nature, or have been hit upon accidentally.

The *science* of agriculture is the rational theory and exposition of the successful art.

Strictly considered, the art and science of agriculture are of equal age, and have grown together from the earliest times. Those who first cultivated the soil by digging, planting, manuring, and irrigating, had their suffi-

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cient reason for every step. In all cases, thought goes before work, and the intelligent workman always has a theory upon which his practice is planned. No farm was ever conducted without physiology, chemistry, and physics, any more than an aqueduct or a railway was ever built without mathematics and mechanics. Every successful farmer is, to some extent, a scientific man. Let him throw away the knowledge of facts and the knowledge of principles which constitute his science, and he has lost the elements of his success. The farmer without his reasons, his theory, his science, can have no plan; and these wanting, agriculture would be as complete a failure with him as it would be with a man of mere science, destitute of manual, financial, and executive skill.

Other qualifications being equal, the more advanced and complete the theory of which the farmer is the master, the more successful must be his farming. The more he knows, the more he can do. The more deeply, comprehensively, and clearly he can *think*, the more economically and advantageously can he work.

That there is any opposition or conflict between science and art, between theory and practice, is a delusive error. They are, as they ever have been and ever must be, in the fullest harmony. If they appear to jar or stand in contradiction, it is because we have something false or incomplete in what we call our science or our art; or else we do not perceive correctly, but are misled by the narrowness and aberrations of our vision. It is often said of a machine, that it was good in theory, but failed in practice. This is as untrue as untrue can be. If a machine fail in practice, it is because it was imperfect in theory. It should be said of such a failure—the machine was good judged by the best theory known to its inventor, but its incapacity to work demonstrates that the theory had a flaw.

But, although art and science are thus inseparable, it must not be forgotten that their growth is not altogether parallel. There are facts in art for which science can, as yet, furnish no adequate explanation. Art, though no older than science, grew at first more rapidly in vigour and in stature. Agriculture was practised hundreds and thousands of years ago, with a success that does not compare unfavourably with ours. Nearly all the essential points of modern cultivation were known to the Romans before the Christian era. The annals of the Chinese show that their wonderful skill and knowledge were applied to agriculture at a vastly earlier date.

So much of science as can be attained through man's unaided senses reached considerable perfection early in the world's history. But that part of science which relates to things invisible to the unassisted eye could not be developed until the telescope and the microscope had been invented, until the increasing experience of man and his improved art had created and made cheap the other inventions by whose aid the mind can penetrate the veil of nature. Art, guided at first by a very crude and imperfectly developed science, has, within a comparatively recent period, multiplied those instruments and means of research whereby Science has expanded to her present proportions.

The progress of agriculture is the joint work of theory and practice. In many departments, agriculture has made great advances during the last century: especially is this true in all that relates to implements and machines, and to the improvement of domestic animals. It is, however, in just these departments that an improved theory has had sway. More recent is the development of agriculture in its chemical and physiological aspects. In these directions the present century, or we might almost say the last thirty years, has seen more accomplished than all previous time.

The first book in the English language on the subjects which occupy a good part of the following pages was

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written by a Scotch nobleman, the Earl of Dundonald, and was published at London in 1795. It was entitled "A Treatise showing the Intimate Connexion that subsists between Agriculture and Chemistry." The learned Earl in his Introduction remarked, that "the slow progress which agriculture has hitherto made as a science is to be ascribed to a want of education on the part of the cultivators of the soil, and to a want of knowledge, in such authors as have written on agriculture, of the intimate connexion that subsists between the science and that of chemistry. Indeed, there is no operation or process, not merely mechanical, that does not depend on chemistry, which is defined to be a knowledge of the properties of bodies, and of the effects resulting from their different combinations." Earl Dundonald could not fail to see that chemistry was ere long to open a splendid future for the ancient art that always had been and always is to be the prime support of the nations. But when he wrote, no longer than seventy-two years ago, how feeble was the light that chemistry could throw upon the fundamental questions of agricultural science! The chemical nature of atmospheric air was then a discovery of barely twenty years' standing. The composition of water had been known but twelve years. The only account of the composition of plants that Earl Dundonald could give was the following:—"Vegetables consist of mucilaginous matter, resinous matter, matter analogous to that of animals, and some proportion of oil. . . . . Besides these, vegetables contain earthy matters, formerly held in solution in the newly-taken-in juices of the growing vegetable." To be sure, he explains by mentioning on subsequent pages that starch belongs to the mucilaginous matters, and that, on analysis by fire, vegetables yield soluble alkaline salts and insoluble phosphate of lime. But these salts, he held, were formed in the process of burning, their lime excepted; and the fact of their being taken from the soil and constituting the indispensable food of plants, his Lordship was unacquainted with. The gist of agricultural chemistry with him was, that plants are "composed of gases with a small proportion of calcareous matter;" for "although this discovery may appear to be of small moment to the practical farmer, yet it is well deserving of his attention and notice, as it throws great light on the nature and food of vegetables." The fact being then known that plants absorb carbonic acid from the air, and employ its carbon in their growth, the theory was held that fertilizers operate by promoting the conversion of the organic matter of the soil or of composts into gases, or into soluble humus, which were considered to be the food of plants.

The first accurate analysis of a vegetable substance was not accomplished until fifteen years after the publication of Dundonald's Treatise, and another like period passed before the means of rapidly multiplying good analyses had been worked out by Liebig. So late as 1838, the Göttingen Academy offered a prize for a satisfactory solution of the then vexed question whether the ingredients of ashes are essential to vegetable growth. It is, in fact, during the last thirty years that agricultural chemistry has come to rest on sure foundations. Our knowledge of the structure and physiology of plants is of like recent development. What immense practical benefit the farmer has gathered from this advance of science! The dense populations of Great Britain, Belgium, Holland, and Saxony, can attest the fact. Chemistry has ascertained what vegetation absolutely demands for its growth, and points out a multitude of sources whence the requisite materials for crops can be derived. To be sure, Cato and Columella knew that ashes, bones, bird-dung, and green manuring, as well as drainage and aëration of the soil, were good for crops; but that carbonic acid, potash, phosphate of lime, and compounds of nitrogen, are the chief pabulum of vegetation, they did not know. They did not know that the atmosphere dissolves the rocks, and converts inert stone into nutritive soil. These grand principles, understood in many of their details, are an inestimable boon to agriculture, and intelligent farmers have not been slow to apply them in practice. The vast trade in phosphatic and Peruvian guano, and in nitrate of soda; the great manufactures of oil of vitriol, of superphosphate of lime, of fish manure, and the mining of fossil bones and of potash salts, are largely or entirely industries based upon and controlled by chemistry in the service of agriculture.

Every day is now the witness of new advances. The means of investigation which, in the hands of the scientific experimenter, have created within the writer's memory such arts as photography and electro-metallurgy, and have produced the steam-engine and magnetic telegraph, are working and will continue to work progress in agriculture. This improvement will not consist so much in any remarkable discoveries that shall enable us "to grow two blades of grass where but one grew before," but in the gradual disclosure of the reasons of that which we have long known, or believed we knew, in the clear separation of the true from the seemingly true, and in the exchange of a wearying uncertainty for settled and positive knowledge.

It is the boast of some who affect to glory in the sufficiency of practice and decry theory, that the former is based upon experience, which is the only safe guide. But this is a one-sided view of the matter. Theory is also based upon experience, if it be truly scientific. The vague surmise of an ignorant and undisciplined mind is not theory. Theory, in the proper and good sense, is always a deduction from facts, the best deduction of which the stock of facts in our possession admits. It is the interpretation of facts. It is the expression of the ideas which facts awaken when submitted to a fertile imagination and well-balanced judgment. A scientific theory is intended for the nearest possible approach to the truth. Theory is confessedly imperfect, because our knowledge of facts is incomplete, our mental insight weak, and our judgment fallible. But the scientific theory which is framed by the contributions of a multitude of earnest thinkers and workers, among whom are likely to be the most gifted intellects and most skilful hands, is, in these days, to a great extent worthy of the Divine truth in nature, of which it is the completest human conception and expression.

Science employs, in effecting its progress, essentially the same methods that are used by merely practical men. Its success is commonly more rapid and brilliant, because its instruments of observation are finer and more skilfully handled; because it experiments more industriously and variedly, thus commanding a wider and more fruitful experience; because it usually brings a more cultivated imagination and a more disciplined judgment to bear upon its work. The devotion of a life to discovery or invention is sure to yield greater results than a desultory application made in the intervals of other absorbing pursuits. It is then for the interest of the farmer to avail himself of the labours of the man of science, when the latter is willing to inform himself in the details of practice, so as rightly to comprehend the questions which press for a solution.

It is characteristic of our time that large associations of practical agriculturists have recognised the immediate pecuniary advantage to be derived from the application of science to their art. This was first done at Edinburgh, in 1843, by the establishment of the "Agricultural Chemistry Association of Scotland."

This organization limited itself to a duration of five years. At the expiration of that time, its labours, which had been ably conducted by Professor James F. W. Johnston, were assumed by the Highland and Agricultural Society of Scotland, and have been prosecuted up to the present day by Dr. Anderson. The Royal Agricultural Society of England began to employ a consulting chemist, Dr. Lyon Playfair, in 1843; and since 1848 most valuable investigations, by Prof. Way and Dr. Völcker, have regularly appeared in its journal. Other British Agricultural Societies have followed these examples with more or less effect.

It is, however, in Germany that the most extensive and well-organized efforts have been made by associations of agriculturists to help their practice by developing theory. In 1851 the Agricultural Society of Leipzig established an Agricultural Experiment Station on its farm at Möckern, near that city. This example was soon imitated in other parts of Germany and the neighbouring countries; and at the present time (1867) there are of similar Experiment Stations in operation—in Prussia 10; in Saxony 4; in Bavaria 3; in Austria 3; in Brunswick, Hesse, Thuringia, Anhalt, Wirtemberg, Baden, and Sweden, 1 each; making a total of 26, chiefly sustained by, and operating in, the interest of the agriculturists of those countries. These stations give constant employment to sixty chemists and vegetable physiologists, of whom a large number are occupied largely or exclusively with theoretical investigations, while the work of others is devoted to more practical matters, as testing the value of commercial fertilizers. Since 1859 a journal, *Die Landwirthschaftlichen Versuchs-Stationen* (Agricultural Experiment Stations), has been published as the organ of these establishments; and the nine volumes now completed, together with the numerous Reports of the Stations themselves, have largely contributed the facts that are made use of in the following pages.

In the United States some similar enterprises have been attempted, but have not been supported with a sufficient combination of talent and pecuniary outlay to ensure any striking success in the direction of agricultural chemistry. An imitation of the example set by European associations is well worthy the consideration of the American Agricultural Societies, many of which could easily command the funds for such an enterprise. It would be found that such a use of their resources would speedily strengthen their hold on the interest and regard of the communities they represent.

Agricultural science, in its widest scope, comprehends a vast range of subjects. It includes something from nearly every department of human learning.

The natural sciences of geology, meteorology, mechanics, physics, chemistry, botany, zoology, and physiology, are most intimately related to it. It is not less concerned with social and political economy, with commerce and law. In the present treatise it will not be attempted to cover nearly all this ground, but some account will be given of certain subjects whose understanding promises to be of the most direct service to the agriculturist. The theory of agriculture, as founded on the chemical, physical, and physiological history of the Plant, is the topic of this volume.

Some preliminary propositions and definitions may be serviceable to the reader.

Science deals with matter and force.

Matter is that which has weight and bulk.

Force is the cause of changes in matter—it is appreciable only by its effects upon matter.

Force resides in and is inseparable from matter.

Force manifests itself in motion.

The different kinds of force are convertible. The different kinds of matter are not convertible.

All matter is perpetually animated by force—is therefore never at rest. What we call rest in matter is simply motion too fine for our perceptions.

The different kinds of matter known to science have been resolved into not more than sixty-four elements or simple substances.

Elements, or ultimate elements, are forms of matter which have thus far resisted all attempts at their simplification.

In ordinary life we commonly encounter but twelve elements in their elementary state, viz.:

Oxygen,
Nitrogen,
Sulphur,
Carbon,
Iron,
Zinc,
Mercury,
Copper,
Lead,
Tin,
Silver,
Gold.

The numberless other substances with which we are familiar are mostly compounds of the above, or of twelve other elements, viz.:

Hydrogen,
Phosphorus,
Chlorine,
Silicon,
Potassium,
Sodium,
Calcium,
Magnesium,
Aluminium,
Manganese,
Chromium,
Nickel.

We distinguish various manifestations of force, which, acting on or through matter, produce all material phenomena. Such are Electricity and Magnetism; Light and Heat depending on vibratory movements: Gravitation, Adhesion, and Cohesion, which determine the aggregation of matter into masses: Crystallization, Solution, and Osmose, in which molecules, and Chemical Affinity, in which the ultimate atoms of matter, are concerned.

The action of force on a body may either increase its *Actual Energy*, or be stored up as *Potential* Energy, as when a watch is wound, in a form available for increasing it hereafter. Solar heat, light, and radiant chemical force, are stored up as potential energy by plants, to reappear as actual energy when they support the heat of the body and its muscular activity as food, or when used for warmth and illumination as fuel.

The sciences that more immediately relate to agriculture are:

I. Physics or natural philosophy,—the science which considers the general properties of matter and such of its phenomena as are not accompanied by essential or permanent change in its obvious qualities. All force manifests itself through matter without destroying or masking the matter itself. Iron may be hot, luminous, or magnetic, may fall to the ground, be melted, welded, and crystallized; but it remains iron, and is at once recognised as such.

II. Chemistry,—the science which studies the properties peculiar to the various kinds of matter, and those phenomena which are accompanied by a fundamental change in the matter acted on. Iron rusts, wood burns, and both lose all the external characters that serve for their identification. They have entered into new combinations, and thus have formed new substances. Affinity, or chemical affinity, unites two or more elements into compounds, unites compounds together into more complex compounds; and, under the influence of heat, light, and other forces, is annulled or overcome, so that compounds resolve themselves into simpler combinations or into their elements. Chemistry is the science of composition and decomposition; it considers the laws and results of affinity.

III. Physiology,—which unfolds the laws of the development, sustenance, and death of living organisms.

When we assert that the object of agriculture is to develop from the soil year after year the greatest possible amount of certain kinds of vegetable and animal produce at the least cost, we suggest the topics which are most important for the agriculturist to understand.

The farmer deals with the plant, with the soil, with manures. These stand in close relation to each other, and to the atmosphere which constantly surrounds and acts upon them. How the plant grows,—the conditions under which it flourishes or suffers detriment,—what it is made of,—the mode of its construction,—how it feeds upon the soil, and rain, and air,—how it serves as food to animals,—how the air, soil, plant, and animal stand related to each other in a

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perpetual round of the most beautiful and wonderful transformations,—these are some of the grand questions that come before us; and they are not less interesting to the philosopher or man of culture, than important to the farmer, who depends upon their practical solution for his comfort; or to the statesman, who regards them in their bearings upon the weightiest of political considerations.

DIVISION I.

Chemical Composition of the Plant.

CHAPTER I.

THE VOLATILE PART OF PLANTS.

§ 1. DISTINCTIONS AND DEFINITIONS.

Relations of inorganic to organic matter.

ORGANIC AND INORGANIC MATTER.—All matter may be divided into two great classes—*Organic* and *Inorganic*.

Organic matter is the product of growth, or of vital organization, whether vegetable or animal. It is mostly combustible; *i.e.* it may be easily set on fire, and burns away into invisible gases. Organic matter either itself constitutes the organs of life and growth, and has a peculiar organized structure, inimitable by art,—is made up of cells, tubes, or fibres (wood and flesh); or else is a mere result or product of the vital processes, and destitute of this structure (sugar and fat).

All matter which is not a part or product of a living organism is *inorganic* or mineral matter (rocks, soils, water, and air). Most of the naturally occurring forms of inorganic matter which directly concern agricultural chemistry are incombustible, and destitute of anything like organic structure.

By the processes of combustion and decay, organic matter is disorganized or converted into inorganic matter, while, on the contrary, by vegetable growth inorganic matter is assimilated, and becomes organic.

Organic matters are in general characterised by complexity of constitution, and are exceedingly numerous and various; while inorganic bodies are of simpler composition, and are fewer in number.

Plants consist of a combustible and an incombustible part.

Volatile and Fixed Matter.—All plants and animals, taken as a whole, and all their organs, consist of a volatile and a fixed part, which may be separated by burning: the former—usually by far the larger share—passing into and mingling with the air as invisible gases; the latter—forming, in general, but from one to five per cent. of the whole—remaining as ashes.

Experiment 1.—A splinter of wood heated in the flame of a lamp takes fire, burns, and yields *volatile matter*, which consumes with flame; and *ashes*, which are the only visible residue of the combustion.

Many organic bodies, products of life, but not essential vital organs, as sugar, starch, gum, &c., are completely volatile when in a state of purity, and leave no ash.

Current Use of the Terms Organic and Inorganic.—It is usual among agricultural writers to confine the term *organic* to the volatile or destructible portion of vegetable and animal bodies, and to designate their ash ingredients as *inorganic matter*. This use of the words is extremely inaccurate. What is found in the ashes of a tree or of a seed, in so far as it is an essential part of the organism, is as truly organic as the volatile portion; and by submitting organic bodies to fire, they may be entirely converted into inorganic matter, the volatile as well as the fixed parts.

The plant resolvable into fifteen elements.

Ultimate Elements that constitute the Plant.—Chemistry has demonstrated that the volatile and destructible part of organic bodies is made up chiefly of four substances, viz. carbon, oxygen, hydrogen, and nitrogen, and contains two other elements in lesser quantity, viz. sulphur and phosphorus. In the ash we may find phosphorus, sulphur, silicon, chlorine, potassium, sodium, calcium, magnesium, iron, and manganese, as well as oxygen, carbon, fluorine, and nitrogen.*

These fifteen bodies are elements, which means in chemical language, that they have not been resolved into other substances. All the varieties of vegetable and animal matter are *compounds*,—are composed of and may be resolved into these elements.

The above fifteen elements being essential to the organism of every plant and animal, it is of the highest importance to make a minute study of their properties.

§ 2. THE ELEMENTS OF THE VOLATILE PART OF PLANTS.

For the sake of convenience, we shall first consider the elements which constitute the volatile part of plants, viz. :

Carbon,
Oxygen,
Nitrogen,
Hydrogen,
Sulphur,
Phosphorus.

The elements which belong exclusively to the ash will be noticed in a subsequent chapter.

Carbon the chief element of the plant.

Carbon, in the free state, is a solid. We are familiar with it in several forms, as lamp-black and charcoal, stone or pit coal, black-lead or graphite, and diamond. Notwithstanding the substances just named present great diversities of appearance and physical characters, they are identical in a certain chemical sense, as by burning they all yield the same product, viz. carbonic acid.

That carbon constitutes a large part of plants is evident from the fact that it remains in a tolerably pure state after the incomplete burning of wood, as in the preparation of charcoal.

Experiment 2.—If a splinter of dry pine wood be set on fire and the burning end be gradually passed into the mouth of a narrow tube (see

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* Rarely, or to a slight extent, lithium, rubidium, iodine, bromine, barium, copper, zinc, and titanium.

Fig. 1), whereby the supply of air is cut off, or if it be thrust into sand, the burning is incomplete, and a stick of charcoal remains.

Fig. 1.

Carbonization and *charring* are terms used to express the blackening of organic bodies by heat, a change which is due to the separation of carbon in the free or uncombined state.

How the carbon of organic bodies is detected.

The presence of carbon in animal matters also is shown by subjecting them to incomplete combustion.

Experiment 3.—Hold a knife-blade in the flame of a tallow candle: the full access of air is thus prevented, and the volatile matters cooled. A portion of carbon escapes combustion, and is deposited on the blade in the form of *lamp-black.*

Oil of turpentine and petroleum (kerosene) contain so much carbon, that a portion escapes in the free state as smoke and soot, when they are set on fire.

When bones are strongly heated in closely-covered iron pots, until they cease yielding any vapours, there remains in the vessels a mixture of carbon with the earthy matter, chiefly tricalcic phosphate, of the bones, which is largely used in the arts, for refining sugar, and in the manufacture of fertilizers, under the name of *animal charcoal* or *bone-black.*

The various forms of carbon.

Anthracite, or stone coal, *coke*—the porous, hard, and lustrous mass left when bituminous coal is heated with a limited access of air—and the metallic-looking *gas-carbon* that is found lining the iron cylinders in which illuminating coal-gas is prepared, consist chiefly of carbon. They usually contain more or less incombustible matters, as well as oxygen, hydrogen, and sometimes nitrogen.

The different forms of coke possess a greater or less degree of porosity and hardness, according to their origin and the temperature at which they have been prepared.

Carbon, in most of its forms, is extremely indestructible, unless exposed to an elevated temperature. Hence stake and fence posts, if charred before they are put in the ground, last vastly longer than when this treatment is neglected.

The porous varieties of carbon, especially wood charcoal and bone-black, have a remarkable power of absorbing gases and colouring matters, and of destroying odours, &c. which is taken advantage of in the refining of sugar and for purposes of disinfection. This action is, in part, one of oxidation.

Carbon is the characteristic ingredient of all organic compounds. There is no single substance that is the exclusive result of vital organization, no ingredient of the animal or vegetable produced by their growth, that does not contain carbon.

The occurrence, importance, and properties of oxygen.

Oxygen.—Carbon is a solid, and is recognised by our senses of sight and feeling. Oxygen, on the other hand, is invisible, odourless, tasteless, and not distinguishable from ordinary air by the unassisted senses. It is an air or gas.

It exists in the free or uncombined state in the atmosphere we breathe, but it is usually obtained pure from some of its compounds. Many metals unite readily with oxygen, forming compounds known as oxides, which by heat separate again into their ingredients, and thus furnish the means of procuring pure oxygen. Iron and copper, when strongly heated and exposed to the air, acquire oxygen, but from the oxides of these metals (forge cinder, copper scale) it is not possible to separate pure oxygen. If, however, the metal mercury (quicksilver) is kept for a long time at a boiling heat, it is slowly converted into a red powder, called red precipitate or oxide of mercury, which on being more strongly heated is decomposed, yielding metallic mercury and oxygen in a pure state.

The substance usually employed as the most convenient source of oxygen gas is a white salt, the chlorate of potash. Exposed to heat, this body melts, and presently evolves oxygen in great abundance.

The preparation of oxygen.

Experiment 4.—The following figure illustrates the apparatus employed for preparing and collecting this gas.

A tube of difficultly fusible glass, eight inches long and half an inch wide, contains the oxide of mercury or chlorate of potash.* To its mouth is connected, air-tight, by a cork, a narrow tube, the free extremity of which passes under the shelf of a tub nearly filled with water. A Florence flask, with a wide vulcanized india-rubber tube passed over its neck, answers better. The shelf has beneath a saucer-shaped cavity opening above by a narrow orifice, over which a bottle filled with water is inverted. Heat being applied to the wide tube, the common air it contains is first expelled, and presently oxygen bubbles rapidly into the bottle and displaces the water. When the bottle is full, it may be corked and set aside, and its place supplied by another. Fill four pint bottles with the gas, and set them aside with their mouths in tumblers of water. From one ounce of chlorate of potash about a gallon of oxygen gas may be thus obtained, which is not quite pure at first, but becomes nearly so on standing over water for some hours. When the escape of gas becomes slow and cannot be quickened by increased heat, remove the delivery tube from the water, to prevent the latter receding and breaking the apparatus.

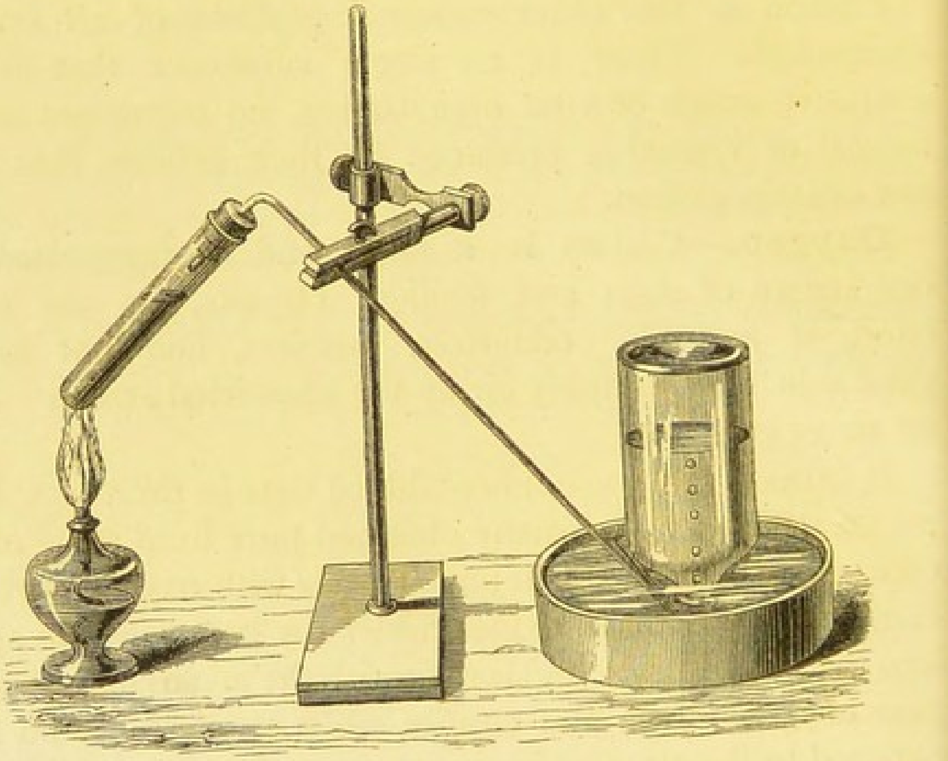

Fig. 2.

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* The chlorate of potash is best mixed with one-eleventh its weight of powdered red oxide of iron or "jewellers' rouge," as this facilitates the preparation, and renders the heat of a common spirit-lamp sufficient.

As this gas makes no peculiar impressions on the senses, we employ its behaviour towards other bodies for its recognition.

Experiment 5.—Place a burning splinter of wood in a vessel of oxygen (lifted for that purpose, mouth upward, from the water). The flame is at once greatly increased in brilliancy. Now remove the splinter from the bottle, blow out the flame, and thrust the still glowing point into the oxygen. It is instantly relighted. The experiment may be repeated many times. This is the usual *test* for oxygen gas, as only one other common gas, the nitrous oxide, shares with oxygen this property.

Combustion.—When the chemical union of two bodies takes place with such energy as to produce visible phenomena of fire or flame, the process is called combustion. Bodies that burn are combustibles, and the gas in which a substance burns is called a supporter of combustion.

Combustion usually attends active oxidation.

Oxygen is the grand supporter of combustion, and all the cases of burning met with in ordinary experience are instances of chemical union between the oxygen of the atmosphere and some other body or bodies.

The rapidity or intensity of combustion depends upon the quantity of oxygen and of the combustible that unite within a given time. Forcing a stream of air into a fire increases the supply of oxygen and excites a more vigorous combustion, whether it be done by a bellows or result from ordinary draught.

Oxygen exists in our atmosphere to the extent of about one-fifth of the bulk of the latter. When a burning body is brought into unmixed oxygen, its combustion is of course more rapid than in ordinary air, four-fifths of which is a gas, presently to be noticed, that is nearly indifferent in its chemical affinities toward most bodies.

In the air a piece of *burning charcoal* soon goes out; but if plunged into oxygen, it burns with great rapidity and brilliancy.

Experiment 6.—Attach a slender bit of charcoal to one end of a sharpened wire that is passed through a wide cork or card; heat the

The phenomena of combustion.

charcoal to redness in the flame of a lamp, and then insert it into a bottle of oxygen (Fig. 3). When the combustion has declined, a suitable test applied to the air of the bottle will demonstrate that another invisible gas has taken the place of the oxygen. Such a test is *lime-water*.* On pouring some of this into the bottle and agitating vigorously, the previously clear liquid becomes milky; and on standing, a white deposit, or *precipitate*, as the chemist terms it, gathers at the bottom of the vessel. Carbon, by thus uniting to oxygen, yields *carbonic dioxide*, which in its turn combines with lime, producing *calcium carbonate*. These substances will be further noticed in a subsequent chapter.


Fig. 3.

Metallic iron is incombustible in the atmosphere under ordinary circumstances, but if heated to redness and brought into pure oxygen gas, it burns as readily as wood burns in the air.

Experiment 7.—Provide a thin knitting-needle, heat one end red hot, and sharpen it by means of a file. Thrust the point thus made into a splinter of wood (a bit of the stick of a match a quarter of an inch long); pass the other end of the needle through a wide, flat cork for a support, set the wood on fire, and immerse the needle in a bottle of oxygen (Fig. 4). After the wood consumes, the iron itself takes fire and burns with vivid scintillations. It is converted into oxide of iron, a part of which will be found as a yellowish-red coating on the sides of the bottle; the remainder will fuse to black, brittle globules, which, falling, often melt quite into the glass. A little water at the bottom of the vessel prevents breakage.


Fig. 4.

The only essential difference between these and ordinary cases of combustion is the intensity with which the process goes on, due to the more rapid access of oxygen to the combustible.

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* To prepare lime-water, put a piece of unslaked lime, as large as a chestnut, into a pint of water, and after it has fallen to powder, agitate the whole for a minute in a well-stoppered bottle. On standing, the excess of lime will settle, and the perfectly clear liquid above it is ready for use.

Slow combustion and decay.

Many bodies unite slowly with oxygen—oxidize, as it is termed—without these phenomena of light and intense heat which accompany combustion. Thus iron *rusts*, lead *tarnishes*, wood *decays*. All these processes are cases of oxidation, and cannot go on in the absence of oxygen.

Since the action of oxygen on wood and other organic matters at common temperatures is really equivalent in a chemical sense to actual burning, Liebig has proposed the term *eremacausis* (slow burning) to designate the chemical process which takes place in decay and putrefaction, and which is concerned in many transformations, as in the making of vinegar and the formation of saltpetre.

Oxygen is necessary to life. The act of breathing introduces it into the lungs and blood of animals, where it aids the several important offices of *respiration*. Animals speedily perish if deprived of free oxygen, which has therefore been called vital air.

Oxygen has a universal tendency to combine with other substances, and form with them new compounds. With carbon, as we have seen, it forms carbonic dioxide. With iron, it unites in various proportions, giving origin to several distinct *oxides*, of which iron-rust is one, and anvil-scales another. In decay, putrefaction, fermentation, and respiration, numberless new products are formed, the result of its chemical affinities.

Oxygen is the most abundant element.

Oxygen is estimated to be the most abundant body in nature. In the free state, but mixed with other gases, it constitutes one-fifth of the bulk of the atmosphere. In chemical union with other bodies, it forms eight-ninths of the weight of all the water of the globe, and one-third of its solid crust—its soils and rocks,—as well as of all the plants and animals which exist upon it. In fact, there are but few compound substances occurring in ordinary experience into which oxygen does not enter as a necessary ingredient.

Nitrogen serves to dilute the oxygen of the air.

Nitrogen.—This body is the other chief constituent of the atmosphere, in which its office appears to be mainly to dilute and temper the affinities of oxygen. Indirectly, however, it serves other most important uses, as will presently be seen.

For the preparation of nitrogen we have only to remove the oxygen from a portion of atmospheric air. This may be accomplished more or less perfectly by a variety of methods. We have just learned that the process of burning is a chemical union of oxygen with the combustible. If, now, we can find a body which is very combustible and one which at the same time yields by union with oxygen a product that may be readily removed from the air in which it is formed, the preparation of nitrogen from ordinary air becomes easy. Such a body is *phosphorus*, a substance to be noticed in some detail presently.

The preparation of nitrogen.

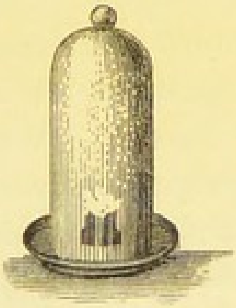

Fig. 5.

Experiment 8.—The bottom of a dinner-plate is covered half an inch deep with water, a bit of chalk hollowed out into a little cup is floated on the water by means of a large flat cork or a piece of wood; into this cup a morsel of dry phosphorus as large as a peppercorn is placed, which is then set on fire and covered by a capacious glass bottle or bell-jar. The phosphorus burns at first with a vivid light, which is presently obscured by a cloud of snow-like phosphoric acid. The combustion goes on, however, until nearly all the oxygen is removed from the included air. The air is at first expanded by the heat of the flame, and a portion of it escapes from the vessel; afterward it diminishes in volume as its oxygen is removed, so that it is needful to pour water on the plate to prevent the external air from passing into the vessel. After some time the white fume will entirely fall, and be absorbed by the water, leaving the enclosed nitrogen quite clear.

Experiment 9.—Another instructive method of preparing nitrogen is the following:—A handful of copperas (ferrous sulphate) is dissolved in half a pint of water, the solution is put into a quart bottle, a gill of liquid ammonia or fresh potash lye is added, the bottle stoppered, and the mixture vigorously agitated for some minutes; the stopper is then lifted, to allow fresh air to enter, and the whole is again agitated as before; this is repeated occasionally for half an hour or more, until no further absorption takes place, when nearly pure nitrogen remains in the bottle.

Free nitrogen, under ordinary circumstances, has scarcely any active properties, but is best characterised by its chemical indifference to most other bodies. That it is incapable of supporting combustion is proved by the first method we have instanced for its preparation.

Experiment 10.—A burning splinter is immersed in the bottle containing the nitrogen prepared by the second method (Exp. 9); the flame immediately goes out.

Nitrogen does not support life.

Nitrogen cannot maintain respiration, so that animals perish if confined in it. For this reason it was formerly called Azote (against life). Decay does not proceed in an atmosphere of this gas, and in general it is difficult to effect its direct union with other bodies. At a high temperature, especially in presence of baryta, it unites with carbon, forming *cyanogen*—a compound existing in Prussian-blue.

The atmosphere is the great store and source of nitrogen in nature. In the mineral kingdom, especially in soils, it occurs in small quantity as an ingredient of saltpetre and ammonia. It is a small but constant constituent of all plants, and in the animal it is a never-failing component of the working tissues, the muscles, tendons, and nerves, and is hence an indispensable ingredient of food.

Hydrogen occurs chiefly in water.

Hydrogen.—Water, which is so abundant in nature and so essential to organic existence, is a compound of two elements, viz.: oxygen, which has already been considered, and hydrogen, which we now come to notice.

Hydrogen, like oxygen, is a gas, destitute, when pure, of either odour, taste, or colour. It does not occur naturally in the free state, except in small quantity in the emanations from boiling springs and volcanoes. Its preparation almost always consists in abstracting oxygen from water by means of agents which have no special affinity for hydrogen, and therefore leave it uncombined.

Sodium, a metal familiar to the chemist, has such an attraction for oxygen that it decomposes water with great rapidity.

How hydrogen may be obtained from water.

Experiment 11.—Hydrogen is therefore readily procured by inverting a bottle full of water in a bowl, and inserting into it a bit of sodium as large as a pea. The sodium must first be wiped free from the naphtha in which it is kept, and then be placed in a small glass capsule. On bringing it, thus prepared, under the mouth of the bottle, it floats upward, and an abundant evolution of gas occurs.

Metallic iron and *zinc* decompose water, uniting with oxygen and setting hydrogen free. This action is almost imperceptible, however, with pure water under ordinary circumstances, because the metals are soon coated with a film of oxide which prevents further contact. If to the water a strong acid be added, or, in case zinc is used, an alkali, the production of hydrogen goes on very rapidly, because the oxide is dissolved as fast as it forms, and a perfectly pure metallic surface is constantly presented to the water.

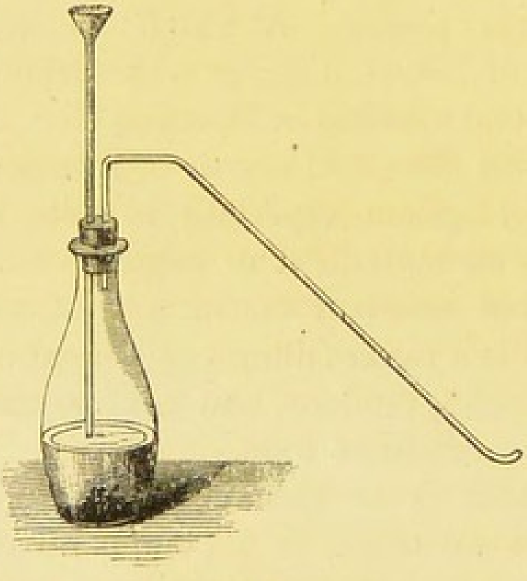

Fig. 6.

Experiment 12.—Into a bottle fitted with cork, funnel, and delivery tubes (Fig. 6), an ounce of iron tacks or zinc clippings is introduced, a gill of water is poured upon them, and lastly an ounce of oil of vitriol is added. A brisk effervescence shortly commences, owing to the escape of nearly pure hydrogen gas, which may be collected in a bottle filled with water, as directed with oxygen. The first portions that pass over are mixed with air, *and should be rejected, as the mixture is dangerously explosive.*

One of the most striking properties of free hydrogen is its levity. It is the lightest body in nature, being fourteen and a half times lighter than common air. It is hence used in filling balloons. Another property is its combustibility; it inflames on contact with a lighted taper, and burns with a flame which is intensely hot, though scarcely luminous if the gas be pure. Finally, it is itself incapable of supporting the combustion of a taper.

How water may be formed by burning hydrogen.

Experiment 13.—All these characters may be shown by the following single experiment. A bottle full of hydrogen is lifted from the water over which it has been collected, and a taper attached to a bent wire (Fig. 7) is brought to its mouth. At first a slight *explosion* is heard from the sudden burning of a mixture of the gas with air that forms at the mouth of the vessel; then the gas is seen *burning* on its lower surface with a pale flame. If now the taper be passed into the bottle, it will be extinguished; on lowering it again, it will be relighted by the burning gas; finally, if the bottle be suddenly turned mouth upwards, the light hydrogen *rises* in a sheet of flame.

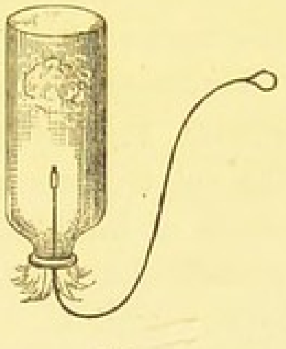

Fig. 7.

In the above experiment, the hydrogen burns only where it is in contact with atmospheric oxygen; the product of the combustion is an oxide of hydrogen, the universally diffused compound, water. The conditions of the experiment do not permit the collection or identification of this water; its production can, however, readily be demonstrated.

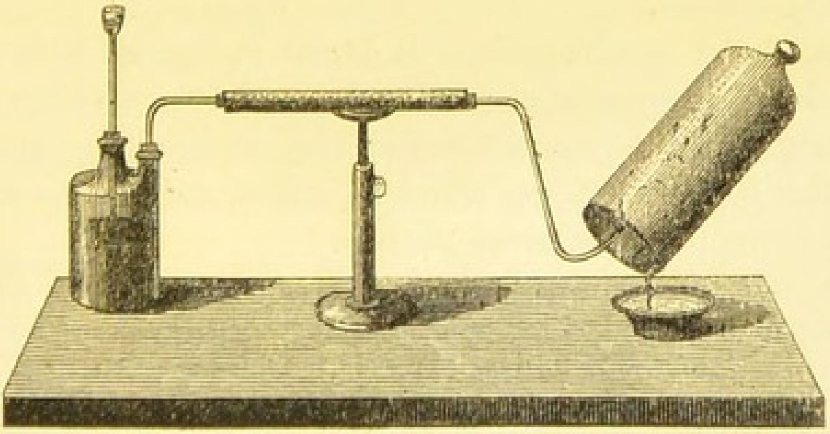

Fig. 8.

Experiment 14.—The arrangement shown in Fig. 8 may be employed to exhibit the formation of water by the burning of hydrogen. Hydrogen gas is generated from zinc and diluted acid in the two-necked bottle. Thus produced, it is mingled with vapour of water, to remove which it is made to stream slowly through a wide tube filled with fragments of dried calcium chloride, which desiccates it perfectly. After *air has been entirely displaced* from the apparatus, the gas is ignited at the up-curved end of the narrow tube, and a clean bell-glass is supported over the flame. Water collects at once, as dew, on the interior of the bell, and shortly flows down in drops into a vessel placed beneath.

In the mineral world we scarcely find hydrogen occurring in much quantity, save as water. It is a constant ingredient of plants and animals, and of nearly all the numberless substances which are products of life.

Hydrogen forms with carbon a large number of compounds, the most common of which are the volatile oils, like oil of turpentine, oil of lemon, &c. The chief ingredients of illuminating gas, ethylene or olefiant gas, the coal or rock oils, petroleum, naphtha, and paraffine, are so-called hydro-carbons.

Sulphur occurs both free and in combination.

Sulphur is a well-known solid substance, occurring in commerce either in sticks (brimstone, roll sulphur), or as a fine powder (flowers of sulphur), having a pale yellow colour and a peculiar odour and taste.

Uncombined sulphur is comparatively rare, the commercial supplies of native sulphur being very limited; but in one or other form of combination this element is universally diffused.

Sulphur is combustible. It burns in the air with a pale blue flame, in oxygen gas with a beautiful purple-blue flame, yielding in both cases a suffocating and fuming gas of a peculiar nauseous taste, which is called *sulphurous acid*, or more correctly, *sulphurous dioxide.*

Experiment 15.—Heat a bit of sulphur as large as a grain of wheat on a slip of iron or glass in the flame of a spirit-lamp, for observing its fusion, combustion, and the development of sulphurous dioxide. Further, scoop out a little hollow in a piece of chalk, twist a wire round the latter to serve for a handle, as in Fig. 3; heat the chalk with a fragment of sulphur upon it until the latter ignites, and bring it into a bottle of oxygen gas. The purple flame is shortly obscured by the opaque white fume of the sulphurous dioxide.

Sulphur forms with oxygen another compound, which, in combination with water, constitutes common *sulphuric acid*, or *oil of vitriol*. This is developed to a slight extent by the action of air on flowers of sulphur, but is prepared on a large scale for commerce by a complicated process.

Sulphur unites with most of the *metals*, yielding compounds known as *sulphides* or *sulphurets*. These exist in nature in large quantities, especially the sulphides of iron, copper, and lead, and many of them are valuable ores. Sulphides may be formed artificially by heating most of the metals with sulphur.

The compounds of sulphur.

Experiment 16.—Heat the bowl of a tobacco-pipe to a low red heat in a stove or furnace; have in readiness a thin iron wire or watch-spring made into a spiral coil; throw into the pipe-bowl some lumps of sulphur, and when these melt and boil with formation of red vapour or gas, introduce the iron coil, previously heated to redness, into the sulphur vapour. The sulphur and iron unite; the iron, in fact, *burns* in the sulphur gas, giving rise to a black sulphide of iron, in the same manner as in Exp. 7 it burned in oxygen gas and produced an oxide of iron. The sulphide of iron melts to brittle, round globules, and remains in the pipe-bowl.

With *hydrogen* the element we are now considering unites to form a gas that possesses in a high degree the odour of rotten eggs, and is in fact the chief cause of the noisomeness of this kind of putrid matter. This substance, commonly called *sulphuretted hydrogen*, also *hydrosulphuric acid*, is dissolved in, and evolved abundantly from, the water of sulphur springs. It may be produced artificially by acting on some metallic sulphides with dilute sulphuric acid.

Experiment 17.—Place a lump of the sulphide of iron prepared in Exp. 16 in a cup or wine-glass, add a little water, and lastly a few drops of oil of vitriol. Bubbles of sulphuretted hydrogen gas will shortly escape.

In soils, sulphur occurs almost invariably in the form of *sulphates*, compounds of sulphuric acid with metal, a class of bodies to be hereafter noticed.

In plants, sulphur is always present, though usually in small quantity. The turnip, the onion, mustard, horse-radish, and asafœtida, owe their peculiar flavours to volatile oils in which sulphur is an ingredient.

Albumen, fibrine and caseine—organic principles never absent from plant or animal—contain also a small amount of sulphur. In hair and horn it occurs to the amount of one and a half to two per cent.

When organic matters are burned with full access of air, their sulphur is oxidized and remains in the ash in the form of a sulphate, or escapes into the air as sulphurous dioxide.

Phosphorus occurs in nature in combination.

Phosphorus is an element which has such intense affinities for oxygen that it never occurs naturally in the free state, and when prepared by art is usually obliged to be kept immersed in water to prevent its oxidizing, or even taking fire. It is known to the chemist in the solid state in three distinct forms. In the more commonly occurring form it is colourless or yellow, translucent, wax-like in appearance; is intensely poisonous, inflames by moderate friction, and is luminous in the dark: hence its name, derived from two Greek words signifying *light bearer*. Another form is brick red, opaque, far less inflammable, and destitute of poisonous properties. Phosphorus is extensively employed for the manufacture of friction matches. For this purpose both the above kinds of phosphorus are used.

When exposed sufficiently long to the air, or immediately on burning, this element unites with oxygen, forming a body of the utmost agricultural importance, viz. *phosphoric anhydride.*

Experiment 18.—Burn a bit of phosphorus under a bottle as in Exp. 8, omitting the water on the plate. The snow-like cloud of phosphoric anhydride gathers partly on the sides of the bottle, but mostly on the plate. It attracts moisture when exposed to the air, and hisses when put into water. Dissolve a portion of it in water, and observe that the solution is acid to the taste.

The occurrence and importance of phosphates.

In nature, phosphorus usually exists in the form of *phosphates*, which are metallic derivatives of phosphoric acid.

In plants and animals, it exists as phosphates of calcium, magnesium, potassium, and sodium.

The bones of animals contain a considerable proportion (10 per cent.) of phosphorus, mostly in the form of calcium phosphate. It is from them that the phosphorus employed for matches is largely procured.

Experiment 19.—Burn a piece of bone in a fire until it becomes white, or nearly so. The bone loses about half its weight. What remains is bone-earth or bone-ash, and of this nearly ninety per cent. is tricalcic phosphate.

Phosphates are readily formed by bringing together solutions of various metals with solution of phosphoric acid.

Experiment 20.—Pour into each of two wine or test glasses a small quantity of the solution of phosphoric acid obtained in Exp. 18. To one, add some lime-water (see note, p. 20) until a white cloud or *precipitate* is perceived. This is *tricalcic phosphate* or *phosphate of lime*. Into the other portion drop solution of alum. A translucent cloud of *aluminium phosphate* is immediately produced.

In soils and rocks, phosphorus exists in the state of such phosphates of calcium, aluminium, and iron. In the organic world the chemist has as yet detected phosphorus in other states of combination in but a few instances. In the brain and nerves, and in the yolk of eggs, an *oil containing phosphorus* has been known for some years, and recently similar phosphorized oils have been found in the pea, in maize, and other grains.

We have thus briefly noticed the more important characters of those six elements which constitute that part of plants, and of animals also, which is volatile or destructible at high temperatures, viz.: carbon, hydrogen, oxygen, nitrogen, sulphur, and phosphorus. Out of these substances, which may be termed the *volatile elements* of vegetation, are compounded, with few exceptions, the great mass of all the numberless products of life to be met with, both in the vegetable and animal world. These elements, excepting hydrogen and sometimes nitrogen, are found in the ash also of all plants.

ULTIMATE COMPOSITION OF VEGETABLE MATTER.

To convey an idea of the relative proportions in which these six elements exist in plants, a statement of the ultimate or elementary percentage composition of several kinds of dry vegetable matter is here subjoined :—

The ultimate volatile elements of plants.

	Grain of Wheat.	Straw of Wheat.	Tubers of Potato.	Grain of Peas.	Hay of Clover.
Carbon	46·1	48·9	44·0	46·5	47·4
Hydrogen	5·8	5·3	5·8	6·2	5·0
Oxygen	43·4	38·9	44·7	40.0	37·8
Nitrogen	2·3	0·4	1·5	4·2	2·1
Ash, including sulphur and phosphorus .	2·4	7·0	4·0	3·1	7·7
	100·0	100·0	100·0	100·0	100·0
Sulphur	0·12	0·14	0·08	0·21	0·18
Phosphorus . . .	0·30	0·08	0·34	0·34	0·20

Our attention may now be directed to the study of such compounds of these elements as constitute the basis of plants in general; since a knowledge of them will prepare us to consider the remaining elements with a greater degree of interest.

Previous to this, however, we must first of all gain a clear idea of that force or energy in virtue of whose action, chiefly, these elements are held in, or separated from, their combinations.

§ 3. Chemical Affinity.

Chemical attraction or affinity is the force (or resultant of the forces) which unites or combines two or more substances of unlike character so as to form a new body different from its ingredients.

Chemical combination differs essentially from mere mixture. Thus we may mix together in one vessel the two gases oxygen and hydrogen, and they will remain uncombined for an indefinite time, occupying their original volume; but if a flame be brought into the mixture they instantly unite with a loud explosion, and in place of the light and bulky gases we find a few drops of water, which is a liquid at ordinary temperatures, and in winter weather becomes solid, which does not sustain combustion like oxygen, nor itself burn as does hydrogen; but is a substance having its own peculiar properties, differing from those of all other bodies.

In the atmosphere we have oxygen and nitrogen in a state of mere mixture, each of these gases exhibiting its own characteristic properties. If they be brought into chemical combination, as can be done in certain circumstances, they may form a solid body which, when combined with water, yields a liquid possessing the most destructive qualities, being in fact nitric acid, or aquafortis.

How compounds differ from mixtures.

Chemical Decomposition.—Water, thus composed or put together by the exercise of affinity, is easily decomposed or taken to pieces, so to speak, by forces that oppose affinity —*e.g.* heat and electricity; or by the greater affinity of some other body—*e.g.* sodium; as already illustrated in the preparation of hydrogen, Exp. 11.

Definite Proportions.—A further distinction between chemical union and mere mixture is, that while two or more bodies may in general be mixed in all proportions, bodies combine chemically in comparatively few proportions which are fixed and invariable. Oxygen and hydrogen, *e.g.* are never found united in nature, except in the form of water; and water, if pure, is always composed of exactly one-ninth hydrogen and eight-ninths oxygen by weight, or, since oxygen is sixteen times heavier than hydrogen, bulk for bulk, of one volume or measure of oxygen to two volumes of hydrogen.

Atomic Weight of Elements.—On the hypothesis that chemical union takes place between *atoms* or indivisible particles of the elements, the numbers expressing the proportions by weight[*] in which they combine are appropriately termed *atomic weights*. These numbers are only relative; and since hydrogen is the element which unites in the smallest proportion by weight, it is assumed as the standard. From the results of a great number of the most exact experiments, chemists have generally agreed upon the atomic weights given in the subjoined table for the elements already described or employed.

Symbols.—For convenience in representing chemical changes, the first letter (or letters) of the Latin name of the *element* is employed instead of the name itself, and is termed its symbol.

Elements combine in definite and constant proportions.

TABLE OF ATOMIC WEIGHTS AND SYMBOLS OF ELEMENTS.[†]

Element.	Atomic Weight.	Symbol.
Hydrogen	1	H
Carbon	12	C
Oxygen	16	O
Nitrogen	14	N
Sulphur	32	S
Phosphorus . . .	31	P
Chlorine	35·5	Cl
Mercury	200	Hg (Hydrargyrum)
Calcium	40	Ca
Iron	56	Fe (Ferrum)

Multiple Proportions.—When two or more bodies unite in several proportions, their quantities, when not expressed by the atomic weights, are twice, thrice, four, five times these weights; they are multiples of the atomic weights by some simple number. Thus, carbon and oxygen form two commonly occurring compounds, viz. *carbonic oxide*, consisting of one atom of each ingredient, and *carbonic dioxide*, which contains to one atom or 12 parts by

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[*] Unless otherwise stated, parts or proportions by *weight* are always to be understood.

[†] Latterly, chemists are mostly inclined to receive as the true atomic weights *double* the numbers that have been commonly employed, those of hydrogen, chlorine and a few others excepted.

weight of carbon, two atoms or 32 parts by weight of oxygen.

The structure of molecules.

MOLECULAR WEIGHTS OF COMPOUNDS.—While elements unite by *indivisible atoms* to form compounds, the compounds themselves combine with each other, or exist as *molecules*,* or *aggregations of atoms*. It has indeed been customary to speak of *atoms of a compound body*, but this is an absurdity, for the smallest particles of compounds admit of separation into their elements. The term molecule implies capacity for division just as atom excludes that idea.

The molecular weight of a compound is the sum of the weights of the atoms that compose it. For example, water being composed of 1 atom or 16 parts by weight of oxygen, and 2 atoms or 2 parts by weight of hydrogen, has the molecular weight of 18.

The following scheme illustrates the molecular composition of a somewhat complex compound, one of the carbonates of ammonia.

Ammonia gas results from the union of an atom of nitrogen with three atoms of hydrogen. One molecule of ammonia gas unites with a molecule of carbonic dioxide gas and a molecule of water, to produce a molecule of carbonate of ammonia.

Carbonate of Ammonia.	1 mol. =	Ammonia, 1 mol. =	Hydrogen, 3 ats.	= 3	= 17 parts	=79 parts.
			Nitrogen, 1 at.	= 14		
		Carbon. dioxide, 1 mol. =	Carbon, 1 ,,	= 12	= 44 parts	
			Oxygen, 2 ats.	= 32		
		Water, 1 mol. =	Hydrogen, 2 ,,	= 2	= 18 parts	
			Oxygen, 1 at.	= 16		

The signification of chemical symbols.

NOTATION OF COMPOUNDS.—For the purpose of expressing easily and concisely the composition of compounds, and the chemical changes they undergo, chemists have agreed to make the symbol of an element signify *one atom* of that element.

Thus H implies not only the light, combustible gas hydrogen, but one part of it by weight as compared with

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* Latin diminutive, signifying *a little mass*.

other elements: and S suggests, in addition to the idea of the body sulphur, the idea of 32 parts of it by weight. Through this association of the atomic weight with the symbol, the composition of compounds is expressed in the simplest manner by writing the symbols of their elements one after the other, thus: carbonic oxide is represented by CO, mercuric oxide by HgO, and ferrous sulphide by FeS.

CO conveys to the chemist not only the fact of the existence of carbonic oxide, but also instructs him that its molecule contains an atom each of carbon and of oxygen, and from his knowledge of the atomic weights he gathers the proportions by weight of the carbon and oxygen in it.

Use of numerals in chemical formulæ.

When a compound contains more than one atom of an element, this is shown by appending a small figure to the symbol of the latter. For example: water consists of two atoms of hydrogen united to one of oxygen, the symbol of water is then H_2O. In like manner the symbol of carbonic dioxide is CO_2.

When it is wished to indicate that more than one molecule of a compound exists in combination or is concerned in a chemical change, this is done by prefixing a large figure to the symbol of the compound. For instance, two molecules of water are expressed by $2\ H_2O$.

The symbol of a compound is usually termed a *formula*. Subjoined is a table of the formulæ of some of the compounds that have been already described or employed.

FORMULÆ OF COMPOUNDS.

Name.	Formula.	Molecular Weight.
Water	H_2O	18
Hydrosulphuric acid	H_2S	34
Ferrous sulphide	FeS	88
Mercuric oxide	HgO	216
Carbonic dioxide	CO_2	44
Calcium chloride	$CaCl_2$	111
Sulphurous anhydride	SO_2	64
Sulphuric ,,	SO_3	80
Phosphoric ,,	P_2O_5	142

The difference between rational and empirical formulæ.

Empirical and Rational Formulæ.—It is obvious that many different formulæ can be made for a body of complex character. Thus, the carbonate of ammonia, whose composition has already been stated (page 33), and which contains

1 atom of Nitrogen,
1 „ „ Carbon,
3 atoms „ Oxygen, and
5 „ „ Hydrogen,

may be most compactly expressed by the formula

$$NCO_3H_5.$$

Such a formula merely informs us what elements and how many atoms of each enter into the composition of the substance. It is an *empirical* formula, being the simplest expression of the facts obtained by analysis of the substance.

Rational formulæ, on the other hand, are intended to convey some notion as to the constitution, formation, or modes of decomposition of the body. For example, the fact that ammonium carbonate results from the union of one molecule each of carbonic acid, water, and ammonia, is expressed by the formula

$$NH_3, H_2O, CO_2 = NH_4\ HCO_3.$$

A substance may have as many rational formulæ as there are rational modes of viewing its constitution.

Chemical changes are represented in equations.

Equations of formulæ serve to explain the results of chemical reactions and changes. Thus the breaking up by heat of potassium chlorate into potassium chloride and oxygen, is expressed by the following statement:

$$\underset{\text{Potass. chlorate.}}{2\,KClO_3} = \underset{\text{Potass. chloride.}}{2\,KCl} + \underset{\text{Oxygen.}}{3\,O_2}$$

The sign of equality, =, shows that what is written before it supplies and is resolved into what follows it. The sign + indicates and distinguishes separate bodies.

The employment of this kind of short-hand for exhibiting chemical changes will find frequent illustration as we proceed with our subject.

The composition of bodies may be expressed in two modes.

Modes of stating Composition of Chemical Compounds.—These are two, viz. atomic or molecular statements, and centesimal statements, or proportions in one hundred parts (per cent., p. c., or °|₀). These modes of expressing composition are very useful for comparing together different compounds of the same elements, and, while usually the atomic statement answers for substances which are comparatively simple in their composition, the statement per cent. is more useful for complex bodies. The composition of the two compounds of carbon with oxygen is given below according to both methods.

	Atomic.	Per cent.		Atomic.	Per cent.
Carbon (C)	12	42·86	(C)	12	27·27
Oxygen (O)	16	57·14	(O_2)	32	72·73
Carbonic oxide (C O)	28	100·00	Carbonic dioxide (C O_2)	44	100·00

The conversion of one of these statements into the other is a case of simple rule of three, which is illustrated in the following calculation of the centesimal composition of water from its atomic formula.

Water (H_2O) has the molecular weight 18, *i.e.* it consists of two atoms of hydrogen, or two parts, and one atom of oxygen, or sixteen parts by weight.

The arithmetical proportions subjoined serve for the calculation, viz.:

H_2O Water H Hydrogen.
18 : 100 :: 2 : per cent. sought (= 11·11 +).
H_2O Water O Oxygen.
18 : 100 :: 16 : per cent. sought (= 88·89 +).

By multiplying together the second and third terms of these proportions, and dividing by the first, we obtain the required per cent. viz. of hydrogen, 11·11; and of oxygen, 88·89.

The reader must bear well in mind that chemical affinity manifests itself with very different degrees of intensity between different bodies, and is variously modified, excited or annulled, by other natural agencies and forces. Heat, light, electricity, &c., affect it very powerfully, as will be hereafter noticed.

§ 4. VEGETABLE ORGANIC COMPOUNDS, OR PROXIMATE PRINCIPLES.

The proximate constituents of plants.

We are now prepared to enter upon the study of the chief organic compounds which constitute the vegetable structure, and which are produced with the elements carbon, oxygen, hydrogen, nitrogen, sulphur, and phosphorus, by the agency of the several physical and chemical forces. The number of distinct substances found in plants is practically unlimited. There are already well known to chemists hundreds of oils, acids, bitter principles, resins, colouring matters, &c. Almost every plant contains some organic body peculiar to itself, and usually the same plant in its different parts reveals to the senses of taste and smell the presence of several individual substances. In tea and coffee occurs a characteristic "active principle," *theine.* From tobacco an oily liquid of eminently narcotic and poisonous properties, *nicotine*, can be extracted. In the orange are found no less than three *oils;* one in the leaves, one in the flowers, and a third in the rind of the fruit.

Notwithstanding the great number of bodies thus occurring in the vegetable kingdom, it is a few which form the bulk of all plants, and especially of those which have an agricultural importance as sources of food to man and animals. These substances, into which any plant may be resolved by simple, mostly mechanical means, are conveniently termed *proximate principles*, and we shall notice them in some detail under six principal groups, viz.:

1. WATER.
2. THE CELLULOSE GROUP OR AMYLOIDS—Cellulose, Wood, Starch, the Sugars and Gums.
3. THE PECTOSE GROUP—the Pulp and Jellies of Fruits and certain Roots.
4. THE VEGETABLE ACIDS.
5. THE FATS and OILS.
6. THE ALBUMINOID or PROTEINE BODIES.

Water is a large and constant constituent of plants.

1. **Water,** H_2O, as already stated, is the most abundant ingredient of plants. It is itself a compound of oxygen and hydrogen, having the following centesimal composition:

Oxygen	88·89
Hydrogen	11·11
	100·00

It exists in all parts of the plant, is the immediate cause of the succulence of the tender parts, and is essential to the life of the vegetable organs.

In the following table are given the percentages of water in some of the more common agricultural products in the *fresh state*, but the proportions are not quite constant, even in the same part of different specimens of any given plant.

WATER IN FRESH PLANTS.

	Per cent.
Meadow grass	72
Red clover	79
Maize, as used for fodder	81
Cabbage	90
Potato tubers	75
Sugar beet	82
Carrots	85
Turnips	91
Pine-wood	40

Plants apparently dry contain water.

In living plants, water is usually perceptible to the sight or touch in the *sap*. But it is not only fresh plants that contain water. When grass is made into hay, the water is by no means all dried out, but a considerable proportion remains in the pores, and is not recognisable by the senses. So, too, seasoned wood, flour and starch, when seemingly dry, contain a quantity of invisible water, which can be removed by heat.

Experiment 21.—Into a wide glass tube, like that shown in Fig. 2, place a spoonful of sawdust, or starch, or a little hay. Warm over a lamp, but very slowly and cautiously, so as not to burn or blacken the substance. Water will be expelled from the organic matter, and will collect on the cold part of the tube.

It is thus obvious that vegetable substances may contain water in *two different conditions*. Red clover, for example, when growing or freshly cut, contains about seventy-nine per cent. of water. When the clover is dried, as for making hay, the greater part of this water escapes, so that the *air-dry* plant contains but about seventeen per cent. On subjecting the air-dry clover to a temperature of 100° for some hours, the water is completely expelled, and the substance becomes really *dry*.

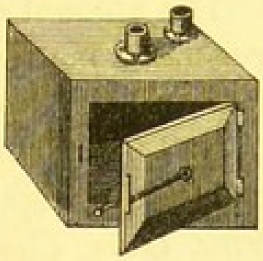

Fig. 9.

To drive off all water from vegetable matters, the chemist usually employs a *water-oven* (Fig. 9), consisting of a vessel of tin or copper plate, with double walls, between which is a space that may be nearly filled with water. The substance to be dried is placed in the interior chamber, the door is closed, and the water is brought to boil by the heat of a lamp or stove. The precise *quantity* of water belonging to, or contained in a substance, is ascertained by first weighing the substance, then drying it until its weight is constant. The *loss* is water.

In the subjoined table are given the average quantities per cent. of water existing in various vegetable products when *air-dry*.

WATER IN AIR-DRY PLANTS.

	Per cent.
Meadow grass (hay)	15
Red clover hay	17
Pine-wood	20
Straw and chaff of wheat, rye, &c.	15
Bean straw	18
Wheat (rye, oat) grain	14
Maize grain	12

The water of plants is either free or combined.

That portion of the water which the fresh plant loses by mere exposure to the air is chiefly the water of its juices or sap, and is manifest to the sight and touch as a liquid in crushing the fresh plant; it is, properly speaking, the *free* *water of vegetation.* The water which remains in the air-dry plant is imperceptible to the senses while in the plant,—can only be discovered on expelling it by heat or otherwise,—and may be designated as the *combined water of vegetation.*

The amount of water contained in either fresh or air-dry vegetable matter is constantly fluctuating with the temperature and the dryness of the atmosphere.

2. THE CELLULOSE GROUP, OR THE AMYLOIDS. — The cellulose group comprises *Cellulose, Starch, Inuline, Dextrine, Gum, Cane sugar, Fruit sugar, and Grape sugar.*

These bodies, especially cellulose and starch, form by far the largest share—perhaps seven-eighths—of all the *dry matter* of vegetation, and most of them are distributed throughout all parts of plants.

The composition and forms of the cells of plants.

Cellulose, $C_6H_{10}O_5$.—Every agricultural plant is an aggregate of microscopic *cells,* i.e. is made up of minute sacks or closed tubes, adhering to each other.

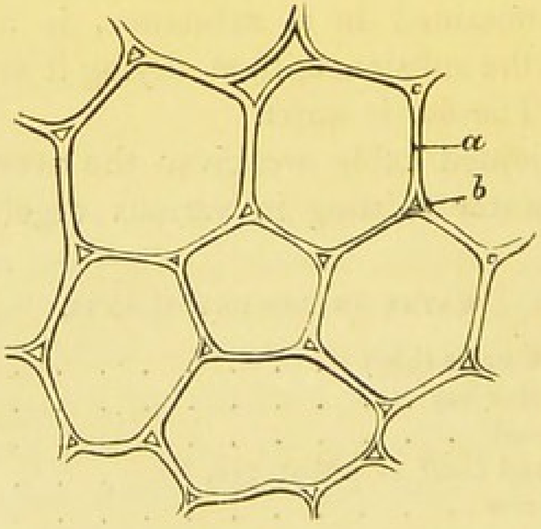

Fig. 10.

Fig. 10 represents an extremely thin slice from the stem of a cabbage, magnified 230 diameters. The united walls of two cells are seen in section at *a,* while at *b* an empty space is noticed.

The outer coating, or wall, of the cell is cellulose. This substance is accordingly the skeleton or framework of the plant, and the material that gives toughness and solidity to its parts. Next to water it is the most abundant body in the vegetable world.

All plants and all parts of all plants contain cellulose, but it is relatively most abundant in their stems and leaves. In seeds it forms a large portion of the husk, shell, or other outer coating, but in the interior of the seed it exists in small quantity.

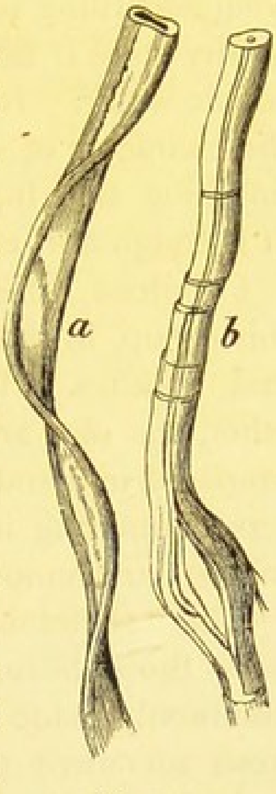

Fig. 11.

The different varieties of cellulose.

The fibres of cotton (Fig. 11 *a*), hemp, and flax (Fig. 11 *b*), and white cloth and unsized paper made from these materials, are nearly pure cellulose.

The fibres of cotton, hemp, and flax are simply long and thick-walled cells, the appearance of which, when highly magnified, is shown in Fig. 11, where *a* represents the thinner, more soft, and collapsed cotton fibre, and *b* the thicker and more durable fibre of linen.

Wood, or woody fibre, consists of long and slender cells of various forms, colours, and dimensions, which are delicate when young (in the sap wood), but as they become older fill up interiorly by the deposition of repeated layers of cellulose, which is intergrown with a substance (or substances) called *lignine.* The hard shells of nuts and stone

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* According to F. Schulze, lignine impregnates (not simply incrusts) the cell-wall; it is soluble in hot alkaline solutions, and is readily oxidized by nitric acid. Schulze ascribes to it the composition,—

Carbon	55·3
Hydrogen	5·8
Oxygen	38·9
	100·0

This is, however, simply the inferred composition of what is left after fruits contain a basis of cellulose, which is impregnated with ligneous matter.

When quite pure, cellulose is a white, often silky or spongy, and translucent body, its appearance varying somewhat according to the source whence it is obtained. In the air-dry state it usually contains about 10 per cent. of hygroscopic water. It has, in common with animal membranes, the character of swelling up when immersed in water, from imbibing this liquid; on drying again, it shrinks in bulk. It is tough and elastic.

Cellulose differs remarkably from the other bodies of this group, in the fact of its slight solubility in dilute acids and alkalies. It is likewise insoluble in water, alcohol, ether, the oils, and in most ordinary solvents. It is hence prepared in a state of purity by acting upon vegetable matters containing it with successive solvents, until all other matters are removed.

The fibres of plants may be separated from their softer parts.

The "skeletonized" leaves, fruit vessels, &c., which compose those beautiful objects called *phantom bouquets*, are commonly made by dissolving away the softer portions of fresh succulent plants by a hot solution of caustic soda, and afterwards whitening the skeleton of fibres that remains by means of chloride of lime (bleaching powder). They are almost pure cellulose.

Skeletons may also be prepared by steeping vegetable matters in a mixture of chlorate of potash and dilute nitric acid for a number of days.

Experiment 22.—To 500 *cubic centimetres** (or one pint) of nitric acid of density 1·1 add 30 grams (or one ounce) of pulverized chlorate of

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the cellulose, &c. have been removed. Lignine cannot be separated in the pure state, and has never been analysed. What is thus designated is probably a mixture of several distinct substances.

Lignine appears to be indigestible by herbivorous animals. (Grouven, V. Hofmeister.)

* On subsequent pages we shall make frequent use of some of the French decimal weights and measures, for the reasons that they are much more convenient than the English ones, and are now almost

potash, and dissolve the latter by agitation. Suspend in this mixture a number of leaves, &c.* and let them remain undisturbed, at a temperature not above 20° Cent. until they are perfectly whitened, which may require from ten to twenty days.

The preparations of leaves should be floated out from the solutions on slips of paper, washed copiously in clear water, and dried under pressure between folds of unsized paper.

Various kinds of fibre are used in making paper.

The fibres of the whiter and softer kinds of wood are now much employed in the fabrication of paper. For this purpose the wood is rasped to a coarse powder by machinery, then freed from lignine, starch, &c., by a hot solution of soda, and finally bleached with chloride of lime.

The husks of maize have been successfully employed in Austria, both for making paper and an inferior cordage.

Though cellulose is insoluble in, or but slightly affected by, dilute acids and alkalies, it is dissolved or altered by these agents, when they are concentrated or hot. The result of the action of strong acids and alkalies is very various, according to their kind and the degree of strength in which they are employed.

The strongest nitric acid transforms cellulose into *trinitrocellulose* (pyroxyline, gun-cotton), a body which burns explosively, and has been employed as a substitute for gunpowder.

Sulphuric acid of a certain strength, by a brief contact with cellulose, converts it into a tough, translucent substance which strongly resembles bladder or similar animal mem-

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exclusively employed in all scientific treatises and investigations. For small weights, the *gramme* or *gram*, abbreviated gm. (equal to 15½ grains, nearly), is the customary unit. The unit of measure by volume is the *cubic centimetre*, abbreviated c. c. (30 c. c. equal to one fluid ounce nearly). Gram weights and glass measures graduated into cubic centimetres are furnished by all dealers in chemical apparatus.

* Full-grown but not old leaves of the elm, maple, and maize, heads of unripe grain, slices of the stem and joints of maize, &c. may be employed to furnish skeletons that will prove valuable in the study of the structure of these organs.

branes. Paper thus treated becomes papyrine, the *vegetable parchment* of commerce.

The manufacture of vegetable parchment.

Experiment 23.—To prepare parchment paper, fill a large cylindrical test tube first to the depth of an inch or so with water, then pour in three times this bulk of oil of vitriol, and mix. When the liquid is perfectly cold, immerse into it a strip of unsized paper, and let it remain for about fifteen seconds ; then remove, and rinse it copiously in water. Lastly, soak it for some minutes in water, to which a little ammonia is added, and wash again with pure water. These washings are for the purpose of removing the acid. The success of this experiment depends upon the proper strength of the acid, and the time of immersion. If need be, repeat the experiment, varying these conditions slightly, until the result is obtained.

Cellulose may be changed into gum and sugar.

Prolonged contact with strong sulphuric acid converts cellulose into dextrine, and finally into sugar (see p. 60). Other intermediate products are, however, formed, whose nature is little understood ; but the properties of one of them is employed as a *test* for cellulose.

Experiment 24.—Spread a slip of unsized paper upon a china plate, and pour upon it a few drops of the diluted sulphuric acid of Exp. 23. After some time the paper is seen to swell up and dissolve, and now, but not before this treatment, strikes a blue or violet colour with iodine. The solution contains dextrine and glucose.

Boiling for some hours with dilute sulphuric acid also transforms cellulose into sugar, and, under certain circumstances, hydrochloric acid and alkalies have the same effect upon it.

The denser and more impure forms of cellulose, as they occur in wood and straw, are slowly acted upon by chemical agents, and are not easily digestible by most animals ; but the cellulose of young and succulent stems, leaves, and fruits, is digestible to a large extent, especially in the stomachs of animals which naturally feed on herbage, and therefore cellulose ranks among the nutritive substances.

Chemical Composition of Cellulose.—This body is a compound of the three elements, carbon, oxygen, and hydrogen. Analyses of it, as prepared from a multitude of sources, demonstrate that its composition is expressed by the formula, $C_6H_{10}O_5$. In 100 parts it contains,—

Carbon	44·44
Hydrogen	6·17
Oxygen	49·39
	100·00

Methods of estimating the cellulose of plants.

Modes of estimating Cellulose.—In statements of the composition of plants, the terms *fibre*, *woody fibre*, and *crude cellulose* are often met with. These are applied to more or less impure cellulose, which is obtained as a residue after removing other matters, as far as possible, by alternate treatment with dilute acids and alkalies, but without acting to any great extent on the cellulose itself. The methods formerly employed, and those by which most of our analyses have been made, are confessedly imperfect. If the solvents are too concentrated, or the temperature at which they act too high, cellulose itself is dissolved; while with too dilute reagents a portion of other matters remains unattacked. The method adopted by Henneberg (*Versuchs Stationen*, vi. 497), with quite good results, is as follows: three grams of the finely divided substance are boiled for half an hour with 200 cubic centimetres of dilute sulphuric acid (containing 1¼ per cent. of oil of vitriol), and after the substance has settled the acid liquid is poured off. The residue is boiled again for half an hour with 200 c. c. of water, and this operation is repeated a second time. The residual substance is now boiled half an hour with 200 c.c. of dilute potash lye (containing 1¼ per cent. of dry caustic potash), and after removing the alkaline liquid it is boiled twice with water as before. What remains is brought upon a filter, and washed with water, then with alcohol, and, lastly, with ether, as long as these solvents take up anything. This crude cellulose contains ash and nitrogen, for which corrections must be made. The nitrogen is assumed to belong to some albuminoid, and from its quantity the amount of the latter is calculated (see p. 94).

Even with these corrections, the quantity of cellulose is not obtained with entire accuracy, as is usually indicated by its appearance and its composition. While, according to V. Hofmeister, the crude cellulose thus prepared from the pea is perfectly white, that from wheat-bran is brown, and that from rape-cake is almost black in colour.

Grouven gives the following analyses of two samples of crude cellulose obtained by a method essentially the same as we have described. (*2ter Salsmünder Bericht*, p. 456.)

	Rye-straw fibre.	Linen fibre.
Water	8·65	5·40
Ash	2·05	1·14
N	0·15	0·26
C	42·47	38·36
H	6·04	5·89
O	40·64	48·95
	100·00	100·00

On deducting water and ash, and making proper correction for the nitrogen, the above samples, together with one of wheat-straw fibre, analysed by Henneberg, exhibit the following composition, compared with pure cellulose:—

	Rye-straw fibre.	Linen fibre.	Wheat-straw fibre.	Pure cellulose.
C	47·5	41·0	45·4	44·4
H	6·8	6·4	6·3	6·2
O	45·7	52·6	48·3	49·4
	100·0	100·0	100·0	100·0

Franz Schulze, of Rostock, proposed in 1857 another method for estimating cellulose, which has recently (1866) been shown to be more correct than the one already described. Kühn, Aronstein, and H. Schulze (Henneberg's *Journal für Landwirthschaft*, 1866, pp. 289–297) have applied this method in the following manner:—One part of the dry pulverized substance (two to four grams) which has been previously extracted with water, alcohol, and ether, is placed in a glass-stoppered bottle, with 0·8 part of chlorate of potash, and 12 parts of nitric acid of specific gravity 1·10, and digested at a temperature not exceeding 18° C. for 14 days. At the expiration of this time the contents of the bottle are mixed with some water, brought upon a filter, and washed, firstly with cold and afterwards with hot water. When all the acid and soluble matters have been washed out, the contents of the filter are emptied into a beaker, and heated to 74° C. for about 45 minutes with weak ammonia (1 part commercial ammonia to 50 parts of water); the substance is then brought upon a weighed filter, and washed, first, with dilute ammonia, as long as this passes off coloured, then with cold and hot water, then with alcohol, and finally with ether. The substance remaining contains a small quantity of ash and nitrogen, for which corrections must be made. The fibre is, however, purer than that procured by the other method, and a somewhat larger quantity (½ to 1½ per cent.) is obtained. The results appear to vary but about one per cent. from the truth.

The percentage of cellulose in vegetable products.

The average proportions of cellulose found in various vegetable matters in the usual or air-dry state, are as follow:—

AMOUNT OF CELLULOSE IN PLANTS.

	Per cent.		Per cent.
Potato tuber	1·1	Red clover plant in flower .	10
Wheat grain	3·0	„ „ hay	34
Wheat meal	0·7	Timothy grass	23
Maize grain	5·5	Maize cobs	38
Barley „	8·0	Oat straw	40
Oat „	10·3	Wheat „	48
Buckwheat grain . . .	15·0	Rye „	54

The occurrence of starch.

Starch, $C_6H_{10}O_5$.—The cells of the seeds of wheat, maize, and all other grains, and the tubers of the potato, contain this familiar body in great abundance. It occurs also in the wood of all forest trees, especially in autumn and winter. It accumulates in extraordinary quantity in the pith of some plants, as in the Sago-palm (*Sagus Rumphii*) of the Malay Islands, a single tree of which may yield 800 lbs.

Starch occurs in greater or less quantity in every flowering plant that has been examined for it.

The manufacture of starch.

The preparation of starch from the potato is very simple. The potato contains, on the average, 76 per cent. water, 20 per cent. starch, and 1 per cent. of cellulose, while the remaining 3 per cent. consists mostly of matters which are easily soluble in water. By grating, the potatoes are reduced to a pulp; the cells are thus broken and the starch-grains set at liberty. The pulp is then agitated on a fine sieve, in a stream of water. The washings run off milky, from suspended starch, while the cellulose is retained by the sieve. The milky fluid is allowed to rest in vats until the starch is deposited. It is then poured off, and the starch is collected and dried.

Wheat starch is commonly made by allowing wheat flour mixed with water to ferment for several weeks. By this process the gluten, &c. are converted into soluble matters, which are removed by washing from the unaltered starch.

Starch is now largely manufactured from maize. A dilute solution of caustic soda is used to dissolve the albuminoids (see p. 86). The starch and bran remaining are separated by diffusing both in water, when the bran rapidly settles, and the water being run off at the proper time, deposits the pure starch, *corn-starch* of commerce, also known as *maizena*.

Starch is prepared by similar methods from rice, horse-chestnuts, and various other plants.

Chap. I.

Arrowroot is pure starch.

Arrowroot is starch obtained by grating and washing the tubers of *Maranta ramosissima* and *M. arundinacea*, plants cultivated in the East and West Indies.

Experiment 25.—Reduce a clean potato to pulp by means of a tin grater. Tie up the pulp in a piece of not too fine muslin, and squeeze it repeatedly in a quart or more of water. The starch grains thus pass the meshes of the cloth, while the cellulose is retained. Let the liquid stand until the starch settles, pour off the water, and dry the residue.

Starch, as usually seen, is a white powder which consists of minute, rounded grains, and hence has a slightly harsh feel. When observed under a powerful magnifier, these grains often present characteristic forms and dimensions.

Starch occurs in granules of different forms.

In potato-starch they are egg or kidney-shaped, and are distinctly marked with curved lines or ridges, which surround a point or eye (*a*, Fig. 12). Wheat-starch consists of grains shaped like a thick burning-glass, or spectacle-lens, having a cavity in the centre, *b*. Oat-starch is made up of compound grains, which are easily crushed into smaller granules, *c*. In maize and rice the grains are usually so densely packed in the cells as to present an angular (six-sided) outline, as in *d*. The starch of the bean and pea has the appearance of *e*. The minute starch-grains of the parsnip are represented at *f*, and those of the beet at *g*.

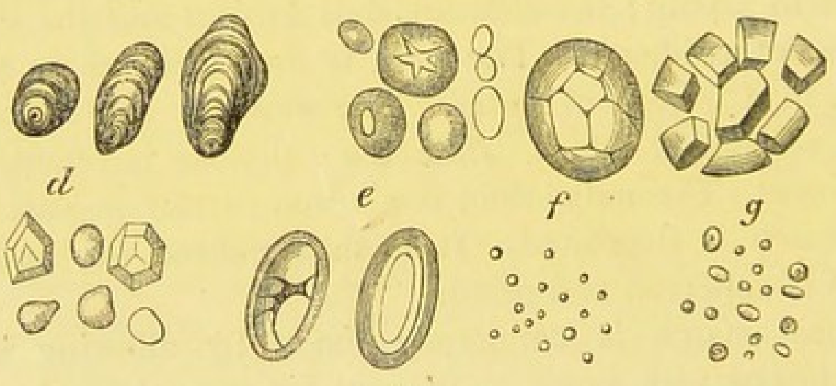

Fig. 12.

The grains of potato-starch are among the largest, being often 1-300th of an inch in diameter; wheat-starch grains are about 1-1000th of an inch; those of rice 1-3000th of an inch, while those of the beet-root are still smaller.

Unorganized Starch exists as a jelly in several plants, according to Schleiden (*Botanik*, p. 127). Dragendorff asserts that in the seeds of colza and mustard the starch does not occur in the form of grains, but in an unorganized state, which he considers to be the same as that noticed by Schleiden.

The starch-grains are unacted upon by cold water, unless broken (see Exp. 26), and quickly settle from suspension in it.

When starch is triturated for a long time with cold water, whereby the grains are broken, the liquid, after filtering or standing until perfectly clear, contains starch in extremely minute quantity.

When starch is heated to near boiling with 12 to 15 times its weight of water, the grains swell and burst, or exfoliate, the water is absorbed, and the whole forms a jelly. This is the starch-paste used by the laundress for stiffening muslin. The starch is but very slightly dissolved by this treatment (see Exp. 27). On freezing, it separates almost perfectly.

When starch-paste is dried, it forms a hard, horn-like mass.

Tapioca and *Sago* are starch, which, from being heated while still moist, is partially converted into starch-paste, and, on drying, acquires a more or less translucent aspect. Tapioca is obtained from the roots of *Manihot utilissima* and *M. Aipi*, plants cultivated in the West Indies and South America. *Cassava* is the residual pulp of the same root, roasted. Sago is made in the islands of the East Indian Archipelago, from the pith of palms. It is granulated by forcing the paste through metallic sieves. Both tapioca and sago are now imitated with potato starch.

Iodine is the test for starch.

Test for Starch.—The chemist is enabled to recognise starch with the greatest ease and certainty by its peculiar deportment towards iodine, which, when dissolved in water or alcohol and brought in contact with starch, gives it a beautiful purple or blue colour. This test may be used even in microscopic observations with the utmost facility.

Experiment 26.—Shake together, in a test tube, 30 c. c. of water and starch of the bulk of a seed of maize. Add solution of iodine, drop by drop, agitating until a faint purplish colour appears. Pour off half the liquid into another test tube, and add at once to it one-fourth its bulk of iodine solution. The latter portion becomes intensely blue by transmitted, or almost black by reflected, light. On standing, observe that in the first case, where starch preponderated, it settles to the bottom, leaving a colourless liquid, which shows the insolubility of starch in cold water; the starch itself has a purple or red tint. In the case where iodine was used in excess, the deposited starch is blue-black.

Experiment 27.—Place a bit of starch as large as a grain of wheat in 30 c. c. of cold water, and heat to boiling. The starch is converted into thin, translucent paste. That a portion is dissolved is shown by filtering through paper and adding to one-half of the filtrate a few drops of iodine solution, when a perfectly clear blue liquid is obtained. The delicacy of the reaction is shown by adding to 30 c. c. of water a little solution of iodine, and noting that *a few drops* of the solution of starch suffice to make the large mass of liquid perceptibly blue.

Starch readily suffers change.

By the prolonged action of dry heat, hot water, acids, or alkalies, starch is converted first into soluble starch, then into dextrine, and finally into sugar (glucose), as will be presently noticed.

The same transformations are accomplished by the action of living yeast, and of the so-called diastase of germinating seeds.

The saliva of man and plant-eating animals usually likewise dissolves starch at blood-heat by converting it into sugar. It is much more promptly converted into sugar by the liquids of the large intestine. It is thus digested when eaten by animals. It is, in fact, one of the most important ingredients of the food of man and domestic animals.

The action of saliva demonstrates that starch-grains are not homogeneous, but contain a small proportion of matter not readily soluble in this liquid. This remains as a delicate skeleton after the grains are otherwise dissolved. It is probably a more dense form of starch.

The *chemical composition* of starch is identical with that of cellulose.

Air-dry starch always contains a considerable amount of hygroscopic water, which usually ranges from 12 to 18 per cent.

Next to water and cellulose, starch is the most abundant ingredient of agricultural plants.

In the subjoined table are given the proportions contained in certain vegetable products, as determined by various chemists. The quantities are, however, somewhat variable.

Starch exists in different proportions in different plants.

AMOUNT OF STARCH IN PLANTS.

	Per cent. Water.	Per cent. Starch.
Wheat	13·2	55·9
Wheat flour	15·8	65·7
Rye	11·0	45·5
Oats	11·9	40·0
Barley	11·5	38·5
Timothy seed	12·6	45·0
Rice (hulled)	13·3	74·1
Peas	5·0	37·3
Beans (white)	16·7	37·7
Clover seed	10·8	10·8
Mustard seed	8·5	9·9
Colza seed	5·8	8·6
Potatoes (dried) . . .	...	62·5

Starch is quantitatively estimated by various methods.

Starch may be estimated by chemical or mechanical means.

1. In case of potatoes or cereal grains, it may be determined roughly by direct mechanical separation. For this purpose 5 to 20 grams of the substance are reduced to fine division by grating (potatoes) or by softening in warm water, and crushing in a mortar (grains). The pulp thus obtained is washed either upon a fine hair-sieve or in a bag of muslin, until the water runs off clear. The starch is allowed to settle, dried, and weighed. The value of this method depends upon the care employed in the operation. The amount of starch falls too low, because it is impossible to break open all the minute cells of the substance analysed.

2. In many cases starch may be estimated with more precision by conversion into sugar (see p. 61).

3. Dr. Dragendorff, of the Rostock Laboratory, proceeds with starch determinations as follows: The pulverized substance, after drying out all hygroscopic moisture at 100°, is digested for 18 to 30 hours, at a temperature of 100°, in 10 to 12 times its weight of a solution of 5 to 6 parts of hydrate of potash in 94 to 95 parts of anhydrous alcohol. The digestion must take place in sealed glass tubes, or in a silver vessel which admits of being closed perfectly. By this treatment the albuminoid substances, the fats, the sugar, and dextrine, are brought into such a condition that simple washing with alcohol or water suffices to remove them completely. The chief part of the phosphoric and silicic acids is likewise rendered soluble. The starch-grains are not affected, neither does the cellulose undergo alteration, either qualitatively or quantitatively. In fact, this treatment serves excellently to isolate starch-grains for microscopic investigations. Besides starch and

The estimation of starch.

cellulose, nothing resists the action of alcoholic potash save portions of cuticle, gum, and some earthy salts.

When the digestion is finished, it is advisable, especially in case the substance is rich in fat, to bring the contents of the tube upon a filter while still hot, as otherwise potash-salts of the fatty acids may crystallize out. It is also well to wash immediately, first with hot absolute alcohol, then with cold alcohol of ordinary strength, and finally with cold water, until these several solvents remove nothing more. In the analysis of matters which contain much mucilage, as linseed, the washing must be completed with alcohol of 8 to 10 per cent. to prevent the swelling up of the residue.

The filter should be of good ordinary (not Swedish) paper, should be washed with hydrochloric acid and water, dried at 100°, and weighed. When the substance is completely washed, the filter and its contents are dried, first at 50°, and finally at 100°. The loss consists of albuminoids, fat, sugar, and a part of the salts of the substance; and when the last three are separately estimated, it may serve to control the estimation, by elementary analysis, of the albuminoids.

The filter, with its contents, is now reduced to powder or shreds, and the whole is heated with water containing 5 per cent. of hydrochloric acid until a drop of liquid no longer reacts blue with iodine. The treatment with potash leaves the starch-grains in such a state of purity from incrusting matters that their conversion into dextrine proceeds with great promptness, and is accomplished before the cellulose begins to be perceptibly acted upon. By weighing the residue that remains from the action of hydrochloric acid, after washing and drying, the amount of cellulose, cork, lignine, gum, and insoluble fixed matters is found. By subtracting these from the weight of the substance after exhaustion with potash, the quantity of starch is learned with great accuracy. The only error introduced by this method lies in the solution of some saline matters by the acid. The quantity is, however, so small as rarely to be appreciable. If needful, it can be taken into account by evaporating the acid solution to dryness, incinerating and weighing the residue. By warming with concentrated malt-extract at 55°, the starch alone is taken into solution, and no correction is needed for saline matters. If it is wished to determine the sugar produced by the transformation of the starch, a weaker acid must of course be employed. In case of mucilaginous substances, the starch must be extracted by digestion with a strong solution of sodium chloride, with which the requisite quantity of hydrochloric acid has been mixed, and the residue should be washed with water to which some alcohol has been added.—*Henneberg's Journal für Landwirthschaft*, 1862, p. 206.

Inuline, $C_{12}H_{20}O_{10}$, closely resembles starch in many points, and appears to replace that body in the roots of the artichoke, elecampane, dahlia, dandelion, chicory, and other composite plants. It is obtained in the form of minute white grains, which dissolve easily in hot water, and mostly separate again as the water cools. Unlike starch, inuline exists in a liquid form in the roots above named, and separates in grains from the clear pressed juice when this is kept some time. According to Bouchardat, the juice of the dahlia tuber, expressed in winter, becomes a semi-solid white mass in this way, after reposing some hours, from the separation of 8 per cent. of this substance.

The *inuline* of dahlia tubers is allied to starch.

Inuline, when pure, gives no coloration with iodine. It may be recognised in plants, where it occurs in a solution usually of the consistence of a thin oil, by soaking a slice of the plant in strong alcohol. Inuline is insoluble in this liquid, and under its influence shortly separates as a solid in the form of spherical granules, which may be identified with the aid of the microscope.

When long boiled with water, it is slowly but completely converted into a kind of sugar (lævulose); hot dilute acids accomplish the same transformation in a short time. It is digested by animals, and doubtless has the same value for food as starch.

In *chemical percentage composition*, inuline agrees perfectly with cellulose and starch.

Dextrine, a gumlike substance, occurs in plants.

Dextrine, $C_6H_{10}O_5$, has been thought to occur in small quantity dissolved in the sap of all plants. According to Von Bibra's late investigations, the substance existing in bread-grains which earlier experimenters believed to be dextrine, is in reality *gum*. Busse, who has examined various young cereal plants and seeds, and potato tubers, for dextrine, found it only in old potatoes and young wheat plants, and there in very small quantity. (*Jahresbericht für Chemie*, 1866, p. 664.)

Dextrine is easily prepared artificially by the transformation of starch, and its interest to us is chiefly due to this fact. When starch is exposed some hours to the heat of an oven, or 30 minutes to the temperature of 213° Cent., the grains swell, burst open, and are gradually converted into a very pale brownish substance, which dissolves readily in water, forming a clear, gummy solution. This is dextrine; and thus prepared it is largely used in the arts, especially in calico-printing, as a cheap substitute for gum-arabic, and bears the name British gum. In the baking of bread it is formed from the starch of the flour, and often constitutes 10 per cent. of the loaf. The glazing on the crust of bread, or upon biscuits that have been steamed, is chiefly due to a coating of dextrine. Dextrine is thus an important ingredient of those kinds of food which are prepared from the starchy grains by cooking.

Dextrine is manufactured from starch.

British gum, or commercial dextrine, appears either in translucent brown masses, or as a yellowish-white powder. On addition of cold water, the dextrine readily dissolves, leaving behind a portion of unaltered starch. When the solution is mixed with strong alcohol the dextrine separates in white flocks, which, upon agitation, unite to translucent lumps. With iodine, solution of commercial dextrine gives a fine purplish-red colour. Pure dextrine is, however, unaffected by iodine.

Experiment 28.—Cautiously heat a spoonful of powdered starch in a porcelain dish, with constant stirring so that it may not burn, for the space of five minutes; it acquires a yellow, and later a brown colour. Now add thrice its bulk of water, and heat nearly to boiling. Observe that a slimy solution is formed. Pour it upon a filter; the liquid that runs through contains dextrine. To a portion add twice its bulk of alcohol; dextrine is precipitated. To another portion add solution of iodine; this shows the presence of dissolved but unaltered starch, which likewise remains solid in considerable quantities upon the filter. To a third portion of the filtrate add one drop of strong sulphuric acid, and boil a few minutes. Test with iodine, which will now prove that all the starch is transformed.

Not only heat, but likewise acids and ferments, produce dextrine from starch, and also from cellulose. In the sprouting of seed it is formed from starch, and hence is an ingredient of malt liquors. It is often an ingredient of the animal. Limpricht obtained nearly a pound of dextrine from 200 lbs. of the flesh of a young horse. (*Ann. Ch. Ph.*, 133, p. 295.)

Its *chemical composition* is the same as that of cellulose, starch, and inuline.

The Gums.—A number of bodies exist in the vegetable kingdom which, from the similarity of their properties, have received the common designation of Gums. The best known are Gum Arabic, chiefly consisting of *Arabine;* the gum of the Cherry and Plum, which contain *Cerasine;* Gum Tragacanth and Bassora Gum, or *Bassorine;* and the *Vegetable Mucilage* of various roots, viz. of mallow and comfrey; and of certain seeds, as those of flax and quince.

True gums dissolve in water.

Arabine and Arabic Acid, $C_{12}H_{22}O_{11}$.—Gum Arabic exudes from the stems of various species of acacia that grow in tropical countries, especially in Arabia and Egypt. It occurs in tear-like, transparent, and, in its purest form, colourless masses. These dissolve easily in their own weight of water, forming a viscid liquid, or mucilage, which is employed for causing adhesion between surfaces of paper, and for thickening colours in calico-printing. Gum arabic, when burned, leaves about 3 per cent. of ash, chiefly carbonates of lime and potash. The gum itself (Arabine) is in fact a compound of lime and potash with *Arabic acid.*

This acid is obtained pure by *dialysis* or by mixing a strong solution of gum arabic with hydrochloric acid, and adding alcohol. The arabic acid is thus precipitated as a milk-white mass, which, when dried at 100°, becomes transparent, and has the composition $C_{12}H_{22}O_{11}$.

In 100 parts arabic acid contains:—

Carbon	42·12
Hydrogen	6·41
Oxygen	51·47
	100·00

By exposure to a temperature of 120°, arabic acid loses one molecule of water, and becomes insoluble in water; being, it would appear, transformed into *Metarabic acid* (Metagummic acid of Frémy).

Cerasine and Metarabic Acid, $C_{12}H_{20}O_{10}$.—The gum which exudes in glassy masses through the bark of cherry, plum, apricot, peach, and almond trees, is a mixture in variable proportions of Arabine, or the arabates of lime and potash, with *Cerasine*, or the metarabates of lime and potash. Cold water dissolves the former, while the cerasine remains undissolved, but swollen to a pasty mass or jelly.

Pure metarabic acid is prepared, as above stated, by exposing arabic acid to a temperature of 120° C., and its composition is $C_{12}H_{20}O_{10}$. It is likewise produced by putting solution of gum arabic in contact with oil of vitriol. On the other hand, metarabic acid is converted into arabic acid, by boiling with water and a little lime or alkali. Metarabic acid, as well as its compounds with lime, potash, &c. are insoluble in water.

Bassorine, $C_{12}H_{20}O_{10}$, as found in Gum Tragacanth, has much similarity to metarabic acid in its properties, being insoluble in water, but swelling up in it to a paste or jelly.

Linseed contains mucilage but no starch.

Vegetable Mucilage, $C_{12}H_{20}O_{10}$, has the same composition, and nearly the same characters, as Bassorine, and is possibly identical with it. It is an almost universal constituent of plants.

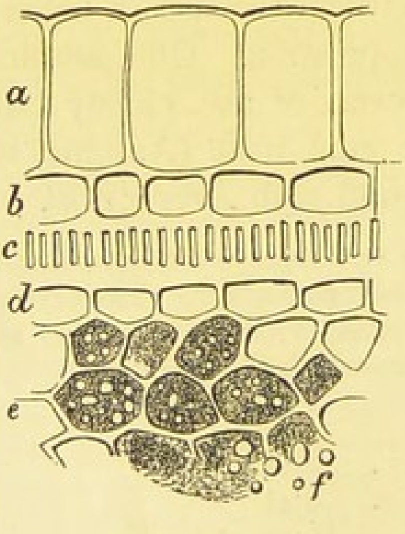

Fig. 13.

It is procured in a state of purity by soaking unbroken flax-seed in cold water, with frequent agitation, heating the liquid to boiling, straining, and evaporating, until addition of alcohol separates tenacious threads from it. It is then precipitated by alcohol containing a little hydrochloric acid, and washed with the same mixture. On drying, it forms a horny, colourless, and friable mass. Fig. 13 represents a highly-magnified section of the flax-seed. The external cells (*a*) contain the mucilage. When soaked in water, the mucilage swells, bursts the cells, and dissolves.

One or other of these kinds of gum has been found in the following plants, viz., basswood, elm, apple, grape, castor-oil, mangold, tea, sunflower, pepper, in various sea-weeds, and in the seeds of wheat, rye, barley, oats, maize, rice, buckwheat, and millet.

In the bread-grains, Arabine, or at least a soluble gum, occurs often in considerable proportion.

Gums occur in most grains.

TABLE OF THE PROPORTION OF GUM IN VARIOUS AIR-DRY PLANTS OR PARTS OF PLANTS.

(*According to Von Bibra.*)

	Per cent.
Wheat grain	4·50
Wheat flour, finest	6·25
Spelt flour (*Triticum spelta*)	2·48
Wheat bran	8·85
Spelt bran	12·52
Rye flour	4·10
Rye flour	7·25
Rye bran	10·40
Barley flour	6·33
Barley bran	6·88
Oat meal	3·50
Rice flour	2·00
Millet flour	10·60
Maize meal	3·05
Buckwheat flour	2·85

The gums are converted into sugar by long boiling with dilute acids.

The recent experiments of Grouven show that, contrary to what has been taught hitherto, gum (at least gum arabic) is digestible by domestic animals.

The occurrence and properties of common or cane sugar.

Saccharose, or **Cane Sugar**, $C_{12}H_{22}O_{11}$, so called because first and chiefly prepared from the sugar-cane, is the ordinary sugar of commerce. It is also manufactured from beet-roots, and is contained in many plants at the time of flowering. When pure it is a white solid, readily soluble in water, forming a colourless, ropy, and intensely sweet solution. It crystallizes in oblique prisms, which are usually small, as in granulated sugar, but in the form of sugar-candy may be found an inch or more in length.

The crystallized sugar obained largely from the sugar-beet, in Europe, and that furnished in America by the sugar-maple and sorghum, are identical with cane-sugar.

Saccharose also exists in the vernal juices of the walnut, birch, and other trees. It occurs, with other sugars, in the stems of unripe maize, in the nectar of flowers, in fresh honey, in parsnips, turnips, carrots, parsley, sweet potatoes, in the stems and roots of grasses, and in a multitude of fruits.

Experiment 29.—Heat cautiously a spoonful of white sugar until it melts (at 160° C.) to a clear yellow liquid. On rapid cooling it gives a transparent mass, known as *barley-sugar*, which is employed in confectionery. At a higher heat it turns brown, froths, emits pungent vapours, and becomes burnt sugar, or *caramel*, which is used for colouring soups, ale, &c.

The quantity per cent. of saccharose in the juice of various plants is given in the annexed table. It is, of course, variable, depending upon the variety of plant in case of cane, beet, and sorghum, as well as upon the stage of growth.

The sap of many plants contains saccharose.

SACCHAROSE IN PLANTS.

	Per cent.	
Sugar-cane, average	18	Peligot.
Sugar beet, „	10	„
Sorghum	9½	Goessmann.
Maize, just flowered	3¼	Lüdersdorff.
Sugar maple, sap average . . .	2½	Liebig.
Red maple, „	2½	„

When a solution of this sugar is heated with dilute acids, or when acted on by yeast, it is converted into a mixture of equal parts of lævulose (fruit sugar) and glucose (grape sugar).

The composition of saccharose is the same as that of arabic acid, and it contains in 100 parts:

Carbon	42·11
Hydrogen	6·43
Oxygen	51·46
	100·00

Lævulose, or Fruit Sugar (Fructose), $C_6H_{12}O_6$, exists mixed with other sugars in sweet fruits, honey, and

The uncrystallizable sugar of honey is lævulose.

molasses. Inuline is converted into this sugar by long boiling with dilute acids, or with water alone. When pure, it is a colourless, amorphous * mass. It is incapable of crystallizing or granulating, and usually exists dissolved in a small proportion of water as a syrup. Its sweetness is equal to that of saccharose.

Lævulose contains in 100 parts:

Carbon	40·00
Hydrogen.	6·67
Oxygen	53·33
	100·00

The crystallizable sugar of honey is glucose.

Glucose, or **Grape Sugar,** $C_6H_{12}O_6$, naturally occurs associated with lævulose in the juices of plants and in honey. Granules of glucose separate from the juice of the grape in drying, as may be seen in old "candied" raisins. Honey often granulates, or candies, on long keeping, from the crystallization of a part of its glucose.

Glucose is formed from dextrine by the action of hot dilute acids, in the same way that lævulose is produced from inuline. In the pure state it exists as minute, colourless crystals, and is, weight for weight, but half as sweet as the foregoing sugars. In composition it is identical with lævulose.

It combines chemically with water in two proportions. Monohydrated glucose ($2\,C_6H_{12}O_6$, H_2O), or Anthon's hard crystallized grape-sugar, which is prepared in Germany by a secret process, is dry to the touch. Another hydrated glucose ($C_6H_{12}O_6$, H_2O) occurs in commerce in an impure state as a soft, sticky, crystalline mass, which becomes doughy at a slightly elevated temperature. Both these hydrates lose their water at 100°.

Dissolved in water, glucose yields a syrup, which is thin, and destitute of the ropiness of cane-sugar syrup. It does not crystallize (granulate) so readily as cane-sugar.

Experiment 30.—Mix 100 c. c. of water with 30 drops of strong sulphuric acid, and heat to vigorous boiling in a glass flask. Stir 10

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* Literally, without shape, *i.e.* not crystallized.

grams of starch with a little water, and pour the mixture into the hot liquid, drop by drop, so as not to interrupt the boiling. The starch dissolves, and passes first into dextrine, and finally into glucose. Continue the ebullition for several hours, replacing the evaporated water from time to time. To remove the sulphuric acid, add to the liquid, which may be still milky from impurities in the starch, powdered chalk, little by little, until the sour taste disappears; filter from the sulphate of lime (gypsum) that is formed, and evaporate the solution of glucose* at a gentle heat, to a thick, syrupy consistence. On long standing it may crystallize or granulate.

By this method is prepared the so-called potato-sugar, or starch-sugar of commerce, which is added to grape-juice for making a stronger wine, and is also employed to adulterate cane or beet sugar.

Glucose is produced in malting.

In the sprouting and malting of grain, glucose † is likewise produced from starch.

Even cellulose is convertible into glucose by the prolonged action of hot dilute acids, and sawdust has thus been made to yield an impure syrup, suitable for the production of alcohol.

In the formation of glucose from cellulose, starch, and dextrine, the latter substances take up the elements of water as represented in the simplest form by the equation :—

$$\underset{\text{Starch, \&c.}}{C_6H_{10}O_5} + \underset{\text{Water.}}{H_2O} = \underset{\text{Glucose.}}{C_6H_{12}O_6}.$$

In this process, 90 parts of starch, &c. yield 100 parts of glucose.

Trommer's Copper Test.—A characteristic test for glucose and lævulose is found in their deportment towards an alkaline solution of oxide of copper, which readily yields up oxygen to these sugars, being itself reduced to yellow or red suboxide.

Experiment 31.—Prepare the copper test by dissolving together in 30 c. c. of warm water a pinch of sulphate of copper and one of tartaric acid ; add to the liquid a solution of caustic potash until it is of a clear dark blue colour. Place in separate test tubes a few drops of solution of cane-sugar, a similar amount of the dextrine solution, obtained in Exp. 28 ; of solution of glucose from raisins, or from Exp. 30; and of molasses :

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* If the boiling has been kept up but an hour or so, the glucose will contain dextrine, as may be ascertained by mixing a small portion of the still acid liquid with five times its bulk of strong alcohol, which will precipitate dextrine, but not glucose.

† According to some authorities, the sugar of malt is distinct from glucose, and has been designated *Maltose.*

add to each a little of the copper solution, and place them in a vessel of hot water. Observe that the saccharose and dextrine suffer no alteration for a long time, while the glucose and molasses shortly cause the separation of suboxide of copper.

Experiment 32.—Heat to boiling a little white cane-sugar with 30 c. c. of water, and three drops of strong sulphuric acid, in an open porcelain dish, for fifteen minutes, supplying the waste of water as needful, and test the liquid as in the last experiment. It will be found that this treatment transforms saccharose into glucose (and lævulose).

Sugar may be estimated by the amount of cupric oxide it can reduce to cuprous oxide.

The quantitative estimation of sugar and of starch is commonly based upon the reaction just described. For this purpose the alkaline copper solution is made of a known strength by dissolving a given weight of sulphate of copper, &c. in a given volume of water, and the glucose, or lævulose, or a mixture of both, being likewise made up to a known volume of solution, it is allowed to flow slowly from a graduated tube into a measured portion of warm copper solution, until the blue colour is discharged. Experiment has demonstrated that one part of glucose or of lævulose reduces 2·205 parts of oxide of copper. Starch and saccharose are first converted into glucose and lævulose by heating with an acid, and then examined in the same manner. For the details required to insure accuracy consult Fresenius' "Quantitative Analysis."

As already stated (Exp. 32), cane-sugar, by long boiling of its aqueous solution, and under the influence of hot dilute acids and yeast, loses its property of ready crystallization, and is converted into lævulose and glucose.

According to Dubrunfaut, two molecules of cane-sugar take up the elements of two molecules (5·26 per cent.) of water, yielding a mixture of equal parts of lævulose and glucose. This change is expressed in chemical symbols as follow:

$$\underset{\text{Cane Sugar.}}{2\,(C_{12}H_{22}O_{11})} + \underset{\text{Water.}}{2\,H_2O} = \underset{\text{Lævulose.}}{C_{12}H_{24}O_{12}} + \underset{\text{Glucose.}}{C_{12}H_{24}O_{12}}.$$

Saccharose suffers changes on boiling, &c.

The alterability of saccharose on heating its solutions occasions a loss of one-third to one-half of what is really contained in cane-juice, and is one reason that solid sugar is obtained from the sorghum with such difficulty. Molasses, sorghum syrup, and honey, usually contain all three of these sugars. In molasses, both the saccharose and glucose are hindered from crystallization by the lævulose, and by saline matters derived from the cane-juice.

Honey-dew, that sometimes falls in viscid drops from the leaves of the lime and other trees, is essentially a mixture of the three sugars with some gum. Some mannas are of similar composition.

Grain appears to contain sugar.

The older observers assumed the presence of glucose in the bread grains. Thus Vauquelin found, or thought he found, 8·5 per cent. of this sugar in Odessa wheat. More recently Peligot, Mitscherlich, and Stein have denied the presence of any sugar in these grains. In his work on the Cereals and Bread (*Die Getreidearten und das Brod*, 1860, p. 163), Von Bibra has re-investigated this question, and found in fresh-ground wheat, &c., a sugar having some of the characters of saccharose, and others of glucose and lævulose. It is probably a mixture.

Von Bibra found in the flour of various grains the following quantities of sugar:—

PROPORTIONS OF SUGAR IN AIR-DRY FLOUR, BRAN, AND MEAL.

	Per cent.
Wheat flour	2·33
Spelt flour	1·41
Wheat bran	4·30
Spelt bran	2·70
Rye flour	3·46
Rye bran	1·86
Barley meal	3·04
Barley bran	1·90
Oat meal	2·19
Rice flour	0·39
Millet flour	1·30
Maize meal	3·71
Buckwheat meal	0·91

Numerous compounds related to glucose are known.

Glucosides.—There occur in the vegetable kingdom a large number of bodies, usually bitter in taste, which contain glucose, or a similar sugar, chemically combined with other substances, or at least yield it on decomposition.

Tannin, the bitter principle of oak and poplar bark; *salicine*, from willow bark; *phloridzine*, from the bark of the apple-tree root, and principles contained in jalap, scammony, the horse-chestnut, and almond, are of this kind. The sugar may be obtained from these so-called glucosides by heating with dilute acids.

There are many other kinds of sugar.

Other Sugars.—Among other sugars or saccharoid bodies occurring in common or cultivated plants, but requiring no extended notice here, are the following:—

Mannite, $C_6H_{14}O_6$, is abundant in the so-called manna of the apothecary, which exudes from the bark of several species of ash that grow in the Eastern hemisphere (*Fraxinus ornus* and *rotundifolia*). It likewise exists in the sap of our fruit trees, in edible mushrooms, and sometimes is formed in the fermentation of sugar (viscous fermentation). It appears in minute colourless crystals, and has a sweetish taste.

Quercite, $C_6H_{12}O_5$, is the sweet principle of the acorn, from which it may be procured in colourless crystals.

Pinite, $C_6H_{12}O_5$, exudes from wounds in the bark of a Californian pine (*Pinus Lambertiana*). Separated from the resin that usually accompanies it, it forms a white crystalline mass of a very sweet taste: it is not fermentable.

Mycose, $C_{12}H_{22}O_{11}$, is a sugar found in ergot of rye. It may be obtained in crystals, and is very sweet.

Sugar of Milk, *Lactose*, $C_{12}H_{22}O_{11}$, H_2O, is the sweet principle of the milk of animals. It is largely prepared for commerce, in Switzerland, by evaporating whey (milk from which casein and butter have been separated for making cheese). In a state of purity it forms transparent, colourless crystals, which crackle under the teeth, and are but slightly sweet to the taste. When dissolved to saturation in water, it forms a sweet but thin syrup.

The amyloids are capable of mutual transformations.

Mutual transformations of the members of the Cellulose Group.—One of the most remarkable facts in the history of this group of bodies is the facility with which its members undergo mutual conversion. Some of these changes have been already noticed, but we may appropriately review them here.

(*a.*) *Transformations in the Plant.*—The machinery of the vegetable organism has the power to transform most, if not all, of these bodies into every other one, and we find nearly all of them in every individual of the higher order of plants in some one or other stage of its growth.

In germination, the starch which is largely contained in seeds is converted into dextrine and glucose. It thereby acquires solubility, and passes into the embryo to feed the

The changes of the amyloids in the plant.

young plant. Here it is again solidified as cellulose, starch, or other organic principle, yielding, in fact, the chief part of the materials for the structure of the seedling.

At spring-time, in cold climates, the starch stored up over winter in the new wood of many trees, especially the maple, appears to be converted into the saccharose which is found so abundantly in the sap; and this sugar, carried upwards to the buds, nourishes the young leaves, and is there transformed into cellulose, and into starch again.

The sugar-beet root, when healthy, yields a juice containing 10 to 14 per cent. of saccharose, and is destitute of starch. Schacht has observed that in a certain diseased state of the beet, its sugar is partially converted into starch, grains of this substance making their appearance. (*Wilda's Centralblatt*, 1863, ii. p. 217.)

The analysis of the cereal grains sometimes reveals the presence of dextrine, at others of sugar or gum.

Thus Stepf found no dextrine, but both gum and sugar, in maize-meal (*Jour. für Prakt. Chem.* 76, p. 92); while Fresenius, in a more recent analysis (*Vs. St.* i. p. 180), obtained dextrine, but neither sugar or gum. The sample of maize examined by Stepf contained 3·05 per cent. gum and 3·71 per cent. sugar; that analysed by Fresenius yielded 2·33 per cent. dextrine.

Gum Tragacanth is a result of the transformation of cellulose, as Mohl has shown by its microscopic study.

The changes of the amyloids in the animal.

(*b.*) *In the Animal*, the substances we have been describing also suffer transformation when employed as food. During the process of digestion, cellulose (so far as it is acted upon), starch, dextrine, and probably the gums, are all converted into glucose.

(*c.*) Many of these changes may also be produced apart from physiological agency, by the action of heat, acids, and ferments, operating singly or jointly.

Cellulose and starch are converted, by boiling with a dilute acid, into dextrine, and finally into glucose. If paper or cotton be placed in contact with strong hydrochloric acid (spirit of salt), it is gradually converted into the same sugar. Cellulose and starch acted upon for some time by strong nitric acid (aqua fortis) give compounds from which dextrine may be separated. Nitrocellulose (gun-cotton) sometimes yields gum by its spontaneous decomposition. A kind of gum also appears in solutions of cane sugar or in beet-juice, when they ferment under certain conditions. Inuline and the gums yield sugar (lævulose), but no dextrine, when boiled with weak acids.

(*d.*) It will be noticed that while physical and chemical agencies produce these metamorphoses in one direction, it is usually only under the influence of life that they can be accomplished in the reverse manner.

In the laboratory we can easily reduce from a more highly organized or more complex constitution to a lower and simpler one. In the vegetable, however, all these changes, and many more, take place with the greatest facility.

Most members of the cellulose group may be viewed as hydrates of carbon.

The Chemical Composition of the Cellulose Group.—It is a remarkable fact that all the substances just described stand very closely related to each other in chemical composition, while several of them are identical in this respect. In the following table their composition is expressed in formulæ.

CHEMICAL FORMULÆ OF THE BODIES OF THE CELLULOSE GROUP.

Cellulose	$C_6H_{10}O_5$.
Starch	
Inuline	
Dextrine	
Bassorine	
Veg. Mucilage	
Arabic acid	$C_{12}H_{22}O_{11}$.
Metarabic acid	
Cane sugar	
Fruit sugar	$C_6H_{12}O_6$.
Grape sugar	

It will be observed that all these bodies contain 6 or 12 atoms of carbon, united to as much hydrogen and oxygen as forms 5, 11, or 6 molecules of water. We can therefore conceive of their conversion one into another, with no further change in chemical composition in any case than doubling and the loss or gain of a few molecules of water.

Isomerism.—Bodies which—like cellulose and dextrine, or like lævulose and glucose—are identical in composition, and yet are characterised by different properties and modes of occurrence, are termed *isomeric;* they are examples of *isomerism.* These words are of Greek derivation, and signify *of equal parts.*

We must suppose that the particles of isomeric bodies which are composed of the same kinds of matter and in the same quantities, exist in different states of arrangement. The mason can build from a given number of bricks and a certain amount of mortar a simple wall, an aqueduct, a bridge, or a castle. The components of these unlike structures may be the same, both in kind and quantity; but the structures themselves differ immensely, from the fact of the diverse arrangement of their materials. In the same manner we may suppose starch to be converted into dextrine by a change in the relative positions of the atoms of carbon, hydrogen, and oxygen, which compose it.

Pectose and Pectine occur in roots and fruits.

3. THE PECTOSE GROUP.—The pectose group includes *Pectose, Pectine, Pectosic, Pectic,* and *Metapectic acids.* These bodies exist in, or are derived from, fleshy fruits, including melons and marrows, the roots of the turnip, beet, onion, and carrot, and also cabbage and celery. They are an important part of the food of men and cattle.

Pectose is the name given to a body which is supposed rather than demonstrated to occur with cellulose in the flesh of unripe fruits, and in the roots of turnips, carrots, and beets. Its characters in the pure state are as good as unknown, because we are as yet acquainted with no means of separating it from cellulose without changing its nature. Pectose is thought to constitute the chief bulk of the dry matter of the above-mentioned fruits and roots, and is concluded to be a distinct body by the products of its transformation, either such as are formed naturally, or those procured by artificial means. In what follows we shall assume, with Frémy (*Annales de Chim. et de Phys.* III. xxiv. 9), that pectose exists, and that it is the source of pectine, &c.

Pectine is produced from pectose in a manner similar to that by which dextrine is obtained from cellulose or starch, viz. by the action of heat, of acids, and of ferments. When the flesh of fruits, or the roots which consist chiefly of pectose, are subjected to the joint action of a moderate heat and an acid, the starch they contain is slowly altered into dextrine and sugar, while the firm pectose shortly softens, becomes soluble in water, and is converted into pectine. It is precisely these changes which occur in the baking of apples and pears, and in the boiling of turnips, carrots, &c., with water. In the ripening of fruits the same transformation takes place. The firm pectose, under the influence of the acids that exist in all fruits, gradually softens, and passes into pectine.

Pectose changes into soluble Pectine during ripening of fruits.

Experiment 33.—Express, and, if turbid, filter through muslin, the juice of a ripe apple, pear, or peach. Add to the clear liquid its own bulk of alcohol. Pectine is precipitated as a stringy, gelatinous mass, which, on drying, shrinks greatly in bulk, and forms, if pure, a white substance that may be easily reduced to powder, and is readily soluble in cold water.

Experiment 34.—Reduce several white turnips or beets to pulp by grating. Inclose the pulp in a piece of muslin, and wash by squeezing in water until all soluble matters are removed, or until the water comes off nearly tasteless. Bring the washed pulp into a glass vessel, with enough dilute hydrochloric acid (1 part by bulk of commercial muriatic acid to 15 parts water) to saturate the mass, and let it stand forty-eight hours. Squeeze out the acid liquid, filter it, and add alcohol, when pectine will separate.

The strong aqueous solution of pectine is viscid or gummy, as seen in the juice that exudes from baked apples or pears.

Pectosic and Pectic Acids.—Under the action of a ferment occurring in many fruits, assisted by a gentle heat, pectine is transformed first into pectosic, and afterwards into pectic acid. These bodies compose the well-known fruit jellies. They are both insoluble in cold water, and remain suspended in it as a gelatinous mass. Pectosic acid is soluble in boiling water, and hence most fruit jellies become liquid when heated to boiling; on cooling, its solution gelatinizes again. Pectic acid is insoluble even in boiling water. It is formed also when the pulp of fruits or roots containing pectose is acted on by alkalies or by ammoniacal solution of oxide of copper. The latter agent (a solvent of cellulose) converts pectose directly into pectic acid, which remains in insoluble combination with oxide of copper.

Metapectic Acid.—By too long boiling, by prolonged contact with acids or alkalies, and by decay, the pectic and pectosic acids, as well as pectine, are transformed into still another substance, viz. *Metapectic acid*, which, according to Frémy, is a very soluble body of quite sour taste. It is the last product of the transformation of the bodies of this group with which we are acquainted. It exists, according to Frémy, in beet molasses and decayed fruits.

Transformations of the Pectose group.

Experiment 35.—Stew a handful of sound cranberries, covered with water, just long enough to make them soft. Observe the speedy solution of the firm pectose. Strain through muslin. The juice contains soluble pectine, which may be precipitated from a small portion by alcohol. Keep the remaining juice heated to near the boiling-point in a water bath (*i.e.* by immersing the vessel containing it in a larger one of boiling water). After a time, which is variable according to the condition of the fruit and must be ascertained by trial, the juice on cooling or standing solidifies to a jelly, which melts on warming and reappears again on cooling—Frémy's pectosic acid. By further heating the juice may form a jelly which is permanent when hot—pectic acid; and on still longer exposure to the same temperature, this jelly may dissolve again, by passing into Frémy's metapectic acid, which alcohol does not precipitate.

Other ripe fruits, as quinces, strawberries, peaches, grapes, apples, &c. may be employed for this experiment, but in any case the time required for the juice to run through these changes cannot be predicted safely, and the student may easily fail in attempting to follow them.

Chemical Composition of the Pectose Group.—Our knowledge on this point is very imperfect. Pectose itself, having never been obtained pure, has not been analysed. The other bodies of this group have been examined, but, owing to the difficulty of obtaining them in a state of purity, the results of different observers are discordant.

The formulæ of FRÉMY are as follow:

Pectose	unknown.
Pectine	$C_{32}H_{48}O_{32}$.
Pectosic acid	$C_{32}H_{46}O_{31}$.
Pectic acid	$C_{16}H_{22}O_{15}$.
Metapectic acid	$C_8 H_{14}O_9$.

Grouven (*2ter Salzmünder Bericht*, p. 470) has prepared pectine on the large scale from beet-root cake (remaining after the juice was expressed for sugar manufacture) by digesting it with cold dilute hydrochloric acid, precipitating and washing with alcohol. Thus obtained, it had all the characters ascribed to pectine. Its centesimal composition, however, corresponded nearly with that assigned by Frémy to pectic acid, and differs somewhat from that given by this chemist for pectine, as is seen from the subjoined figures:

The composition of the Pectose group is obscure.

	Pectine. $C_{32}H_{48}O_{32}$.	Pectic Acid. $C_{16}H_{22}O_{15}$.	Grouven's Pectine.
Carbon	40·67	42·29	42·95
Hydrogen	5·08	4·84	5·44
Oxygen	54·25	52·87	51·61
	100·00	100·00	100·00

From the best analyses and from analogy with cellulose it is probable that pectose has the same composition as pectine, or differs from it only by a few molecules of water. If we subtract from the formulæ of Frémy certain molecules of H_2O, we see that the residual proportions of carbon, hydrogen, and oxygen are the same in all these bodies, and correspond to the formula $C_8H_{10}O_7$. This nearness of composition assists us in comprehending the ease with which the transformations of pectose into the other members of the group are effected.

Relations of the Cellulose and Pectose Groups.—It was formerly thought that the pectine bodies are convertible into sugar by the prolonged action of acids. Frémy has shown that this is not the case.

Sacc (*Ann. Ch. et Phys.* 25, 218) and Porter (*Ann. Ch. et Pharm.* 71, 115) have investigated a body having the properties and nearly the composition of pectic acid, which is produced by the action of nitric acid on wood.

Gladstone and Divers (*Jour. Chem. Soc.* 1853, 1863) have observed a substance having the essential characters of pectic acid among the products of the spontaneous decomposition of nitrocellulose (gun-cotton).

It is probable, though not yet fairly demonstrated, that in the living plant cellulose passes into pectose and pectine; without doubt also the reverse transformations may be readily accomplished.

Several acids are abundantly found in plants.

4. The Vegetable Acids.—The Vegetable Acids are very numerous. Some of them are found in all classes of plants, and nearly every family of the vegetable kingdom contains one or several acids peculiar to itself. Those which concern us here are few in number, and, though doubtless of the highest importance in the economy of vegetation, are of subordinate interest to the objects of this work, and will be noticed but briefly. They are *oxalic*, *acetic*, *tartaric*, *malic*, and *citric* acids. They occur in plants either in the free state, or as salts of calcium, potassium, &c. They are mostly found in fruits.

Oxalates often occur in plants.

Oxalic Acid, $C_2H_2O_4$, 2 *aq.*, exists largely in the common sorrel, and, according to the best observers, is found in greater or less quantity in nearly all plants. The acidity of rhubarb-stalks, sorrel-leaves, and other vegetables, is due to this acid or its salts. The pure acid presents itself in the form of colourless, brilliant, transparent, oblique prisms, not unlike Epsom salts at first sight, but having an intensely sour taste.

Oxalic acid forms, with lime, a *salt*—the calcium oxalate—which is insoluble in pure water. It nevertheless exists dissolved in the cells of plants, so long as they are in active growth (Schmidt, *Ann. Chem. u. Pharm.* 61, 297). Towards the end of the period of growth it often accumulates in such quantity as to separate into microscopic crystals. These are found in large quantity in the mature leaves and roots of the beet, in the root of garden rhubarb, and especially in many lichens.

Oxalates commonly exist in plants.

Potassic hydric oxalate, or acid oxalate, is soluble in water, and exists in the juices of sorrel and garden rhubarb. It was formerly used for removing ink-stains from cloth and leather, under the name of salt of sorrel. Oxalic acid is now employed for this purpose. Sodium oxalate is soluble in water, and is found in the juices of plants that grow on the seashore. Ammonium oxalate is employed as a test for lime.

Experiment 36.—Dissolve 5 grams of oxalic acid in 50 c. c. of hot water, add solution of ammonia or solid ammonium carbonate until the odour of the latter slightly prevails, and allow the liquid to cool slowly. Long, needlelike crystals of a *salt* of oxalic acid and ammonia —*ammonium oxalate*—separate on cooling, the compound being sparingly soluble in cold water. Preserve for future use.

Experiment 37.—Add to any solution of lime, as lime-water (see note, p. 20), or hard well water, a few drops of ammonium oxalate solution. Calcium oxalate immediately appears as a white powdery precipitate, which, from its extreme insolubility, serves to indicate the presence of the minutest quantities of lime. Add a few drops of hydrochloric or nitric acid to the calcium oxalate: it disappears. Hence oxalate of ammonia is a test for lime only in solutions containing no free mineral acid. (Acetic and oxalic acids, however, have little effect upon the test.)

Relations of acids to bases and salts.

Definition of Acids, Bases, and Salts.—In the popular sense, an *acid* is any body having a sour taste. It is, in fact, true that all sour substances are acids, but all acids are not sour, some being tasteless, others bitter, and some sweet. A better characteristic of an acid is its capability of exchanging one, two, or more atoms of its hydrogen for the metal contained in a salt or oxide. The strongest acids, *i.e.* those bodies whose acid characters are most strongly developed, if soluble, so as to have any effect on the nerves of taste, are sour, viz. sulphuric acid, phosphoric acid, nitric acid, &c.

Bases, by union with acids, produce salts, water being at the same time separated. The strongest bases, when soluble, are bitter and biting to the taste, and corrode the skin. Potash, soda, ammonia, and lime, are examples. Magnesia, oxide of iron, and many other compounds of metals with oxygen, are insoluble bases, and hence destitute of taste. Potash, soda, and ammonia are termed *alkalies;* lime and magnesia, *alkaline earths.*

Salts result from the chemical reactions of acids with bases. Thus, in Exp. 20, the salt, phosphate of lime or calcium, was produced by bringing together phosphoric acid, and the base, lime. In Exp. 37, from calcium oxide, calcium oxalate was made in a similar manner. Common salt—in chemical language, sodium chloride—is formed when sodium hydrate is mixed with hydrochloric acid, water being, in this case, produced at the same time.

$$2\,NaHO + 2\,HCl = 2\,NaCl + H_2O.$$

Acids and alkalies may be detected by their action on organic colours.

Tests for Acids and Alkalies.—Many vegetable colours are altered by soluble acids or soluble bases (alkalies) in such a manner as to answer the purpose of distinguishing these two classes of bodies. A solution of cochineal may be employed. It has a ruby-red colour when concentrated, but on mixing with much pure water becomes orange or yellowish-orange. Acids do not affect this colour, while alkalies turn it to an intense carmine or violet-carmine, which is restored to orange by acids.

Experiment 38.—Prepare tincture* of cochineal by pulverizing 3 grams of cochineal, and shaking frequently with a mixture of 50 c. c. of strong alcohol and 200 c. c. of water. After a day or two, pour off the clear liquid for use.

To a cup of water add a few drops of strong sulphuric acid, and to another similar quantity add as many drops of ammonia. To the liquids add separately 5 drops of cochineal tincture, observing the coloration in each case. Divide the dilute ammonia into two portions, and pour into one of them the dilute acid, until the carmine colour just passes into orange. Should excess of acid have been incautiously used, add ammonia, until the carmine reappears, and destroy it again by new portions of acid, added dropwise. The acid and base thus *neutralize* each other, and the solution contains ammonium sulphate, but no free acid or base. It will be found that the orange-cochineal indicates very minute quantities of ammonia, and the carmine-cochineal correspondingly small quantities of acid. Tincture of litmus (procurable of the

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* Tinctures, in the language of the apothecary, are *alcoholic* solutions.

apothecary), or of dried red cabbage, may also be employed. Litmus is made red by soluble acids, and blue by soluble bases. With red cabbage, acids develop a crimson, and the bases a green colour.

In the formation of salts, the acids and bases more or less *neutralize each other's properties*, and their compounds, when soluble, have a less sour or less acrid taste, and act less vigorously on vegetable colours than the acids or bases themselves. Some soluble salts have no taste at all resembling either their base or acid, and have no effect on vegetable colours. This is true of common salt, glauber salts or potassium sulphate, and saltpetre or sodium nitrate. Others exhibit the properties of their base, though in a reduced degree. Ammonium carbonate, for example, has much of the odour, taste, and effect on vegetable colours that belong to ammonia. Sodium carbonate has the taste and other properties of caustic soda in a greatly mitigated form. On the other hand, sulphates of aluminium, iron, and copper, have slightly acid characters.

Certain acids form with the same base *several distinct salts.* Thus carbonic acid and soda may produce sodium carbonate, Na_2CO_3, or sodium hydric carbonate, $NaH\,CO_3$. The latter is much less alkaline than the former, but both turn cochineal to a carmine colour. Again, phosphoric acid may form three distinct salts with soda or with lime, which will be noticed in another place. Oxalic acid also yields several kinds of salts, as do the other organic acids presently to be described.

Acetic Acid, $C_2H_4O_2$, occurs in plants as potassium acetate and in other forms. It is easily produced by the destructive distillation of cellulose.

$$C_6H_{10}O_5 + H_2O = 3\,C_2H_4O_2.$$

It is an acid liquid boiling at 119°.

Acetates and malates occur in plants.

Malic Acid, $C_4H_6O_5$, is the chief sour principle of apples, currants, gooseberries, plums, cherries, strawberries, and most common fruits. It exists in small quantity in a multitude of plants. It is found abundantly in combination with potash, in the garden rhubarb; and impure potassium malate may be obtained in crystals by simply evaporating the juice of the leaf-stalks of this plant. It is likewise abundant as lime-salt in the nearly ripe berries of the mountain ash, and in barberries. Calcium malate also occurs in considerable quantity in the leaves of tobacco, and is often encountered in the manufacture of maple sugar, separating as a white or grey sandy powder during the evaporation of the sap.

Pure malic acid is only seen in the chemical laboratory, and occurs as white crystalline masses of an intensely sour taste. It is extremely soluble in water.

Tartaric acid is found in the vine.

Tartaric Acid, $C_4H_6O_6$, is abundant in the grape, from the juice of which, during fermentation, it is deposited in combination with potash as *argol*. The crust of wine consists essentially of potassium hydric tartrate, which is less soluble in the fermented than in the original juice. This, on purification, yields the cream of tartar (potassic hydric tartrate) of commerce. Tartrates of potassium or calcium exist in small quantities in tamarinds, in the unripe berries of the mountain ash, in the berries of the sumach, in cucumbers, potatoes, pine-apples, and many other fruits. The acid itself may be obtained in large glassy oblique crystals, which are very sour to the taste.

Citric acid occurs in the lemon.

Citric Acid, $C_6H_8O_7$, exists in the free state in the juice of the lemon, and in unripe tomatoes. It accompanies malic acid in the currant, gooseberry, cherry, strawberry, and raspberry. It is found in small quantity, united to lime, in tobacco leaves, in the tubers of the Jerusalem artichoke, in the bulbs of onions, in beet-roots, in coffee-berries, and in the needles of fir-trees.

In the pure state, citric acid forms large transparent or white trimetric crystals, very sour to the taste.

Relations of the Vegetable Acids to each other and to the Amyloids.—The four acids above noticed usually occur together in our ordinary fruits, and it appears that some of them undergo mutual conversion in the living plant.

According to Liebig, the unripe berries of the mountain ash contain much tartaric acid, which, as the fruit ripens, is converted into malic acid. Schmidt (*Ann. Chem. u. Pharm.* 114, 109) first showed that tartaric acid can be artificially transformed into malic acid. The chemical change consists merely in the removal of one atom of oxygen.

$$\underset{\text{Tartaric Acid.}}{C_4H_6O_6} - O = \underset{\text{Malic Acid.}}{C_4H_6O_5}.$$

When citric, malic, and tartaric acids are boiled with nitric acid, or heated with caustic potash, they all yield oxalic acid.

Cellulose, starch, dextrine, the sugars, and, according to some, pectic acid, yield oxalic acid, when heated with potash or nitric acid. Commercial oxalic acid is thus made from starch and from sawdust.

Gum (arabic), sugar, starch, and, according to some, pectine, yield tartaric acid by the action of nitric acid.

Oils occur abundantly in seeds.

5. FATS AND OILS.—We have only space here to notice this important class of bodies in a very general manner. In all plants and nearly all parts of plants we find some representatives of this group; but it is chiefly in certain seeds that they occur most abundantly. Thus the seeds of hemp, flax, beech, colza, cotton, bayberry, pea-nut, almond, sunflower, &c. contain 10 to 70 per cent. of oil, which may be in great part removed by pressure. In some plants, as the common waxberry, and the tallow-tree of Nicaragua, the fat is solid at ordinary temperatures, and must be extracted by aid of heat; while, in most cases, the fatty matter is liquid. The cereal grains, especially oats and maize, contain oil in appreciable quantity. The mode of occurrence of oil in plants is shown in Fig. 14, which represents a highly magnified section of the flax-seed. The oil exists as minute, transparent globules in the cells, *f*. From these seeds the oil may be completely extracted by ether, benzine, or carbonic disulphide, which dissolve all fats with readiness, but scarcely affect the other vegetable principles.

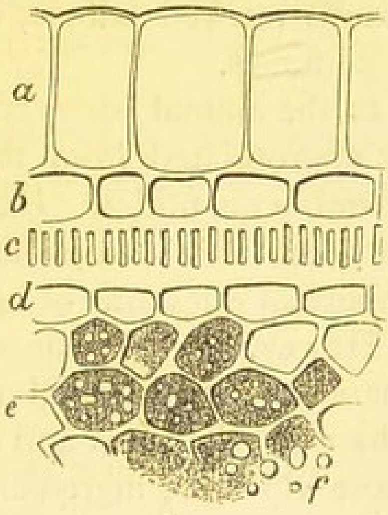

Fig. 14.

Solid fats occur in plants.

Many plants yield small quantities of wax, which either gives a glossy coat to their leaves, or forms a bloom upon their fruit. The lower leaves of the oat plant at the time of blossoming contain, in the dry state, 10 per cent. of fat and wax (Arendt). Scarcely two of these oils, fats, or

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kinds of wax, are exactly alike in their properties. They differ more or less in taste, odour, and consistency, as well as in their chemical composition.

Experiment 39.—Place a handful of fine and fresh corn or oatmeal which has been dried for an hour or so, at a heat not exceeding 212°, in a bottle. Pour on twice its bulk of ether, cork tightly, and agitate frequently for half an hour. Drain off the liquid (filter, if need be) into a clean porcelain dish, and allow the ether to evaporate. A yellowish oil remains, which, by gently warming for some time, loses the smell of ether and becomes quite pure.

The fixed oils greatly differ from the volatile oils.

The fatty oils must not be confounded with the *ethereal*, *essential*, or *volatile oils*. The former do not evaporate except at a high temperature, and when brought upon paper leave a permanent "grease spot." The latter readily volatilize, leaving no trace of their presence. The former, when pure, are without smell or taste. The latter usually possess marked odours, which adapt many of them to use as perfumes.

In the animal body, fat (in some insects, wax) is formed or appropriated from the food, and accumulates in considerable quantities. How to feed an animal so as to cause the most rapid and economical *fattening* is one of the most important questions of agricultural chemistry.

There are three principal fats.

However greatly the various fats may differ in external characters, they are all mixtures of a few elementary fats. The most abundant and commonly occurring fats, especially those which are ingredients of the food of man and domestic animals, viz. tallow, olive oil, and butter, consist essentially of three substances, which we may briefly notice. These elementary fats are *Stearine*, *Palmitine*, and *Oleine*,* and they consist of carbon, oxygen, and hydrogen, the first-named element being greatly preponderant.

Stearine is represented by the formula $C_{57}H_{110}O_6$. It is the most abundant ingredient of the common fats,

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* Margarine, formerly thought to be a distinct fat, is a mixture of stearine and palmitine.

and exists in largest proportion in the harder kinds of tallow.

Experiment 40.—Warm mutton or beef fat in a bottle that may be tightly corked, with ten times its bulk of pure and dry ether, until a clear solution is obtained. Let it cool slowly, when stearine will crystallize out in pearly scales.

Palmitine, $C_{51}H_{98}O_6$, receives its name from the palm oil of Africa, of which it is a large ingredient. It forms a good part of butter, and is one of the chief constituents of bees'-wax, and of waxberry tallow.

Oleine, $C_{57}H_{104}O_6$, is the liquid ingredient of fats, and occurs most abundantly in the oils. It is prepared from olive oil by cooling down to the freezing-point, when the stearine and palmitine solidify, leaving the oleine still in the liquid state.

Other elementary fats, viz. butyrine, laurine, myristine, &c., occur in small quantity in butter, and in various vegetable oils. Linseed oil contains linoleine ; castor oil, ricinoleine, &c.

We have already given the formulæ of the principal fats, but for our purposes a better idea of their composition may be gathered from a centesimal statement, viz. :

Fats contain three-fourths of their weight of carbon.

CENTESIMAL COMPOSITION OF THE ELEMENTARY FATS.

	Stearine.	Palmitine.	Oleine.
Carbon	76·6	75·9	77·4
Hydrogen . . .	12·4	12·2	11·8
Oxygen	11·0	11·9	10·8
	100·0	100·0	100·0

We shall presently show that these and other fats are *Glycerides*, compounds which consist of *fatty acids* and *glycerine*, minus the elements of water.

Some fats contain phosphorus.

Phosphorized Fats.—The animal brain and spinal cord and the yolk of the egg contain a considerable amount of fat which has long been known to be characterised by a small content of phosphorus. Von Bibra found the quantity of phosphorus in this (impure) fat to range from

1·21 to 2·53 per cent. Knop (*Vs. St.* 1, p. 26) was the first to show that analogous phosphorized fats exist in plants. From the seeds of the pea he extracted 2·5 per cent. of a thick brown oil which was free from sulphur and nitrogen, but contained 1·25 per cent. of phosphorus.

The composition of this oil was as follows:

Carbon	66·85
Hydrogen	9·52
Oxygen	22·38
Phosphorus	1·25
	100·00

Many seeds contain phosphorized oils.

Topler (*Henneberg's Jahresbericht*, 1859–60, p. 164) subsequently examined the oils of a large number of seeds for phosphorus with the subjoined results:

Source of Fat.	Per cent. of Phosphorus	Source of Fat.	Per cent. of Phosphorus.
Lupine	0·29	Walnut	trace.
Pea	1·17	Olive	none.
Horse-bean	0·72	Wheat	0·25
Vetch	0·50	Barley	0·28
Winter lentil	0·39	Rye	0·31
Horse-chestnut	0·30	Oat	0·44
Cacao	none.	Flax	none.
Millet	"	Colza	"
Poppy	"	Mustard	"

According to Hoppe-Seyler (*Med. Chem. Unters.* i.), the phosphorized principle of oil of maize, and of the brain, nerves, yolk of eggs, &c. is primarily the substance discovered in 1864 by Liebreich in the brain, and termed Protagon. It is a white crystallized body, having the following composition:—

Carbon	67·2
Hydrogen	11·6
Nitrogen	2·7
Phosphorus	1·5
Oxygen	17·0
	100·0

Its formula may be $C_{116}H_{241}N_4PO_{22}$. When heated to the boiling-point it is decomposed, and yields, among other products, glycerine, phosphoric acid, and stearic acid (*Ann. Ch. Ph.* 134, p. 30).

In saponification, fats are decomposed.

Saponification.—The fats are characterised by forming soaps when heated with strong potash or soda lye. They are by this means decomposed, and give rise to *fatty acids*, which remain combined with the alkalies, and *glycerine*, a sweet liquid—in reality an alcohol.

Experiment 41.—Heat a bit of tallow with a strong solution of caustic potash until it completely disappears, and a soap soluble in water is obtained. To one-half the hot solution of soap add hydrochloric acid until the latter predominates. An oil will separate which gathers at the top of the liquid, and, on cooling, solidifies to a cake. This is not, however, the original fat. It has a different melting-point, and a different chemical composition. It is composed of one or several fatty acids, corresponding to the elementary fats from which it was produced.

When saponified by the action of potash, stearine yields *stearic acid*, $C_{18}H_{36}O_2$; palmitine yields *palmitic acid*, $C_{16}H_{32}O_2$; and oleine gives *oleic acid*, $C_{18}H_{34}O_2$. The so-called stearine candles are a mixture of stearic and palmitic acids. The glycerine, $C_3H_8O_3$, that is simultaneously produced, remains dissolved in the liquid. Glycerine is now found in commerce in a nearly pure state, as a colourless, syrupy liquid, having a pleasant sweet taste.

The chemical act of saponification often consists in the rearrangement of the elements of one molecule of fat and three molecules of water into three molecules of fatty acid and one molecule of glycerine.

$$\underset{\text{Palmitine.}}{C_{51}H_{98}O_6} + \underset{\text{Water.}}{3\,H_2O} = \underset{\text{Palmitic Acid.}}{3\,C_{16}H_{32}O_2} + \underset{\text{Glycerine.}}{C_3H_8O_3}.$$

The destruction of fats is likewise effected by the influence of strong acids, and by heating with water alone to a temperature of 200° C.

Soaps are salts of fat acids.

Ordinary soap is nothing more than a mixture of stearate, palmitate, and oleate of potash or soda, with or without glycerine. Common soft soap consists of the potash-compounds of the above-named acids, mixed with glycerine and water. Hard soap is usually the corresponding soda-compound, free from glycerine. When soft potash-soap is boiled with common salt (sodium chloride), hard soda-soap and potassium chloride are formed by transposition of the ingredients. On cooling, soda-soap forms a solid cake upon the liquid, and the glycerine remains dissolved in the latter.

Oils may originate from the transformation of glucoids.

Relations of Fats to Amyloids.—The oil or fat of plants is in many cases a product of the transformation of starch or other member of the cellulose group, for the oily seeds, when immature, contain starch, which vanishes as they ripen, and in the sugar-cane the quantity of wax is said to be largest when the sugar is least abundant, and *vice versâ.* In germination the oil of the seed is converted back again into starch, sugar, &c.

The *Estimation of Fat* (including wax) is made by warming the pulverized and dry substance repeatedly with renewed quantities of ether, or carbon disulphide, as long as the solvent takes up anything. On evaporating the solutions the fat remains nearly in a state of purity, and after drying thoroughly, may be weighed.

The proportion of fat in various plants differs.

PROPORTIONS OF FAT IN VARIOUS VEGETABLE PRODUCTS.

	Per cent.		Per cent.
Meadow grass	0·8	Turnip	0·1
Red clover (green)	0·7	Wheat seed	1·6
Cabbage	0·4	Oat ,,	5·5
Meadow hay	2·5	Maize ,,	5·2
Clover hay	3·2	Pea ,,	3·0
Wheat straw	1·5	Cotton ,,	34·0
Oat straw	2·0	Flax ,,	34·0
Wheat bran	4·5	Colza ,,	45·0
Potato tuber	0·3		

The albuminoids contain nitrogen.

6. The Albuminoids or Proteine Bodies.—The bodies of this class differ from the groups hitherto noticed in the fact of their containing, in addition to carbon, oxygen, and hydrogen, 15 to 18 per cent. of *nitrogen,* with a small quantity of *sulphur*, and, in some cases, *phosphorus.*

In plants, the proteine bodies occur in a variety of modifications, and though found in small proportion in all their parts, being everywhere necessary to growth, they are chiefly accumulated in the seeds, especially in those of the cereal and leguminous grains.

The *albuminoids*, as we shall designate them, that occur in plants, are so similar in many characters, are in fact so nearly identical with the albuminoids which constitute a large portion of every animal organism, that we may advantageously consider them in connexion.

There are three chief albuminoids.

We may describe most of these bodies under three sub-groups. The type of the first is *albumen*, or the white of egg; of the second, *fibrine*, or animal muscle; of the third, *caseine*, or the curd of milk.

Common Characters.—The greater number of these substances occur in several, at least two, modifications, one soluble, the other insoluble in water.

In living or undecayed animals and plants we find the albuminoids chiefly in the *soluble*, and, in fact, in the dissolved state. They may be obtained in the solid form by evaporating off at a gentle heat the water which is naturally associated with them. They are thus mostly obtained as transparent colourless or yellowish solids, destitute of odour or taste, which dissolve again in water, but are insoluble in alcohol.

Recently, both in the animal and vegetable, soluble albuminoids have been observed in colourless or red crystals, often of considerable size, but so associated with other bodies as, in general, not to admit of separation in the pure state.

The *insoluble albuminoids*, some of which also occur naturally in plants and animals, are, when purified as much as possible, white, flocky, lumpy or fibrous bodies, quite odourless and tasteless.

As further regards the deportment of the albuminoids towards solvents, some are soluble in alcohol, none in ether. They are soluble in potash and soda-lye; acids separate them from these solutions; strong acetic acid dissolves them with one exception. In very dilute mineral acids (sulphuric and hydrochloric) some of them dissolve in great part, others swell up like jelly.

Albuminoids are easily coagulated.

Coagulation.—A remarkable characteristic of the group of bodies now under notice is their ready conversion from the soluble to the insoluble state. In some cases this coagulation happens spontaneously, in others by elevation of temperature, or by contact with acids, metallic oxides, or various salts.

The albuminoids, when subjected to heat, melt and burn with a smoky flame and a peculiar odour—that of burnt hair or horn,—while a shining charcoal remains which is difficult to consume.

There are several tests for the albuminoids.

Tests for the Albuminoids.—The chemist employs the behaviour of the albuminoids towards a number of reagents [*] as tests for their presence. Some of these are so delicate and characteristic as to allow the distinction of this class of substances from all others, even in microscopic observations.

1. *Iodine* colours them intensely yellow or bronze.

2. Warm and strong *hydrochloric acid* colours all these bodies blue or violet, or, if applied in large excess, dissolves them to a liquid of these colours.

3. In contact with *nitric acid* they are stained a deep and vivid yellow. Silk and wool, which consist of bodies closely approaching the albuminoids in composition, may be dyed or printed yellow by means of nitric acid.

4. A solution of *mercurous nitrate* in excess of nitric acid [†] tinges them of a deep red colour. This test enables us to detect albumen, for example, even where it is dissolved in 100,000 parts of water.

Albumen is contained in white of egg

Albumen.—*Animal Albumen.*—The white of a hen's egg on drying yields about 12 per cent. of albumen in a state of tolerable purity. The fresh white of egg serves to illustrate the peculiarities of this substance, and to exhibit the deportment of the albuminoids generally towards the above-named reagents.

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[*] Reagents are substances commonly employed for the recognition of bodies, or, generally, to produce chemical changes. All chemical phenomena result from the mutual action of at least two elements, which thus act and *react* on each other. Hence the substance that excites chemical changes is termed a reagent, and the phenomena or results of its application are called reactions.

[†] This solution, known as Millon's test, is prepared by dissolving mercury in its own weight of nitric acid of sp. gr. 1·4, heating towards the close of the process, and finally adding to the liquid twice its bulk of water.

Experiment 42.—Beat or whip the white of an egg so as to destroy the delicate transparent membrane in the cells of which the albumen is held, and agitate a portion of it with water; observe that it *dissolves* readily in the latter.

Experiment 43.—Heat a part of the undiluted white of egg in a tube or cup; between 60° and 72° it becomes opaque, white, and solid (coagulates), and is converted into the insoluble modification. A higher heat is needful to coagulate solutions of albumen in proportion as they are diluted with more water.

Experiment 44.—Add strong alcohol to a portion of the solution of albumen of Exp. 42. It produces coagulation.

Experiment 45.—Observe that albumen is coagulated by certain dilute acids applied in small quantity, especially by nitric acid.

Experiment 46.—Put a little albumen, either soluble or coagulated, into each of four test tubes. To one, add solution of iodine; to a second, strong hydrochloric acid; to a third, nitric acid; and to the last nitrate of mercury. Observe the characteristic colorations that appear immediately, or after a time, as described above. In the last three cases the reaction is hastened by a gentle heat.

Blood-albumen and egg-albumen resemble each other closely.

Albumen occurs in the soluble form in the blood, and in all the liquids of the healthy animal body except the urine. In some cases its characters are slightly different from those of egg-albumen. The albumen of the blood, which may be separated by heating blood-serum (the clear yellow liquid that floats above the clot), contains a little less sulphur than coagulated egg-albumen. In the crystalline lens of the eye, and in the blood-corpuscles, the albumen has again slightly different characters, and has been termed *globuline*. Under certain conditions the blood of animals yields a substance known as *hæmatoidine*, which, while having nearly the composition and many of the properties of albumen, commonly requires a much larger proportion of water for solution, and forms distinct crystals of a transparent red colour. Other albuminoids, some containing iron, are contained in or have been prepared from blood.

Albumen occurs in the juices of plants.

Vegetable Albumen.—In the juices of all plants is found a minute quantity of a substance which agrees in nearly all respects with animal albumen, and is hence termed *vegetable albumen*. The clear juice of the potato tuber (which may be procured by grating potatoes, squeezing the pulp in a cloth, and letting the liquor thus obtained stand in a cool place until the starch has deposited) contains albumen in solution, as may be shown by heating to near the boiling-point, when a coagulum separates, which, after boiling successively with alcohol and ether to remove fat and colouring matters, is scarcely to be distinguished, either in its chemical reactions or composition, from the coagulated albumen of eggs.

The juice of succulent vegetables, as cabbage, yields vegetable albumen in larger quantity, though less pure, by the same treatment.

Water which has been agitated for some time in contact with flour of wheat, rye, oats, or barley, is found by the same method to have extracted albumen from these grains.

The coagulum, thus prepared from any of these sources, exhibits the reactions characteristic of the albuminoids, when put in contact with mercurous nitrate, nitric, or hydrochloric acids.

Experiment 47.—Prepare impure vegetable albumen from potatoes, cabbage, or flour, as above described, and apply the mercurous nitrate test.

The coagulation of blood is due to the separation of fibrine.

Fibrine.—*Blood Fibrine.*—The blood of the higher animals, when in the body or when fresh drawn, is perfectly fluid. Shortly after it is taken from the veins it partially solidifies—it coagulates, or becomes clotted. It thereby separates into two portions, a clear, pale-yellow liquid—the serum, and the clot. As already stated, the serum contains albumen. The clot consists chiefly of fibrine. On squeezing and washing the clot with water, the colouring matter of the blood is removed, and a white stringy mass remains, which is one form of the substance in question. Blood fibrine cannot be separated in the pure and soluble state from fresh blood, as it so soon coagulates spontaneously.

Prepared as just described, fibrine has many of the properties of albumen. Placed in a solution of saltpetre, especially if a little potash-lye be added, it dissolves in a few days to a clear liquid, which coagulates on heating or by addition of metallic salts, in the same manner as a solution of albumen. In very dilute hydrochloric acid it swells up, but does not dissolve.

Experiment 48.—Observe the separation of blood into clot and serum; coagulate the albumen of the former by heat, and test it with warm hydrochloric acid. Tie up the clot in a piece of muslin, and squeeze and wash in water until colouring matter ceases to run off. Warm it with nitric acid as a test.

Muscle consists of a kind of fibrine.

Flesh Fibrine.—If a piece of lean beef or other meat be repeatedly squeezed and washed in water, the colouring matters are gradually removed, and a white residue is obtained, which resembles blood fibrine in its external characters. It is, in fact, the actual fibre of the animal muscle, and hence its name. It is characterised by dissolving in very dilute hydrochloric acid (one part acid and 1,000 of water) to a clear liquid, from which it is again separated by careful addition of an alkali, or a solution of common salt.

The chief albuminoid of wheat is fibrine.

Vegetable Fibrine.—When wheat flour is mixed with a little water to a thick dough, and this is washed and kneaded for some time in a vessel of water, the starch and albumen are mostly removed, and a yellowish tenacious mass remains, which bears the name *gluten*. When wheat is slowly chewed, the saliva carries off the starch and other matters, and the gluten mixed with bran is left behind—well known to country lads as "wheat gum."

Experiment 49.—Wet a handful of good fresh wheat flour slowly with a little water to a sticky dough, and squeeze this under a fine stream of water until the latter runs off clear. Heat a portion of this gluten with Millon's test.

Gluten is a mixture of several albuminoids, and contains besides some starch and fat. One of the albuminoids is dissolved from it by alcohol, and separates on removing the alcohol by evaporation.

The albuminoids of crude gluten dissolve in very dilute potash-lye (one to one and a half parts potash to 1,000 parts of water), and the liquid, after standing some days at rest, may be poured off from any residue of starch. On adding acetic acid in slight excess, the purified albuminoids are separated in the solid state. By extracting successively with weak, with strong, and with absolute alcohol, a form of caseine (*gluten-caseine* of Ritthausen) remains undissolved; this is perhaps identical with the caseine (legumine) of the pea.

On evaporating the alcoholic solution to one-half, there separates, on cooling, a brownish-yellow mass. This, when treated with absolute alcohol, leaves *vegetable fibrine* nearly pure.

Vegetable fibrine is readily soluble in hot alcohol, but slightly so in cold alcohol. It does not at all dissolve in water. It has no fibrous structure like animal fibrine, but forms, when dry, a tough, horn-like mass. In composition it approaches animal fibrine.

Caseine is the chief albuminoid of milk.

Caseine.—*Animal Caseine* is the peculiar ingredient of new cheese. It exists dissolved to the extent of 3 to 6 per cent. in fresh milk; unlike albumen, is not coagulated by heat, but is coagulated by acids, by rennet (the membrane of the calf's stomach), and by heating to boiling with salts of lime and magnesia.

Experiment 50.—Observe the coagulation of caseine when milk is treated with a few drops of sulphuric acid. Test the curd with mercurous nitrate.

Experiment 51.—Boil milk with a little magnesium sulphate (Epsom salts) until it curdles.

When caseine is separated from milk by rennet, as in making cheese, it carries with it a considerable portion of the phosphates and other salts of the milk; these salts are not found in the caseine precipitated by acids, being held in solution by the latter.

The caseine of milk coagulates spontaneously when it stands for some time. Caseine has recently been detected in the brain of animals. (Hoppe-Seyler, *Med. Chem. Unters.* ii.)

Vegetable Caseine.—This substance is found in large proportion (20 to 24 per cent.) in the pea and bean, and indeed generally in the seeds of the so-called leguminous plants. It closely resembles milk caseine in all respects.

Experiment 52.—Prepare a solution of vegetable caseine from crushed peas, oats, almonds, or pea-nuts, by soaking them for some hours in warm water, and allowing the liquid to settle clear. Coagulate the caseine by addition of an acid to the solution. It may be coagulated by rennet, and by salts of magnesia and lime, in the same manner as animal caseine.

Cheese may be made from peas.

The Chinese prepare a vegetable cheese by boiling peas to a pap, straining the liquor, adding gypsum until coagulation occurs, and treating the curd thus obtained in the same manner as practised with milk-cheese, viz. salting, pressing, and keeping until the odour and taste of cheese are developed. It is cheaply sold in the streets of Canton under the name of *Tao-foo.* Vegetable caseine occurs in small quantity in oats, the potato, and many plants; and may be exhibited by adding a few drops of acetic acid to turnip juice, for instance, which has been freed from albumen by boiling and filtering. The caseine from peas and leguminous seeds has been designated *legumine,* that of the oat has been named *avenine.* Almonds yield a caseine, which has been termed *emulsine.* As already mentioned, caseine (Ritthausen's gluten-caseine) exists in wheat gluten, and in rye. Each of these sources yield a caseine of somewhat peculiar characters; the causes of these differences are not yet ascertained, but probably lie in impurities, or result from mixture of other albuminoids.

In crude wheat gluten two other albuminoids exist, viz.:

Gliadine, Glutine, or Vegetable Glue, is very soluble in water and alcohol. It strongly resembles animal glue.

Mucidine resembles gliadine, but is less soluble in strong alcohol, and is insoluble in water. When moist, it is yellowish-white in colour, has a silky lustre and slimy consistence. It exists also in rye grain. (Ritthausen, *Jour. für Prakt. Chem.* 88, 141; and 99, 463.)

The nature of the albuminoids is still obscure.

Composition of the Albuminoids. — There are various reasons why the exact composition of the bodies just described is a subject of uncertainty. They are, in the first place, naturally mixed and associated with other matters from which it is very difficult to separate them fully. Again, if we succeed in removing foreign substances, it must usually be done by the aid of acids, alkalies, and other strong reagents, which easily alter or destroy their proper characters and composition. Finally, if we analyse the pure substances, our methods of analysis are perhaps scarcely delicate enough to indicate their differences with accuracy.

The results of chemical investigation demonstrate that the albuminoids are either identical in composition or differ but slightly from each other, as is seen from the table below. The deduction of a correct atomic formula from these analyses is perhaps impossible in the present state of our knowledge.

In the subjoined table are given analyses of those albuminoids which have been here described. Those indicated by asterisks are recent results of Dr. Ritthausen; the others are average statements of the best analyses.

The percentage composition of the albuminoids.

COMPOSITION OF ALBUMINOIDS.

	Carbon.	Hydrogen.	Nitrogen.	Oxygen.	Sulphur.
Animal albumen . .	53·5	7·0	15·5	22·4	1·6
Vegetable albumen . .	53·4	7·1	15·6	23·0	0·9
Blood fibrine . . .	52·6	7·0	17·4	21·8	1·2
Flesh fibrine . . .	54·1	7·3	16·0	21·5	1·1
Wheat fibrine* . . .	54·3	7·2	16·9	20·6	1·0
Animal caseine . . .	53·6	7·1	15·7	22·6	1·0
Vegetable caseine . .	53·9	7·2	15·0	23·0	0·9
Gluten-caseine* } wheat	51·0	6·7	16·1	25·4	0·8
Gliadine*	52·6	7·0	18·1	21·5	0·8
Mucidine*	54·1	6·9	16·6	21·5	0·9

Phosphorus is not included in the above table, for the reason that in all cases its quantity, and in most instances its very presence, is still uncertain. Voelcker and Norton found in vegetable caseine 1·4 to 2·2 per cent. of phosphorus, and smaller quantities have been mentioned by other of the older analysts as occurring in albumen and fibrine. The phosphorus of these and of animal caseine is thought not to belong to the albuminoid, but to be due to an admixture of phosphate of lime.

In his recent investigation of gluten-caseine, Ritthausen found phosphoric acid that appears to have been partially uncombined with a fixed base, and to have therefore resulted from phosphorus in organic combination. It is not unlikely that vegetable caseine may contain an admixture of protagon (p. 78) or the products of its decomposition, from which it is not easy to effect its separation.

The relations and changes of the albuminoids.

Mutual Relations of the Albuminoids.—Some have supposed that these bodies are identical in composition, the differences among the analytical results being due to foreign matters, and differ from each other in the same way that cellulose and starch differ, viz. on account of different arrangement of the atom. Others have adopted the notion of Mulder, to the effect that the albuminoids are compounds of various proportions of hypothetical sulphur and phosphorus compounds, with a common ingredient, which he termed *proteine* (from the Greek signifying "to take the first place," because of the great physiological importance of such a body). Hence the albuminoids are often called the proteine bodies. These suppositions are interesting, and have their use in science, so long as we are occupied with extending our knowledge, but for our present purposes may be disregarded.

The transformations which these substances are capable of undergoing sufficiently show that they are closely related, without, however, satisfactorily indicating in what manner.

In the animal organism, the albuminoids of the food, of whatever name, are dissolved by the gastric juice of the stomach, and ultimately pass into the blood, where they form blood albumen and blood fibrine. As the blood nourishes the muscles, they are modified into flesh fibrine, or, entering the lacteal system, are converted into caseine, while in the appropriate part of the circulation they are formed into the albumen of the egg, or embryo.

Changes of the albuminoids.

In the living plant, similar changes of place and of character occur among these substances.

Finally, outside the organism the following transformations have been observed :—Flesh fibrine exposed while moist to the air at a summer temperature for some days dissolves into a liquid ; if this liquid be heated to near boiling, coagulation takes place, and the substance which separates has the properties of albumen. On removing the albumen, and adding vinegar to the remaining liquid, a curdy coagulum is formed, which agrees in its properties with caseine. (Bopp, *Ann. Ch. Ph.* 60, p. 30 ; Gunning, *Jour. für Prakt. Chem.* 69, p. 52.)

Lehmann has shown that when albumen is dissolved in potash, and mixed with a little milk-sugar and oily fat, the mixture coagulates with rennet in a manner entirely similar to the curdling of milk. (Gorup-Besanez, *Phys. Chem.* p. 139.)

Sullivan has observed that the caseine of milk which was kept in closed air-tight vessels for a long time, at first coagulated, but afterward dissolved again to a nearly clear liquid, which, on examination, was found to contain no caseine, but by heating, coagulated, showing the conversion of caseine into albumen, or a similar body. (*Phil. Mag.* 4, xviii. 203.)

Animals transform, but do not make albuminoids.

The Albuminoids in Animal Nutrition.—We step aside for a moment from our proper plan to direct attention to the beautiful adaptation of this group of organic substances to the nutrition of animals. Those bodies which we have just noticed as the animal albuminoids, together with others of similar composition, constitute a large part of the healthy animal organism, and especially characterise its actual working machinery, being essential ingredients of the muscles and cartilages, as well as of the nerves and brain. They likewise exist largely in the nutritive fluids of the animal—in blood and milk. So far as we know, the animal body has not the power to produce a particle of albumen, or fibrine, or caseine; it can only transform these bodies as presented to it from external sources. They are hence indispensable ingredients of food, and have been aptly designated by Liebig as the *plastic elements of nutrition*. It is in all cases the plant which originally constructs these substances, and places them at the disposal of the animal.

The albuminoids are mostly capable of existing in the liquid or soluble state, and thus admit of distribution throughout the entire animal body, as blood, &c. They likewise readily assume the solid condition, thus becoming more permanent parts of the living organism, as well as capable of indefinite preservation for food in the seeds and other edible parts of plants.

The albuminoids are highly complex bodies.

Complexity of Constitution.—The albuminoids are highly complex in their chemical constitution. This fact is shown as well by the multiplicity of substances which may be produced from them by destructive and decomposing processes, as by the ease with which they are broken up into other and simpler compounds. Subjected in the soluble or moist state to the action of warm air, they speedily decompose or putrefy, yielding a great variety of products. Heated with acids, alkalies, and oxidizing agents, they all give origin to the same or to analogous products, among which more than twenty different compounds have been distinguished.

Occurrence in Plants.—Aleurone.—It is only in the old and virtually dead parts of a living plant that albuminoids are ever wanting. In the young and growing organs they are abundant, and exist dissolved in the sap or juices. They are especially abundant in seeds, and here they are deposited in an organized form, chiefly in grains similar to those of starch, and are nearly or altogether insoluble in water.

These grains of albuminoid matter are not, in many cases at least, pure albuminoids. They appear to contain

In plants the albuminoids often occur in definite forms.

vegetable albumen, caseine, fibrine, &c., associated together, though, in general, caseine and fibrine are largely predominant. Hartig, who first described them minutely, has distinguished them by the name *Aleurone*, a term which we may conveniently employ. By the word *Aleurone* is not meant simply an albuminoid, or mixture of albuminoids, but those *organized granules* found in the plant, of which the albuminoids are chief ingredients.

In Fig. 15 is represented a magnified slice through the outer cells (bran) of a husked oat grain. The cavities of these outer cells, *a*, *c*, are chiefly occupied with very fine grains of aleurone (caseine). In one cell, *b*, are seen the much larger starch grains. In the interior of the oat grain and other cereal seeds, the cells are chiefly occupied with starch, but throughout grains of aleurone are more or less intermingled.

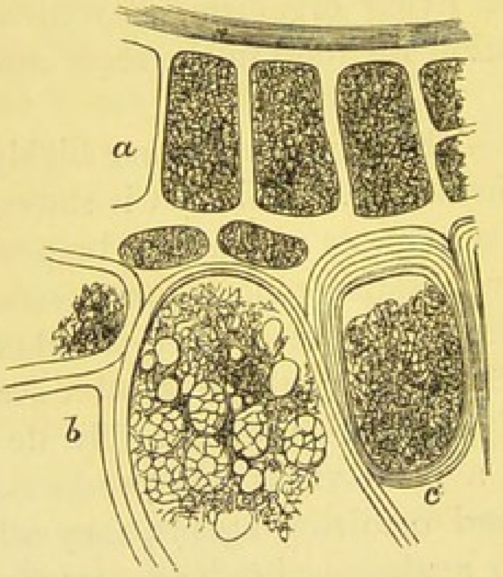

Fig. 15.

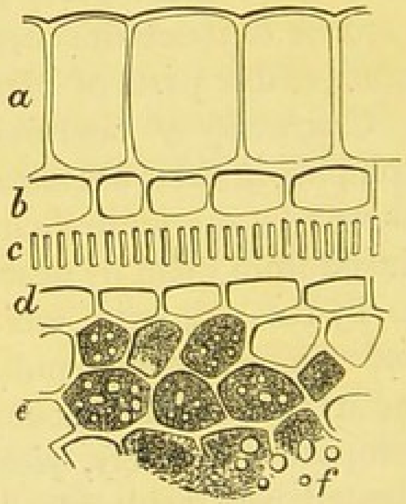

Fig. 16.

Fig. 16 exhibits a section of the exterior part of a flax seed. The outer cells, *a*, contain vegetable mucilage; the interior cells, *e*, are mostly filled with minute grains o aleurone, among which droplets of oil, *f*, are distributed.

In Fig. 17 are shown some of the forms assumed by individual albuminoid grains: *a* is aleurone from the seed of the vetch, *b* from the castor bean, *c* from flax seed, *d* from the fruit of the waxberry (*Myrica cerifera*), and *e* from mace (the aril of the nutmeg, the fruit of the *Myristica moschata*).

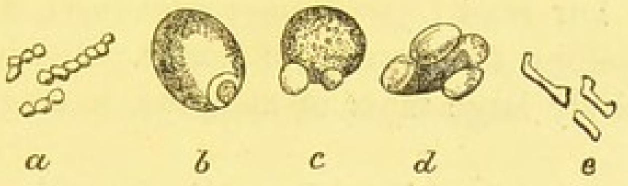

Fig. 17.

Apparently crystallized albuminoids occur in plants as well as in animals.

Crystalloid Aleurone.—It has been already remarked that crystallized albuminoids may be obtained from the blood of animals. It is equally true that bodies of similar character exist in plants, as was first observed by Hartig (*Entwickelungsgeschichte des Pflanzenkeims*, p. 104). In form they sometimes imitate crystals quite perfectly, Fig. 18, *a*; in other cases, *b*, they are rounded masses, having some crystalline planes or facets. They are soft, yield easily to pressure, swell up to double their bulk when soaked in weak acids or alkalies, and their angles have none of the constancy peculiar to proper crystals. They have the likeness of crystals, but are not truly crystallized.

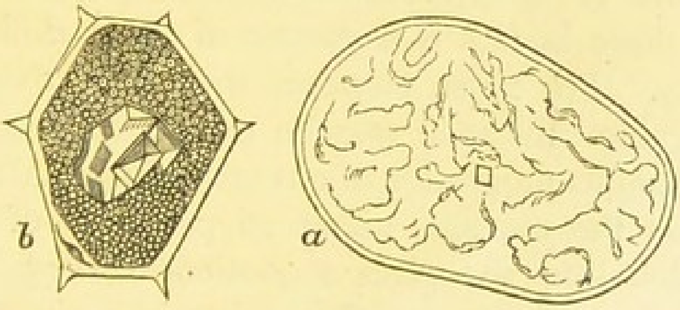

Fig. 18.

As Cohn first noticed (*Jour. für Prakt. Chem.* 80, p. 129), crystalloid aleurone may be observed in the outer portions of the potato tuber, in which it invariably presents a cubical form. It is best found by examining the cells that adhere to the rind of a potato that has been boiled. In Fig. 18, *a* represents a cell from a boiled potato, in the centre of which is seen the cube of aleurone. It is surrounded by the exfoliated remnants of starch grains. In the same figure, *b* exhibits the contents of a cell from the seed of the bur reed (*Sparganium ramosum*), a plant that is common along the borders of ponds. In the centre is a comparatively large mass of aleurone, having crystalloid facets.

According to Maschke (*Jour. für Pr. Ch.* 79, p. 184), the crystalloid aleurone that is abundant in the Brazil nut is a compound of *caseine with some acid of unknown composition.* This aleurone may be dissolved in water, and recovered in its original form on evaporation.

Kubel's analysis of aleurone, prepared from the Brazil nut by Hartig, gave as its percentage of nitrogen 9·46. Aleurone from the yellow lupine yielded him 9·26 per cent. Since pure caseine has 16 to 18 per cent. of nitrogen, the aleurone contained about 52 to 59 per cent. of albuminoids.

The amount of albuminoids present in a substance, may be calculated from its per cent. of nitrogen.

Estimation of the Albuminoids.—The quantitative separation of these bodies is a matter of great difficulty and uncertainty. For most purposes their collective quantity in any organic substance may be calculated with sufficient accuracy from its proportion of nitrogen. All the albuminoids contain, on the average, about 16 per cent. of nitrogen. This divided into 100 gives a quotient of 6·25. If, now, the percentage of nitrogen that exists in a given plant be multiplied by 6·25, the product will represent its percentage of albuminoids, it being assumed that all the nitrogen of the plant exists in this form, which in most cases is practically true.

Frühling and Grouven have recently investigated the condition of the nitrogen of various plants, and have found that *nitric acid*, or rather potassium nitrate, which has long been known to occur in vegetation, is present in but trifling quantity in most agricultural plants. In mature clover, sainfoin, lucerne, wheat, rye, oats, barley, the pea, and the lentil, it did not exceed 2 parts in 10,000 of the air-dry plant. In maize, they found twice this quantity; in beet and potato tops alone of all the plants examined was nitric acid present to the amount of four-tenths of one per cent. (*Vs. St.* ix. 153). That ammonia (NH_3) also exists in plants is certain, but that its quantity is commonly considerable we have no sufficient proof.

Different vegetable products contain very different amounts of albuminoids.

QUANTITY OF ALBUMINOIDS IN VARIOUS VEGETABLE PRODUCTS.

	Per cent.
Maize fodder, green	1·2
Beet tops ,,	1·9
Carrot tops ,,	3·5
Meadow grass ,,	3·1
Red clover ,,	3·7
White clover ,,	4·0
Turnips, fresh	1·2
Carrots ,,	1·3
Potatoes ,,	2·0
Corn cobs, air-dry	1·4
Straw of summer grain, air-dry	2·6
Straw of winter ,, ,,	3·0
Pea straw ,,	7·3
Bean straw ,,	3·4
Meadow hay ,,	8·5
Red clover hay ,,	13·4
White clover hay ,,	14·9
Buckwheat grain ,,	7·8
Barley ,, ,,	10·0
Maize ,, ,,	10·7
Rye ,, ,,	11·0
Oat ,, ,,	12·0
Wheat ,, ,,	13·2
Pea ,, ,,	22·4
Bean ,, ,,	24·1
Lentil ,, ,,	24·5

APPENDIX TO § 4.

CHLOROPHYLL—TANNIN—ALKALOIDS.

Before dismissing the subject of the Proximate Constituents of plants, we must notice several other substances of subordinate agricultural interest. Two of these, viz. *Chlorophyll* and *Tannin*, though not figuring in the analysis of agricultural plants, are nevertheless of almost universal occurrence in all forms of vegetation, though usually present in very minute quantity.

The green colour of leaves is due to chlorophyll.

Chlorophyll, i.e. *leaf-green*, is the name applied to the substance which occasions the green colour in vegetation. It is found in all the surfaces of annual plants and of the annually renewed parts of perennial plants. It might readily be supposed that it constitutes a large portion of the leaves of vegetation, but the fact is quite otherwise. The green parts of plants usually contain chlorophyll only at their surface, and in quantity no greater than coloured fabrics contain of particles of dye.

Chlorophyll being soluble in ether, accompanies fat or wax when these are removed from green vegetable matters by the solvent. It is soluble in hydrochloric and sulphuric acids, imparting to these liquids its intense green colour. According to Pfaundler, the (impure?) chlorophyll of grass has the following percentage composition :—

Carbon	60·83
Hydrogen	6·39
Oxygen	32·78

Frémy has shown that chlorophyll may be easily decomposed into two colouring matters—a yellow, *Xanthophyll*, and a blue, *Cyanophyll*. This is accomplished by treating chlorophyll with a mixture of hydrochloric acid and ether ; the cyanophyll dissolves in the latter, and the xanthophyll is taken up by the former solvent. The yellow colour of autumn leaves is perhaps due to xanthophyll.

According to Sachs, there exists in those parts of plants which, though not green, are capable of becoming so, a colourless substance, *Leucophyll*, which, in contact with oxygen, acquires a green colour, being converted into chlorophyll.

Tannin, or the astringent principle of plants.

Tannin is the general designation of the bitter astringent principles (used in leather-making) of the bark and leaves of the poplar, oak, sumach, plum, pear, and many other trees ; of tea, coffee, and of gall-nuts. It is found in small quantity in the young bean plant, and in many germinating seeds.

There are several kinds of tannin.

Tannin is closely related to the carbohydrates, as is demonstrated alike by the microscopic study of its development in the plant and by our knowledge of its chemical composition. The tannins are weak acids, and are distinguished, according to their origin, as *Gallotannic acid* (from nut-galls), *Caffeotannic acid* (from coffee), *Quercitannic acid* (from the oak), &c. As already hinted, the tannins are *Glucosides*, or compounds of sugar with some other substance. In gall-tannin the sugar is glucose, and the substance associated with, or rather yielded by it on decomposition, is known as *Gallic acid.* By boiling gall-tannin with a dilute acid, or by subjecting its solution to fermentation, decomposition into the two substances named is accomplished.

According to Strecker, the composition of gall-tannin and this conversion are indicated by the following formulæ:—

$$\underset{\text{Tannin.}}{C_{27}H_{22}O_{17}} + \underset{\text{Water.}}{4\,H_2O} = \underset{\text{Gallic Acid.}}{3\,C_7H_6O_5} + \underset{\text{Glucose.}}{C_6H_{12}O_6}.$$

Many of the active principles of plants are known as alkaloids.

The ALKALOIDS are a class of bodies very numerous in poisonous and medicinal plants, of which they usually constitute the active principle. Among those which have an agricultural interest are *Quinine, Nicotine, Caffeine*, and *Theobromine.*

Quinine, $C_{20}H_{24}N_2O_2$, occurs, along with another base, *cinchonine*, in Peruvian bark. The trees which yield it are various species of Cinchona, notably *C. succirubra* and *C. officinalis.* The salts of quinine are usually very bitter; some of them are of great medicinal value.

Nicotine, $C_{10}H_{14}N_2$, is the narcotic and extremely poisonous principle in tobacco, where it exists in combination with malic and citric acids. In the pure state it is a colourless oily liquid, having the odour of tobacco in an extreme degree. It is inflammable and volatile, and so deadly that a single drop will kill a large dog. French tobacco contains 7 or 8 per cent.; Virginia, 6 or 7 per cent.; and Maryland and Havannah about 2 per cent. of nicotine. Nicotine contains 17·3 per cent. of nitrogen, but no oxygen.

Caffeine, $C_8H_{10}N_4O_2$, exists in coffee and tea combined with tannic acid. In the pure state it forms white, silky, fibrous crystals, and has a bitter taste. In coffee it is found to the extent of one-half per cent.; in tea it occurs in much larger quantity, sometimes as high as 6 per cent.

Theobromine, $C_7H_8N_4O_2$, resembles caffeine in its characters, and is closely related to it in chemical composition. It is found in the cacao-bean, from which chocolate is manufactured.

The Alkaloids are remarkable from containing nitrogen, and from having strongly basic characters. They derive their designation, *alkaloids*, from their likeness to the alkalies.

CHAPTER II.

THE ASH OF PLANTS.

§ 1. The Ingredients of the Ash.

Chap. II.

The ash of plants contains thirteen elements.

As has been stated, the volatile or destructible part of plants, *i.e.* the part which is converted into gases or vapours under the ordinary conditions of burning, consists chiefly of Carbon, Hydrogen, Oxygen, and Nitrogen, together with minute quantities of Sulphur and Phosphorus. These elements, and such of their compounds as are of general occurrence in agricultural plants, viz. the Organic Proximate Principles, have been already described in detail.

The non-volatile part or ash of plants also contains, or may contain, Carbon, Oxygen, Sulphur, and Phosphorus. It is, however, in general, chiefly made up of nine other elements, whose common compounds are fixed at the ordinary heat of burning.

In the subjoined Table, the names of the thirteen chief elements of the ash of plants are given, and they are grouped under two heads, the *non-metals* and the *metals*, by reason of an important distinction in their chemical nature.

ELEMENTS OF THE ASH OF PLANTS.

Non-Metals.	Metals.
Oxygen,	Potassium,
Carbon,	Sodium,
Sulphur,	Calcium,
Phosphorus,	Magnesium,
Silicon,	Iron,
Chlorine,	Manganese.
Fluorine.	

If to the above be added

Hydrogen and Nitrogen,

the list includes all the elementary substances which are invariably present in all plants.

Hydrogen, however, is never an ingredient of the perfectly burned and dry ash of any plant, but nitrogen may remain in the ash under certain conditions, to be noticed hereafter, in the form of a *Cyanide* (compound of carbon and nitrogen).

Besides the above, certain other elements are found, either occasionally in common plants, or in some particular kind of vegetation: these are Iodine, Bromine, Titanium, Arsenic, Lithium, Rubidium, Cæsium, Barium, Aluminium, Zinc, Copper.

There are usually seven non-metals in plant-ashes.

We may now complete our study of the composition of the plant by describing those elements that are peculiar to the ash, and those compounds which may occur in it. It will be convenient also to notice in this section some substances which, although not ingredients of the ash, may exist in the plant, or are otherwise considered of importance.

The non-metallic elements are often called the *acid elements*, from certain compounds having acid characters which they form by union among themselves. From their near resemblance to the element chlorine, one of the most characteristic and active of the non-metals, they are also often termed the *chlorous* elements. Of these non-metals plant-ashes may contain Oxygen, Sulphur, Phosphorus, Carbon, Silicon, Chlorine, Iodine, Bromine, and Fluorine. Arsenic and Titanium, often included here, present many of the characters of metals.

With the exception of Silicon, Titanium, and Carbon, these elements by themselves are readily volatile. Their compounds with each other, which we may refer to in our study of agricultural chemistry, are also volatile, with two notable exceptions, the Silicic and Phosphoric acids.

In order that they may resist the high temperature at which ashes are formed, they must be combined with the metallic elements, or their oxides, as *salts*.

Chap. II.

Oxygen, *symbol* O, *atomic weight* 16, is an ingredient of the ash, since it unites with nearly all the other elements of vegetation, either during the life of the plant or in the act of combustion. It unites with Carbon, Sulphur, Phosphorus, and Silicon, forming bodies which are called anhydrides, and which unite with metallic oxides to form salts; while with the metals it produces oxides, which have the characters of bases. Chlorine alone of the elements of the plant does not unite with oxygen, either in the living plant or during its combustion.

CARBON AND ITS COMPOUNDS.

Carbon, *symbol* C, *atomic weight* 12, has been noticed already with sufficient fulness (p. 15). It is often contained as charcoal in the ashes of the plant, owing to its being enveloped in a coating of fused saline matters, which shield it from the action of oxygen.

The most important compound of carbon is the dioxide.

Carbonic Dioxide, *symbol* CO_2, *molecular weight* 44, in the colourless gas which causes the sparkling or effervescence of beer and soda-water, and the frothing of yeast.

It is formed by the oxidation of carbon when vegetable matter is burned (Exp. 6). It is therefore found in the ash of plants, combined with those bases which in the living organism existed in union with organic acids; the latter being destroyed by burning.

It also occurs in combination with lime in the tissues of many plants. Its compounds with bases are *carbonates*, to be noticed presently. When a carbonate, as marble or limestone, is drenched with a strong acid, like vinegar or muriatic acid, the carbonic acid is set free with effervescence.

Cyanogen, *symbol* CN.—This important compound of Carbon and Nitrogen is a gas which has an odour resembling that of bitter almonds, and which burns on contact with a lighted taper with a fine purple flame. In its union with oxygen by combustion, carbonic acid is formed, and nitrogen set free,

$$2\,CN + 4\,O = 2\,CO_2 + 2\,N.$$

Cyanogen is a compound of carbon and nitrogen

Cyanogen may be prepared by heating an intimate mixture of two parts by weight of ferrocyanide of potassium (yellow prussiate of potash) and three parts of corrosive sublimate. The operation may be conducted in a test tube or small flask, to the mouth of which is fitted a cork penetrated by a narrow glass tube. On applying heat, the gas issues, and may be set on fire to observe its beautiful flame.

Cyanogen, combined with iron, forms the Prussian blue of commerce, and its name, signifying the *blue-producer*, was given to it from that circumstance.

Cyanogen unites with the metallic elements, giving rise to a series of bodies which are termed *Cyanides*. Some of these often occur in small quantity in the ashes of plants, being produced in the act of burning by the union of nitrogen with carbon and a metal. For this result, the temperature must be very high, carbon must be in excess, the metal is usually potassium or calcium, the nitrogen may be either free nitrogen of the atmosphere or that originally existing in the organic matter.

With hydrogen, cyanogen forms the deadly poison *hydrocyanic* or prussic acid (HCy), which is produced from amygdaline, one of the ingredients of bitter almonds, peach, and cherry seeds, when these are crushed in contact with water.

When a cyanide is brought in contact with steam at high temperatures, it is decomposed, all its nitrogen being converted into ammonia.

Cyanogen is contained in a normal product of one common plant. The oil of mustard is the pungent *sulphocyanide of allyle*, C_3H_5CNS.

SULPHUR AND ITS COMPOUNDS.

There are many important compounds of sulphur.

Sulphur, *symbol* S, *atomic weight* 32.—The properties of this element have been already described (p. 26). Some of its compounds have also been briefly alluded to, but require more detailed notice.

Hydrosulphuric Acid, *symbol* H_2S, *molecular weight* 34.—This substance, familiarly known as sulphuretted hydrogen, occurs dissolved in the water of numerous so-called sulphur springs, as those of Harrogate, Yorkshire, from which it escapes as a fetid gas. It is not unfrequently emitted from volcanoes and fumaroles. It is likewise produced in the decay of organic bodies which contain sulphur, especially eggs, the intolerable odour of which, when rotten, is chiefly due to this gas.

The ashes of plants sometimes yield this gas when they are moistened with water. In such cases, a *sulphide of potassium* or *calcium* has been formed in small quantity during the incineration.

Hydrosulphuric acid is set free in the gaseous form by the action of an acid on various sulphides, as those of iron (Exp. 17), antimony, &c.

as well as by the action of water on the sulphides of the alkali and alkali-earth metals. It may be also generated by passing hydrogen gas into melted sulphur, or by heating fat and sulphur together.

Sulphuretted hydrogen has a slight acid taste. It is highly poisonous and destructive, both to animals and plants.

Sulphurous Anhydride or **Dioxide,** *symbol* SO_2, *molecular weight* 64.—When sulphur is burned in the air, or in oxygen gas, it forms copious white suffocating fumes, which consist of one atom of sulphur united to two atoms of oxygen; SO_2 (Exp. 15).

Sulphurous anhydride in the presence of water has the power of discharging, for a time at least, most of the red and blue vegetable colours. It has, however, no action on many yellow colours. It is largely employed for bleaching straw and wool.

Sulphurous anhydride is emitted from volcanoes, and from fissures in the soil of volcanic regions. It is produced when bodies containing sulphur are burned with imperfect access of air, and is thrown into the atmosphere in large quantities from fires which are fed by mineral coal, as well as from the numerous roasting heaps of certain metallic ores, the sulphides, which are worked in mining regions.

Sulphurous anhydride may unite with bases, yielding salts known as *sulphites*, some of which, viz. sulphite of lime and sulphite of soda, are employed to check or prevent fermentation, an effect also produced by the acid itself.

Sulphuric Anhydride, *symbol* SO_3, *molecular weight* 80, is known to the chemist as a white silky solid, which attracts moisture with great avidity, and, when thrown into water, hisses like a hot iron, forming the hydrated or true sulphuric acid.

Sulphuric acid is the oil of vitriol of commerce.

Sulphuric Acid, *symbol* H_2O, SO_3, or H_2SO_4, *molecular weight* 98, is a substance of the highest importance, its manufacture being the basis of the chemical arts. In its concentrated form it is known as *oil of vitriol*, and is a colourless, heavy, corrosive liquid, of an oily consistency, and sharp, sour taste.

It is manufactured on a large scale by mingling sulphurous anhydride, nitric acid, and steam, in large lead-lined chambers, the floors of which are covered with water. The sulphurous anhydride takes up oxygen from the nitric acid, and the sulphuric acid thus formed dissolves in the water, and is afterwards boiled down to the proper strength in vessels of lead or platinum.

Sulphuric acid is largely employed in making super-phosphate.

The chief agricultural application of commercial sulphuric acid is in the preparation of "superphosphate of lime," which is consumed as a fertilizer in immense quantities. This is made by mixing sulphuric acid of sp. gr. 1·6 with bone-dust, bone-ash, or some mineral phosphate.

Sulphuric acid occurs in the free state, though extremely dilute, in certain natural waters, where it is produced by the oxidation of sulphide of iron.

Sulphuric acid is very corrosive, and destroys most vegetable and animal matters.

Experiment 53.—Stir a little oil of vitriol with a pine stick. The wood is immediately browned or blackened, and a portion of it dissolves in the acid, communicating a dark colour to the latter. The commercial acid is often brown from contact with straws and chips.

Strong sulphuric acid produces great heat when mixed with water, as is done in making superphosphate.

Experiment 54.—Place in a *thin* glass vessel, a beaker for example, 30 c. c. of water; into this pour, in a fine stream, 120 grams of oil of vitriol, stirring all the while with a narrow test tube containing a teaspoonful of water. If the acid be of full strength, so much heat is thus generated as to boil the water in the stirring tube.

In mixing oil of vitriol and water, the acid should always be slowly poured into the water, with stirring, as above directed. When water is added to the acid, it floats upon the latter, or mixes with it but superficially, and the liquids may be thrown about by the sudden formation of steam at the points of contact, when subsequently stirred.

The sulphates are important salts.

Sulphuric acid forms with the bases an important class of salts—the *sulphates*—to be presently noticed, some of which are found in the ash, but exist also in the sap of plants. When organic matters containing sulphur, as hair, albumen, &c., are burned with full access of air, this element remains in the ash as sulphate, or is partially dissipated as sulphurous acid.

PHOSPHORUS AND ITS COMPOUNDS.

Phosphorus, *symbol* P, *atomic weight* 31, has been sufficiently described (p. 28). Of its numerous compounds but two require additional notice.

Phosphoric Anhydride, *symbol* P_2O_5, *molecular weight* 142, does not occur as such in nature. When phosphorus is burned in dry air or oxygen, anhydrous phosphoric acid is the snow-like product (Exp. 18). It has no sensible acid properties until it has united to water, which it combines with so energetically as to produce a hissing noise from the heat developed. On boiling it with water for some time, it completely dissolves, and the solution contains

The phosphates are most important ingredients of plants and soils.

Phosphoric Acid, *symbol* $P_2O_5, 3H_2O$, *molecular weight* 196; or H_3PO_4, 98.—The chief interest which this compound has for the agriculturist lies in the fact that the combinations which are formed between it and various bases —*phosphates*—are among the most important ingredients of plants and their ashes.

When bodies supposed to contain phosphorus in other forms than phosphoric acid or phosphates are disorganized by heat or decay, the phosphorus appears in the ashes or residue in the form of phosphoric acid or phosphates.

The formation of several phosphates has been shown in Exp. 20. Further accounts of them will be given under the metals.

CHLORINE AND ITS COMPOUNDS.

The properties of chlorine.

Chlorine, *symbol* Cl, *atomic weight* 35·5.—This element exists in the free state as a greenish-yellow, suffocating gas, which has a peculiar odour, and the property of bleaching vegetable colours. It is endowed with the most vigorous affinities for many other elements, and hence is never met with, naturally, in the free state.

Sprengel claims to have found that *Glaux maritima* and *Salicornia herbacea*, plants growing in salt marshes, exhale chlorine. He says that the chlorine thus evolved is quickly converted into hydrochloric acid, by acting on the vapour of water which exists in the atmosphere. Such an exhalation of chlorine is manifestly impossible. The gas, were it eliminated within the plant, would be consumed before it could escape into the atmosphere.

Experiment 55.—Chlorine may be prepared by heating a mixture of hydrochloric acid and black oxide of manganese or red-lead. The gas being nearly five times as heavy as common air, may be collected in glass bottles by passing the tube which delivers it to the bottom of the receiving vessel. Care must be taken not to inhale it, as it energetically attacks the interior of the breathing passages, producing the disagreeable symptoms of a cold.

Chlorine dissolves in water, forming a yellow solution. Very weak chlorine water was found by Humboldt to facilitate the sprouting of seeds.

In some form of combination chlorine is distributed over the whole earth, and is never absent from the plant.

The compounds of chlorine are termed *chlorides*, and may be prepared, in most cases, by simply putting their elements in contact, at ordinary or slightly elevated temperatures.

Hydrochloric acid is one of the chief compounds of chlorine.

Hydrochloric Acid, *symbol* HCl, *molecular weight* 36·5.—When Chlorine and Hydrogen gases are mingled together, they slowly combine if exposed to diffused light; but if placed in the sunshine, they unite explosively, and chloride of hydrogen or hydrochloric acid is formed. This compound is a gas that dissolves with great avidity in water, forming a liquid which has a sharp, sour taste, and possesses all the characters of an acid.

The *muriatic acid* of the apothecary is water holding in solution several hundred times its bulk of hydrochloric acid gas, and is prepared from common salt, whence its ancient name *spirits of salt.*

Hydrochloric acid is the usual source of chlorine gas. The latter is evolved from a heated mixture of this acid with peroxide of manganese. In this reaction the hydrogen of the hydrochloric acid unites with the oxygen of the peroxide of manganese, producing water, while chloride of manganese and free chlorine are separated.

$$4\,HCl + MnO = MnCl_2 + 2\,H_2O + 2\,Cl.$$

When chlorine dissolved in water is exposed to the sunlight, there ensues a change the reverse of that just noticed. Water is decomposed, its oxygen is set free, and hydrochloric acid is formed.

$$2\,H_2O + 4\,Cl = 4\,HCl + 2\,O.$$

This reaction probably takes place when the germination of seeds is hastened by chlorine. The oxygen thus liberated is doubtless the real agent which excites growth in the sleeping germ.

The two reactions just noticed are instructive examples of the different play of affinities between several elements under unlike circumstances.

Hydrochloric acid, being volatile, does not occur in the ashes of plants, but some of its salts, and notably the chloride of sodium, exist in plants and their ashes. Hydrochloric gas is found in volcanic emanations.

This acid is a ready means of converting various metals or metallic oxides into chlorides, and its solution in water is a valuable solvent and reagent for the purposes of the chemist.

Iodine compounds occur in some plants.

Iodine, *symbol* I, *atomic weight* 127.—This interesting body is a black solid at ordinary temperatures, having an odour resembling that of chlorine. Gently heated, it is converted into a violet vapour. It occurs in seaweeds, and is obtained from their ashes. It gives with starch a blue or purple compound, and is hence employed as a test for that substance (p. 49). It is analogous to chlorine in its chemical relations. It is not known to occur in sensible quantity in agricultural plants, although it may well exist in the grasses of salt-marshes, and in the produce of soils which are manured with seaweed.

Bromine and **Fluorine** also exist in very small quantity in many plants.

SILICON AND ITS COMPOUNDS.

Silicon, *symbol* Si, *atomic weight* 28.—This element, in the free state, is only known to the chemist. It may be prepared in three modifications: one, a brown powdery substance; another resembling graphite (black-lead, p. 15), and a third, that occurs in crystals, having nearly the hardness of the diamond.

Silicic anhydride, the same as silex flint and quartz.

Silicic Anhydride, *symbol* SiO_2, *molecular weight* 60.—This compound, known also as *Silica*, and anciently termed *Silex*, is widely diffused in nature, and occurs to an enormous extent in rocks and soils, both in the free state and in combination with other bodies.

Free silica exists in nearly all soils, and in many rocks, especially in sandstones and granites, in the form known to mineralogists as *quartz*. The glassy, white or transparent, often yellowish or red fragments of common sand, *which are hard enough to scratch glass*, are almost invariably this mineral. In the purest state, it is *rock-crystal*. Jasper, flint, and agate are somewhat less pure silica.

Silicates.—Silicic Anhydride is extremely insoluble in pure water and in most acids. It has none of the sensible qualities of acids, but is nevertheless capable of union with bases. It is slowly dissolved by strong, and especially by hot solutions of potash and soda, forming soluble *silicates* of these alkalies.

Water-glass is an alkaline silicate.

Experiment 56.—*Formation of Silicate of Potash or Potassium Silicate.* Heat a piece of quartz or flint, as large as a chestnut, as hot as possible in the fire, and quench it suddenly in cold water. Reduce it to fine powder in a porcelain mortar, and boil it in a porcelain dish with twice its weight of caustic potash, and eight or ten times as much water, for two hours, taking care to supply the water as it evaporates. Pour off the whole into a tall narrow bottle, and leave at rest until the undissolved silica has settled. The clear liquid is a basic silicate of potash, *i.e.* a silicate which contains a number of molecules of base for each molecule of silica. It has, in fact, the taste and feel of potash solution. The so-called *water-glass*, now employed in the arts, is a similar silicate of potash or soda, made by boiling flints or sand with alkali under pressure.

Many artificial silicates are formed by fusion.

When silica is strongly heated with potash or soda, or with lime, magnesia, or oxide of iron, it readily melts and unites with these bodies, though nearly infusible by itself: silicates are the result. The silicates thus formed with potash and soda are soluble in water, like the product of Exp. 56, when the alkali exceeds a certain proportion—when highly basic; but with silica in excess (acid silicates) they dissolve with difficulty. A mixed silicate of an alkaline metal, calcium and aluminium, with a large proportion of silica, is nearly or altogether insoluble, not only in water, but in most acids—constitutes, in fact, ordinary glass.

Many silicates occur in rocks.

A multitude of silicates exist in nature as rocks and minerals. Ordinary clay, common slate, soapstone, mica, felspar, hornblende, garnet, and other compounds of frequent and abundant occurrence, are silicates. The natural silicates are of two classes, viz. the *acid silicates* (containing a preponderance of silica) and *basic silicates* (with large proportion of base): the former are but slowly dissolved or decomposed by acids, while the latter are readily attacked even by carbonic acid. Many native silicates are *anhydrous*, or destitute of water; others are *hydrous*, i.e. they contain water as a large and essential ingredient.

Hydrated Silica.—Various compounds of silica with water are known to the chemist. Of these but three need be mentioned here.

Silica in Solution.—This body, doubtless a hydrate, is known dissolved in water or acids. It is formed when the solution of an alkaline silicate is decomposed by means of a large excess of some strong acid, like the hydrochloric or sulphuric.

Experiment 57.—Dilute half the solution of silicate of potash obtained in Exp. 56 with ten times its volume of water, and add it gradually to a large quantity of diluted hydrochloric acid. In this experiment the hydrochloric acid decomposes and destroys the silicate of potash, uniting itself with the base with production of chloride of potassium, which dissolves in the water present. The silica thus liberated unites chemically with water, and remains also in solution as silicic acid.

A strong aqueous solution of silica obtainable.

By the process known as *dialysis*, Graham has removed from solutions like that of the last experiment everything but the silica, and obtained solutions of silica in pure water. Graham prepared a liquid that gave, when evaporated and heated, 14 per cent. of anhydrous silica. This solution was clear, colourless, and not viscid. It reddened litmus paper like an acid. Though not sour to the taste, it produced a peculiar feeling on the tongue. Evaporated to dryness at a low temperature, it left a transparent, glassy mass, which had the composition SiO_2, H_2O. This dry residue was insoluble in water. These solutions of silica in pure water are incapable of existing for a long time without suffering a remarkable change. Even when protected from all external agencies, they sooner or later, usually in a few days or weeks, lose their fluidity and transparency, and coagulate to a stiff jelly, from the separation of a nearly insoluble hydrate of silica, which we shall designate as *gelatinous silica.*

The addition of $\frac{1}{10000}$ of an alkali or earthy carbonate, or of a few bubbles of carbonic acid gas, to the strong solutions, occasions their immediate gelatinization. A minute quantity of potash or soda, or excess of hydrochloric acid, prevents their coagulation.

Gelatinous silica is very slightly soluble in water.

Gelatinous Silica.—This substance, which results from the coagulation of the soluble silica just described, usually appears also when the strong solution of a silicate has strong hydrochloric acid added to it, or when a silicate is decomposed by direct treatment with a concentrated acid.

It is a white opaline, or transparent jelly, which, on drying in the air, becomes a fine white powder, or forms transparent grains. This powder, if dried at ordinary temperatures, is $3SiO_2, 2H_2O$. At the temperature of 100° C. it loses half its water. At a red heat it becomes anhydrous.

Gelatinous silica is distinctly, though very slightly, soluble in water. Fuchs and Bresser have found by experiment that 100,000 parts of water dissolve 13 to 14 parts of gelatinous silica. Heated to 100°, it becomes insoluble.

Opal.—Several native forms of silica and hydrous silica are slightly soluble in water: opal is one of these. Part of it dissolves still more freely in alkaline solutions.

All the hydrates of silica are readily soluble in solutions of the alkalies and alkaline carbonates, and readily unite with moist slaked lime, forming silicates.

Experiment 58.—*Gelatinous Silica.*—Pour a small portion of the solution of silicate of potash of Exp. 56 into strong hydrochloric acid. Gelatinous silica separates and falls to the bottom, or the whole liquid becomes a transparent jelly.

Experiment 59.—*Conversion of Soluble into Insoluble Hydrated Silica.*—Evaporate the solution of silica of Exp. 57, which contains free hydrochloric acid, in a porcelain dish. As it becomes concentrated, it is very likely to gelatinize, as happened in Exp. 58, on account of the removal of the solvent. Evaporate to perfect dryness, finally, on a water-bath (*i.e.* on a vessel of boiling water which is covered by the dish containing the solution). Add to the residue water, which dissolves away the chloride of potassium, and leaves insoluble hydrated silica $3SiO_2, H_2O$, as a gritty powder.

Silicates occur usually in plant-ashes.

In the ash of plants, silica is usually found in combination with alkalies or lime, owing to the high temperature to which it has been subjected.

In the plant, however, it exists chiefly, if not entirely, in the free state.

Titanium, an element which has some analogies with silicon, though rarely occurring in large quantities, is yet often present in the form of *Titanic Acid*, TiO_2, in rocks and soils, and, according to Salm Horstmar, may exist in the ashes of barley and oats.

Arsenic, in minute quantity, has been found in turnips which had been manured with a fertilizer (superphosphate) in the preparation of which oil of vitriol, containing this element, was employed.

The metallic elements of plant-ashes.

The metallic elements which remain to be noticed, viz. Potassium, Sodium, Calcium, Magnesium, Iron, Manganese, Lithium, Rubidium, Cæsium, Aluminium, Zinc, and Copper, are *basic* in their character, *i.e.* they replace hydrogen in the acid bodies that have just been described to produce salts. Each one is, in this sense, the base of a series of saline compounds.

ALKALI-METALS. — The elements, Potassium, Sodium, Lithium, Rubidium, and Cæsium, are termed *alkaline-metals.* Their oxides are very soluble in water, and are called *alkalies.* The metals themselves do not occur free in nature, and can only be prepared by tedious chemical processes. They are silvery-white bodies, and are *lighter than water.* Exposed to the air, they quickly tarnish, from the absorption of oxygen, and are rapidly converted into the corresponding alkalies. Thrown upon water, they mostly inflame and burn with great violence, decomposing the liquid (Exp. 11).

There are two alkaline-metals in all plants.

Of the alkaline-metals, Potassium is invariably found in all plants. Sodium is especially abundant in marine and strand vegetation; it is generally found in agricultural plants, but is occasionally present in traces only in them.

POTASSIUM AND ITS COMPOUNDS.

Potassium, *symbol* K,* *atomic weight* 39.—When heated in the air, this metal burns with a beautiful violet light, and forms potassium oxide, K_2O.

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* From the Latin, *Kalium*.

When this oxide is put into water, it forms

Potassium Hydrate, KHO, 56, which is the *caustic potash* of the apothecary and chemist. It may be procured in white translucent masses or sticks, which rapidly absorb moisture and carbonic dioxide from the air, and readily dissolve in water, forming *potash-lye.* It strongly corrodes many vegetable and most animal matters, and decomposes and dissolves fats, forming *potash-soaps.* It unites with acids forming the potassium salts, water being set free.

SODIUM AND ITS COMPOUNDS.

Sodium, Na,* 23, burns with a brilliant yellow flame, yielding sodium oxide, Na_2O.

Sodium Hydrate, or Caustic Soda, $NaHO$, 40. —This body is like caustic potash in appearance and general characters. It forms soaps with the various fats. While the potash-soaps are usually soft, those made with soda are commonly hard.

LITHIUM—RUBIDIUM—CÆSIUM.

The rare alkaline-metals.

Lithium, Li 7.—The compounds of this metal are of much rarer occurrence than those of potassium and sodium. The element itself is the lightest metal known, being but little more than half as heavy as water. It burns with a vivid white light when heated in the air.

Lithia, Li_2O, 30, and its Hydrate, closely resemble the corresponding compounds of the two elements above described. They yield by union with acids the lithium-salts.

Rubidium, Rb, 85·5, and **Cæsium**, Cs, 133.—Besides potassium, sodium, and lithium, there are two other recently discovered alkali-metals, viz. Rubidium and Cæsium. These elements are comparatively rare, although they appear to be widely distributed in nature in minute quantity.

Rubidium has been found in the ashes of tobacco and sugar-beet, as well as in commercial potash. Cæsium, which is the rarer of the two, has as yet not been detected in the ashes of plants, but probably occurs in them. These metals and their compounds have in general the closest similarity to the other alkali-metals.

ALKALI-EARTH METALS.—The two metallic elements next to be noticed, viz. Calcium and Magnesium, give, with

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* From the Latin, *Natrium.*

oxygen, the *alkaline-earths*, lime and magnesia. The metals are only procurable by difficult chemical processes, and from their eminent oxidability are not found in nature. They are but little heavier than water. Their oxides are but slightly soluble in water.

CALCIUM AND ITS COMPOUNDS.

Calcium, Ca, 40, is a brilliant ductile metal having a light yellow colour. In moist air it rapidly tarnishes and acquires a coating of lime.

Quicklime is the calcium oxide.

Lime, CaO, 56, is the result of the oxidation of calcium. It is prepared for use in the arts by subjecting limestone or oyster-shells to an intense heat, and usually retains the form and much of the hardness of the material from which it is made. It has the bitter taste and corroding properties of the alkalies, though in a less degree. It is often called *quicklime*, to distinguish it from its compound with water. It may occur in the ashes of plants when they have been maintained at a high heat after the volatile matter has been burned away. It is the base of the salts of lime.

Slaked lime is the calcium hydrate.

Calcium Hydrate, or **Hydrate of Lime**, CaH_2O_2, or CaO, H_2O, 74.—Quicklime, when exposed to the air, gradually absorbs water, and falls to a fine powder. It is then said to be *air-slaked*. When water is poured upon quicklime it penetrates the pores of the latter, and shortly the falling to powder of the lime and the development of much heat give evidence of chemical union between the lime and the water. This chemical combination is further proved by the increase of weight of the lime, 56 lbs. of quicklime becoming 74 lbs. by *water-slaking*. On heating slaked lime to redness, its water may be expelled.

When lime is agitated for some time with much water, and the mixture is allowed to settle, the clear liquid is found to contain a small amount of lime in solution (one part of lime to 700 parts of water). This liquid is called *lime-*

water, and has already been noticed as a test for carbonic dioxide. Lime-water has the alkaline taste in a marked degree.

MAGNESIUM AND ITS COMPOUNDS.

The compounds of magnesium.

Magnesium, Mg, 24.—Metallic magnesium has a silver-white colour. When heated in the air it burns with extreme brilliancy (magnesium light), and is converted into magnesia.

Magnesia, MgO, 40, is the oxide of magnesium. It is found in the druggists' shops in the shape of a bulky white powder, under the name of *calcined magnesia.* It is prepared by subjecting either hydrate, carbonate, or nitrate of magnesium to a strong heat. It occurs in the ashes of plants.

Magnesium Hydrate, MgH_2O_2, is produced slowly and without heat, when magnesia is mixed with water. It occurs as a transparent glassy mineral (Brucite) at Texas, Pennsylvania, and several other places. It readily absorbs carbonic dioxide, and passes into magnesium carbonate. Magnesium hydrate is so slightly soluble in water as to be tasteless. It requires 55,000 times its weight of water for solution.

Heavy Metals. — The two metals remaining to be noticed are Iron and Manganese. These again considerably resemble each other, though they differ exceedingly from the metals of the alkalies and alkaline earths. They are about eight times heavier than water. Each of these metals forms two important basic oxides, which are usually totally insoluble in pure water.

IRON AND ITS COMPOUNDS.

Iron, Fe,* 56.—The properties of metallic iron are so well known that we need not occupy any space in recapitulating them.

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* From the Latin name *Ferrum*.

Ferrous oxide, or protoxide of iron.

Ferrous Oxide, FeO, 72.—When sulphuric acid in a diluted state is put in contact with metallic iron, hydrogen gas shortly begins to escape in bubbles from the liquid, and the iron dissolves, uniting with the acid to form the ferrous sulphate, the salt commonly known as copperas or green vitriol.

$$H_2SO_4 + Fe = FeSO_4 + H_2.$$

If now lime-water or potash-lye be added to the solution of iron thus obtained, a white or greenish-white precipitate separates, which is a hydrated ferrous oxide (FeO, H_2O). This precipitate rapidly absorbs oxygen from the air, becoming black, and finally brown. The anhydrous ferrous oxide is black. Carbonate of protoxide of iron, or *ferrous* carbonate, is of frequent occurrence as a mineral (spathic iron), and exists dissolved in many mineral waters, especially in the so-called chalybeates.

Ferric oxide is the rust of iron.

Ferric Oxide, Fe_2O_3, 160.—When ferrous oxide is exposed to the air, it acquires a brown colour from union with more oxygen, and becomes hydrated ferric oxide. The yellow or brown rust which forms on surfaces of metallic iron when exposed to moist air is the same body. Iron in the form of ferric oxide is found in the ashes of all agricultural plants, the other oxides of iron passing into this when exposed to air at high temperatures. It is found in immense beds in the earth, and is an important ore (specular iron, hæmatite). It dissolves in acids, forming the ferric salts, which have a yellow colour.

MAGNETIC OXIDE OF IRON, Fe_3O_4, or FeO, Fe_2O_3, is a combination of the two oxides above mentioned. It is black, and is strongly attracted by the magnet. It constitutes, in fact, the native magnet, or loadstone, and is a valuable ore of iron.

MANGANESE AND ITS COMPOUNDS.

Manganese, Mn, 55.—Metallic manganese is difficult to procure in the free state, and much resembles iron. Its oxides which concern the agriculturist are the red and the black oxides.

Manganous Oxide, MnO, 71, has an olive-green colour. It is the base of all the usually occurring salts of manganese. Its hydrate, prepared by decomposing manganous sulphate by lime-water, is a white substance, which, on exposure to the air, shortly becomes brown and finally black from absorption of oxygen. The salts of manganous oxide are mostly pale rose-red in colour.

Sesquioxide of Manganese, Mn_2O_3, occurs native as the mineral *braunite*, or, combined with water, as *manganite*. It is a substance having a red or black-brown colour. It dissolves in cold acids, forming salts of an intensely red colour. These are, however, easily decomposed by heat, or by organic bodies, into oxygen and manganous salts.

Oxides of manganese occur in plant-ashes and in soils.

Red Oxide of Manganese, Mn_3O_4, or MnO, Mn_2O_3.—This oxide remains when manganese or any of its oxides are subjected to a high temperature with access of air. The metal and the manganous oxide gain oxygen by this treatment; the higher oxides lose oxygen until this compound oxide is formed, which, as its formula shows, corresponds to the magnetic oxide of iron. It is found in the ashes of plants.

Black Oxide of Manganese, MnO_2.—This body is found extensively in nature. It is employed in the preparation of oxygen and chlorine (for bleaching powder), and is an article of commerce.

Some other metals occur as oxides or salts in ashes, though not in such quantity or in such plants as to possess any agricultural significance in this respect.

Alumina occurs in the club-moss.

Alumina, the sesquioxide of the metal ALUMINIUM, is found in considerable quantity (20 to 50 per cent.) in the ashes of the club-moss (*Lycopodium*). It is united with an organic acid (*tartaric*, according to Berzelius; *malic*, according to Ritthausen) in the plant itself. It is often found in small quantity in the ashes of agricultural plants, but whether it be an ingredient of the plant or due to particles of adhering clay is not in all cases clear.

Zinc has been found in a variety of yellow violet that grows on the refuse-heaps of the zinc mines of Aix-la-Chapelle.

Copper occurs in many plants.

Copper is frequently present in minute quantity in the ash of trees, especially of such as grow in the vicinity of manufacturing establishments, where dilute solutions containing copper are thrown to waste. Traces of this metal occur in many plants.

The salts or compounds of metals with non-metals found in the ashes of plants or in the unburned plant remain to be considered.

Of the elements, acids, and oxides, that have been noticed as constituting the ash of plants, it must be remarked that with the exception of silica, magnesia, oxide of iron, and oxide of manganese, they all exist in the ash in the form of salts (compounds of acids and bases). In the living agricultural plant it is probable that, of them all, only silica occurs in the uncombined state.

We shall notice in the first place the salts which may occur in the ash of plants, and shall consider them under the following heads, viz. Carbonates, Sulphates, Phosphates, and Chlorides. As to the Silicates, it is unnecessary to add anything here to what has been already mentioned.

Earthy and alkaline carbonates occur in plant-ashes.

THE CARBONATES which occur in the ashes of plants are those of Potassium, Sodium, and Calcium. Rubidium Carbonate, similar to sodium carbonate, and Lithium Carbonate, rather insoluble in water, may also be present, but in exceedingly minute quantity. The Carbonates of Magnesium, Iron, and Manganese are decomposed by the heat at which ashes are prepared.

Potassium Carbonate, K_2CO_3, 114.—The *pearl-ash* of commerce is a tolerably pure form of this salt. When wood is burned, the potash which it contains is found in the ash, chiefly as carbonate. If wood-ashes are repeatedly washed or *leached* with water, all the salts soluble in this liquid are removed; by boiling this solution down to dryness, which is done in large iron pots, crude *potash* is obtained, as a dark or brown mass. This, when somewhat purified, yields pearl-ash. Potassium carbonate, when pure, is white, and has a bitter, biting taste—the so-called alkaline taste. It has such attraction for water, that, when exposed to the air, it absorbs moisture and becomes a liquid.

If hydrochloric acid be poured upon potassium carbonate, a brisk effervescence immediately takes place, owing to the escape of carbonic dioxide, while potassium chloride and water are formed, which remain behind.

$$K_2CO_3 + 2\,HCl = 2\,KCl + H_2O + CO_2.$$

Potassium Hydric Carbonate, $KHCO_3$.—A solution of potassium carbonate when exposed to carbonic acid gas absorbs the latter, and the acid potassium carbonate is produced, so called because to a given amount of potassium it contains twice as much carbonic acid as the carbonate.

The ashes of marine plants contain much soda.

Sodium Carbonate, Na_2CO_3, 106.—This substance, commonly called Carbonate of Soda, so important in the arts, was formerly made from the ashes of certain marine plants (*Salsola* and *Salicornia*), in a manner similar to that now employed in wooded countries for the preparation of potash. It is at present almost wholly obtained from common salt by a somewhat complicated process. It occurs in commerce in an impure state under the name of *soda-ash*. When nearly pure it forms commercial *soda*, which usually exists in transparent crystals or crystallized masses. These contain 63 per cent. of water, which slowly escapes when the salt is exposed to the air, leaving a nearly anhydrous or water-free carbonate as a white, opaque powder.

Sodium carbonate has a nauseous alkaline taste, not nearly so decided, however, as that of the potassium carbonate. It is often present in the ashes of plants.

Sodium Hydric Carbonate, $NaHCO_3$.—The Bicarbonate, or *supercarbonate of soda* of the apothecary, is this salt in a nearly pure state. It is prepared in the same way as the corresponding potassium salt. The bicarbonates, both of potash and soda, give off half their carbonic acid at a moderate heat, and lose all of this ingredient by contact with excess of any acid. Their use in baking depends upon these facts. They neutralize any acid (lactic or acetic) that is formed during the " rising" of the dough, and assist to make the bread " light" by inflating it with carbonic dioxide.

Calcium Carbonate, $CaCO_3$, 112.—This compound, commonly called Carbonate of Lime, is the white powder formed by the contact of carbonic dioxide with lime-water. When slaked lime is exposed to the air, the water it contains is gradually displaced by carbonic dioxide, and calcium carbonate is the result. Air-slaked lime always contains much carbonate. This salt is distinguished from calcium hydrate by its being destitute of any alkaline taste.

In nature, calcium carbonate exists to an immense extent as coral, chalk, marble, and limestone. These rocks, when strongly heated, especially in a current of air, part with carbonic dioxide, and quicklime remains behind.

Calcium carbonate occurs in plant-ashes.

Calcium carbonate occurs largely in the ashes of most plants, particularly of trees. In the manufacture of potash it remains undissolved, and constitutes a chief part of the residual *leached ashes.*

The calcium carbonate found in the ashes of plants is supposed to come mainly from the decomposition by heat of organic salts of calcium (oxalate, tartrate, malate, &c.), which exist in the juices of the vegetable, or are abundantly deposited in its tissues in the solid form. Calcium carbonate itself is, however, not an unusual component of vegetation, being found in the form of minute, rhombic crystals, in the cells of a multitude of plants.

THE SULPHATES which we shall notice at length are those of Potassium, Sodium, and Calcium. Magnesium Sulphate is well known as Epsom salts, and Ferrous Sulphate is copperas or green vitriol. Lithium Sulphate is very similar to potassium sulphate.

Potassium Sulphate, K_2SO_4, 174.—This salt may be procured by dissolving potash or potassium carbonate in diluted sulphuric acid. On evaporating its solution, it is obtained in the form of hard, brilliant crystals, or as a white powder. It has a bitter taste. Ordinary potash, or pearl-ash, contains several per cents. of this salt.

Sodium Sulphate, Na_2SO_4, 142.—*Glauber's salt* is the common name of this familiar substance. It has a bitter taste, and is much employed as a purgative for cattle and horses. It exists, either crystallized and transparent, containing 10 molecules, or nearly 56 per cent. of water, or anhydrous. The crystals rapidly lose their water when exposed to the air, and yield the anhydrous salt as a white powder.

Calcium Sulphate, $CaSO_4$, 136.—The burnt *Plaster of Paris* of commerce is this salt in a more or less pure state. It is readily formed by pouring diluted sulphuric acid on lime or marble. It is found in the ash of most plants, especially in that of clover, the bean, and other legumes.

Crystals of calcium sulphate occur in some plants.

In nature, calcium sulphate, or Sulphate of Lime, is usually combined with two molecules of water, and thus constitutes *Gypsum*, $CaSO_4\ 2H_2O$, which is a rock of frequent and extensive occurrence. In the cells of many plants, as for instance the bean, gypsum may be discovered by the microscope in the shape of minute crystals. It requires 450 times its weight of water to dissolve it, and being almost universally distributed in the soil, is rarely absent from the water of wells and springs.

THE PHOSPHATES which require special description are those of Potassium, Sodium, and Calcium.

There exists, or may be prepared artificially, numerous phosphates of each of these bases. The chemist is acquainted with no less than *thirteen* different phosphates of sodium. But three classes of phosphates have any immediate interest to the agriculturist. As has been stated (p. 104), the hydrated phosphoric acid, prepared by boiling anhydrous phosphoric acid with water, is represented by the formula H_3PO_4. The phosphates may be regarded as phosphoric acid in which one, two, or all the atoms of hydrogen are substituted by an equivalent number of atoms of one or of several metals. We may illustrate this statement with the three phosphates of calcium, giving in one view their mode of derivation, their symbols, and the names which we shall employ in this treatise.

(*a.*) $2H_3PO_4$ and CaO give H_2O and CaH_42PO_4, the monocalcic phosphate, or *acid phosphate of lime.*

(*b.*) $2H_3PO_4$ and $2CaO$ give $2H_2O$ and $Ca_2H_22PO_4$, the dicalcic phosphate.

(*c.*) $3H_3PO_4$ and $3CaO$ give $3H_2O$ and Ca_32PO_4, the tricalcic phosphate, or *bone-earth.*

Potassium Phosphates.—Of these salts, the neutral and subphosphates exist largely (to the extent of 40 to 50 per cent.) in the ash of the seeds of wheat, rye, maize, and other bread grains. None of these phosphates occur in commerce; they closely resemble the corresponding soda-salts in their external characters.

Sodium Phosphates.—Of these the *disodic phosphate*, $Na_2H\,PO_4$, 12 aq.,* alone needs notice. It is found in the druggists' shops in the form of glassy crystals, which contain 56 per cent. of water. The crystals become opaque if exposed to the air, from the loss of water. This salt has a cooling, saline taste, and is very soluble in water.

There are three important calcium phosphates.

Calcium Phosphates.—Both the dicalcic and the tricalcic phosphates probably occur in plants. The *dicalcic* salt, $Ca_2H_22PO_4$, 2 aq., is a white crystalline powder, sparingly soluble in water, but easily soluble in acids. In nature it is found as a urinary concretion in the sturgeon of the Caspian Sea. It has been stated to be an ingredient of guanos, and of animal excrements in general.

The *tricalcic phosphate*, or, as it is sometimes termed, the *bone-phosphate*, $Ca_3\,2\,PO_4$, or $3\,CaO, P_2O_5$, is a chief ingredient of the bones of animals, and constitutes 90 to 93 per cent. of the ash or earth of bones. It may be formed by adding a solution of calcium chloride to one of trisodic phosphate, and appears as a white precipitate. It requires 100,000 parts of pure water for solution, but dissolves

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* The water which is found in crystallized salts, and which usually may be expelled at a gentle heat, is termed *water of crystallization*, and is often designated by aq. (from the Latin *aqua*) to distinguish it from *basic water*, which is more intimately combined.

in acids and in solutions of many salts. In the mineral kingdom tricalcic phosphate is the chief ingredient of *apatite* and its varieties *osteolite*, *phosphorite*, &c. These minerals are employed in the preparation of the so-called *superphosphate of lime*, which is consumed to an enormous extent as a turnip-manure. The superphosphate of commerce, when genuine, is essentially a mixture of calcium sulphate, the sulphate of lime, with the three phosphates above noticed, of which the monocalcic phosphate should predominate.

The Phosphates of Magnesium, Aluminium, Iron, and Manganese, are bodies mostly insoluble in water: they often occur in soils and manures.

The Chlorides are all characterised by their ready solubility in water. The chlorides of Lithium, Calcium, and Magnesium are *deliquescent*, i.e. they liquefy by absorbing moisture from the air. The chlorides of Potassium and Sodium alone need to be described.

Potassium Chloride, KCl, 74·5.—This body may be produced either by exposing metallic potassium to chlorine gas, in which case the two elements unite together directly, or by dissolving caustic potash in hydrochloric acid. In the latter case water is also formed, as is expressed by the equation $KHO + HCl = H_2O + KCl$.

Chloride of Potassium closely resembles common salt (sodium chloride) in appearance, solubility in water, taste, &c. It is but rarely an article of commerce, but is present in the ash and in the juices of plants, especially of seaweeds, and is likewise found in all fertile soils.

Common salt, sodium chloride, is of frequent occurrence in plants.

Sodium Chloride, $NaCl$, 58·5.—This substance is common or culinary salt. It was formerly termed *muriate of soda*. It is scarcely necessary to speak of its occurrence in immense quantities in the water of the ocean, in saline springs, and in the solid form, as rock-salt, in the earth. Its properties are so familiar as to require no description. It is rarely absent from the ash of plants.

Besides the salts and compounds just described, there occur in the living plant other substances, most of which have been indeed already alluded to, but may be noticed again in order in this place.

These compounds, being destructible by heat, do not appear in the analysis of the ash of a plant.

Nitrates occur in plants.

NITRATES: *Nitric acid*—the compound by which nitrogen is chiefly, perhaps wholly, furnished to plants for the elaboration of the albuminoid principles—is not unfrequently present as a *nitrate* in the tissues of the plant. It usually occurs there as potassium nitrate (nitre, saltpetre).

The properties of this salt scarcely need description. It is a white, crystalline body, readily soluble in water, and has a cooling, saline taste. When heated with carbonaceous matters, it yields oxygen to them, and a *deflagration*, or rapid and explosive combustion, results. *Touch-paper* is paper soaked in solution of nitre, and dried. The leaves of the sugar-beet, sunflower, tobacco, and some other plants, have been found to contain this salt. When such vegetables are burned, the nitric acid is decomposed, often with slight deflagration, or glowing like touch-paper, and the alkali remains in the ash as carbonate. The characters of nitric acid and the nitrates may be studied at length in Roscoe's "Chemistry."

Many organic salts are found in plants.

OXALATES, ACETATES, CITRATES, MALATES, TARTRATES, and salts of other less common organic acids, are generally to be found in the tissues of living plants. On burning, the metals with which they were in combination—potassium and calcium in most cases—remain as carbonates.

SALTS OF AMMONIA exist in minute amount in some plants. What particular salts thus occur is uncertain, and their quantity is so slight as to render any special notice of them unnecessary in this chapter.

Since it is possible for each of the acids above described to unite with each of the bases in one or several proportions, and since we have as many oxides and chlorides

The saline compounds in plants not always exactly known.

as there are metals, and even more, the question at once arises—which of the 60 or more compounds that may thus be formed outside the plant do actually exist within it? In answer, we must remark that all of them may exist in the plant. Of these, however, but few have been proved to exist as such in the vegetable organism. As to the state in which iron and manganese occur, we know little or nothing, and we cannot often assert positively that in a given plant potassium exists as phosphate, or sulphate, or carbonate. In the ash of wheat, we judge indeed from the predominance of potash and phosphoric acid that phosphate of potassium is a large constituent of the grain, but of this we are not sure, though in the absence of evidence to the contrary we are warranted in assuming these two ingredients to be united. But calcium carbonate and sulphate have been discovered by the microscope in the cells of various plants, in crystals whose characters are unmistakeable.

For most purposes it is unnecessary to know more than that certain *elements* are present, without paying attention to their mode of combination. And yet there is a choice in the manner of representing the composition of a plant as regards its ash-ingredients.

The paragraphs that follow are devoted to a more particular statement of the *mode of occurrence*, *relative abundance*, *special function*, and *indispensability* of the fixed ingredients of plants.

§ 2. QUANTITY, DISTRIBUTION, AND VARIATIONS OF THE ASH-INGREDIENTS.

The ash constituents of plants may be studied from several points of view.

The ash of plants consists of the various fixed oxides and salts, noticed in § 1.

The ash-ingredients are usually present in each cell of every plant.

The ash-ingredients exist partly in the cell-wall, incrusting or imbedded in the cellulose, and partly in the plasma or contents of the cell.

Chap. II.

One portion of the ash-ingredients is soluble in water, and occurs in the juice or sap. This is true, in general, of the salts of the alkaline-metals, and of the sulphates and chlorides of magnesium and calcium. Another portion is insoluble, and exists in the tissues of the plant in the solid form. Silica, the phosphates of calcium, and the magnesium compounds are mostly insoluble.

The ash-ingredients may be separated from the volatile matter by burning or by any process of oxidation. In burning, portions of sulphur, chlorine, alkaline metals, and phosphorus, may be lost under certain circumstances, by volatilization. The ash remains as a skeleton of the plant, and often actually retains and exhibits the microscopic form of the tissues.

The same plant may vary as to its percentage of ash.

The proportion of Ash is not invariable, even in the same kind of plant, and in the same part of the plant. Different kinds of plants often exhibit very marked differences in the quantity of ash they contain. The following table exhibits the amount of ash in 100 parts (of *dry matter*) of a number of plants and trees, and in their several parts. In all cases is given the *average* proportion, as deduced from a large number of the most trustworthy examinations. In some instances are cited the extreme proportions hitherto put on record.

Different plants have different proportions of ash.

PROPORTIONS OF ASH IN VARIOUS VEGETABLE MATTERS.

ENTIRE PLANTS, ROOTS EXCEPTED.

	Average.		Average.
Red clover	6·7	Turnips, 10·7—19·7	15·5
White clover	7·2	Carrot, 15·0—21·3	17·1
Timothy	7·1	Hops	9·9
Potatoes	5·1	Hemp	4·6
Sugar beet, 16·3—18·6	17·5	Flax	4·3
Field beet, 14·0—21·8	18·2	Heath	4·5

ROOTS AND TUBERS.

Potato, 2·6—8·0	4·1	Turnip, 6·0—20·9	12·0
Sugar beet, 2·9—6·0	4·4	Carrot, 5·1—10·9	8·2
Field beet, 2·8—11·3	7·7	Artichoke	5·2

Different parts of the same plant have different proportions of ash.

STRAW AND STEMS.

	Average.		Average.
Wheat, 3·8—6·9	5·4	Peas, 6·5—9·4	7·9
Rye, 4·9—5·6	5·3	Beans, 5·1—7·2	6·1
Oats, 5·0—5·4	5·3	Flax	3·7
Barley	6·8	Maize	5·5

GRAINS AND SEED.

Wheat, 1·5—3·1	2·0	Buckwheat, 1·1—2·1	1·4
Rye, 1·6—2·7	2·0	Peas, 2·4—2·9	2·7
Oats, 2·5—4·0	3·3	Beans, 2·7—4·3	3·7
Barley, 1·8—2·8	2·3	Flax	3·6
Maize, 1·3—2·1	1·5	Sorghum	1·9

WOOD.

Beech	1·0	Red Pine	0·3
Birch	0·3	White Pine	0·3
Grape	2·7	Fir	0·3
Apple	1·3	Larch	0·3

BARK.

Birch	1·3	Fir	2·0
Red Pine	2·8	Walnut	6·4
White Pine	3·3	Cherry	10·4

From the above table we gather:—

1. That *different plants* yield different quantities of ash. It is abundant in succulent foliage, like that of the beet (18 per cent.), and small in seeds, wood, and bark.

2. That *different parts of the same plant* yield unlike proportions of ash. Thus the wheat grain contains 2 per cent. while the straw yields 5·4 per cent. The ash in sugar-beet tops is 17·5, in the roots 4·4 per cent. In the ripe oat, Arendt found (*Das Wachsthum der Haferpflanze*, p. 84):

In the three lower joints of the stem	4·6	per cent. of ash.
In the two middle joints of the stem	5·3	,, ,,
In the one upper joint of the stem	6·4	,, ,,
In the three lower leaves	10·1	,, ,,
In the two upper leaves	10·5	,, ,,
In the ear	2·6	,, ,,

3. We further find that, *in general, the upper and outer parts* of the plant contain the most mineral matters. In

the oat, as we see from the above figures of Arendt, the ash increases from the lower portions to the upper, until we reach the ear. If, however, the ear be dissected, we shall find that its outer parts are richest in ash. Norton found :

In the husked grain of brown oats . .	2·1 per cent. of ash.	
In the husk of brown oats	8·2 ,,	,,
In the chaff of brown oats	19·1 ,,	,,

Norton also found that the top of the oat-leaf gave 16·22 per cent. of ash, while the bottom yielded but 13·66 per cent. (*Amer. Jour. Science*, 1847).

From the table it is seen that wood (0·3 to 2·7 per cent.) and seed (1·5 to 3·7 per cent.), the lower or inner parts of the plant are poorest in ash. The stems of herbaceous plants (3·7 to 7·9 per cent.) are next richer, while the leaves of herbaceous plants, which have such an extent of surface, are the richest of all (6 to 8 per cent.).

The stage of growth influences the proportion of ash.

4. Investigation has demonstrated further that the *same plant in different stages of growth* varies in the proportions of ash in dry matter, yielded both by the entire plant and by the several organs or parts.

The following results, obtained by Norton, on the oat, illustrate this variation. Norton examined the various parts of the oat-plant at intervals of one week throughout its entire period of growth. He found:

	Leaves.	Stem.	Knots.	Chaff.	Grain unhusked.
June 4 . .	10·8	10·4	—	--	—
,, 11 . .	10·7	9·8	—	—	—
,, 18 . .	9·0	9·3	—	—	—
,, 25 . .	10·9	9·1	—	—	—
July 2 . .	11·3	7·8	—	—	4·9
,, 9 . .	12·2	7·8	—	—	4·3
,, 16 . .	12·6	7·9	—	6·0	3·3
,, 23 . .	16·4	7·9	10·9	9·1	3·6
,, 30 . .	16·4	7·4	9·6	12·2	4·2
Aug. 6 . .	16·0	7·6	10·4	13·7	4·3
,, 13 . .	20·4	6·6	10·4	18·6	4·0
,, 20 . .	21·1	6·6	11·7	21·9	3·6
,, 27 . .	22·1	7·7	11·2	22·4	3·5
Sept. 3 . .	20·9	8·3	10·7	27·4	3·6

Experiments on the ash of the oat.

Here, in the case of leaves and chaff, we observe a constant increase of ash, while in the stem there is a constant decrease, except at the time of ripening, when these relations are reversed. The knots of the stem preserved a pretty uniform ash-content. The unhusked grain at first suffered a diminution, then an increase, and lastly a decrease again.

Arendt found in the oat-plant fluctuations, not in all respects accordant with those observed by Norton. Arendt obtained the following proportions of ash :—

	3 lower joints of Stem.	2 middle joints of Stem.	Upper joint of Stem.	Lower Leaves.	Upper Leaves.	Ears.	Entire plant.
June 18 .	4·4	—	—	9·7	7·7	—	8·0
„ 30 .	2·5	2·9	3·5	9·4	7·0	3·8	5·2
July 10 .	3·5	4·7	5·2	10·2	6·9	3·6	5·4
„ 21 .	4·4	5·0	5·5	10·1	9·7	2·8	5·2
„ 31 .	6·4	5·3	6·4	10·1	10·5	2·6	5·1

Here we see that the ash increased in the stem and in each of its several parts after the first examination. The lower leaves exhibited an increase of fixed matters after the first period, while in the upper leaves the ash diminished toward the third period, and thereafter increased. In the ears, and in the entire plant, the ash decreased quite regularly as the plant grew older. Pierre found that the proportion of ash of the colza (*Brassica oleracea*) diminished in all parts of the plant (which was examined at five periods) except in the leaves, in which it increased (*Jahresbericht über Agriculturchemie*, iii. p. 122). The sugar beet (Bretschneider) and potato (Wolff) exhibit a decrease of the percentage of ash, both in tops and roots.

Experiments on the ash of the turnip.

In the turnip, examined at four periods, Anderson (*Trans. High. and Ag. Soc.* 1859–61, p. 371) found the following per cent. of ash in dry matter :—

	July 7.	Aug. 11.	Sept. 1.	Oct. 5.
Leaves	7·8	20·6	18·8	16·2
Bulbs	17·7	8·7	10·2	20·9

In this case, the ash of the leaves increased during about half the period of growth from 7·8 to 20·6, and thence diminished to 16·2. The ash of the bulbs fluctuated in the reverse manner, falling from 17·7 to 8·7, then rising again to 20·9.

In general, the proportion of ash of the entire plant diminishes regularly as the plant grows old.

Soil influences the percentage of ash.

5. The influence of the *soil* in causing the proportion of ash of the same kind of plant to vary is shown in the following results, obtained by Wunder (*Versuchs-Stationen*, iv. p. 266) on turnip bulbs, raised during two successive years, in different soils.

	In Sandy Soil.		In Loamy Soil.	
	1st year.	2d year.	1st year.	2d year.
Per cent. of ash .	13·9	11·3	9·1	10·9

Varieties of the same species show differences in ash percentage.

6. As might be anticipated, *different varieties* of the same plant, grown on the same soil, take up different quantities of non-volatile matters.

In five varieties of potatoes, cultivated in the same soil and under the same conditions, Herapath (*Quar. Journ. Chem. Soc.* ii. p. 20) found the percentages of ash in dry matter of the tuber as follow:

Variety of Potato.	White Apple.	Prince's Beauty.	Axbridge Kidney.	Magpie.	Fortyfold.
Ash per cent..	4·8	3·6	4·3	3·4	3·9

Different individuals show different ash percentage.

7. It has been observed further that *different individuals of the same variety of plant*, growing side by side, on the same soil (in the same field at least), contain different proportions of ash-ingredients, according as they are, on the one hand, *healthy, vigorous plants*, or, on the other, *weak and stunted.* Pierre (*Jahresbericht über Agriculturchemie*, iii. p. 125) found in entire colza plants of various degrees of vigour the following percentages of ash in dry matter:—

In extremely feeble plants, 1856 . .	8·0	per cent. of ash.
In very feeble plants, 1857	9·0	,, ,,
In feeble plants, 1857	11·4	,, ,,
In strong plants, 1857	11·0	,, ,,
In extremely strong plants, 1857 . .	14·3	,, ,,

Pierre attributes the larger per cent. of ash in the strong plants to the relatively greater quantity of leaves developed on them.

Similar results were obtained by Arendt in case of oats. Wunder (*Versuchs-St.* iv. p. 115) found that the leaves of small turnip plants yielded somewhat more ash per cent. than large plants. The former gave 19·7, the latter 16·8 per cent.

8. The reader is prepared from several of the foregoing statements to understand partially the *cause of the variations* in the proportion of ash in different specimens of the same kind of plant.

Variations ash-per centage explained.

The fact that different parts of the plant are unlike in their composition, the upper and outer portions being, in general, the richer in ash-ingredients, may explain in some degree why different observers have obtained different analytical results.

It is well known that very many circumstances influence the relative development of the organs of a plant. In a dry season, plants remain stunted, are rougher on the surface, have more and harsher hairs and prickles, if these belong to them at all, and develop fruit earlier than otherwise. In moist weather, and under the influence of rich manures, plants are more succulent, and the stems and foliage, or vegetative parts, grow at the expense of the reproductive organs. Again, different varieties of the same plant, which are often quite unlike in their style of development, are of necessity classed together in our table; and under the same head are also brought together plants gathered at different stages of growth.

In order that the wheat plant, for example, should always have the same percentage of ash, it would be necessary that it should always attain the same relative development in each individual part. It must then always grow under the same conditions of temperature, light, moisture, and soil. This is, however, as good as impossible; and if we admit the wheat plant to vary in form within certain limits without losing its proper characteristics, we must admit corresponding variations in composition.

The difference between the Tuscan wheat, which is cultivated exclusively for its straw, of which the Leghorn hats are made, and the "pedigree wheat" of Mr. Hallett (*Journ. Roy. Agr. Soc. of Eng.* vol. xxii. p. 374), is in some respects as great as between two entirely different plants. The hat wheat has a short, loose, bearded ear, containing not more than a dozen small grains, while the pedigree wheat has shown beardless ears of 8¾ inches in length, closely packed with large grains to the number of 120!

Now, the hat wheat, if cultivated and propagated in the same careful manner as has been done with the pedigree wheat, might in time become as prolific of grain as the atter, while the pedigree wheat might perhaps with greater ease be made more valuable for its straw than its grain.

We easily see then, that, as circumstances are perpetually making new varieties, so analysis continually finds diversities of composition.

Seeds do not vary so much in ash-percentage as leaves and stems.

9. *Of all the parts of plants the seeds are the least liable to vary in composition, so far as ash is concerned.* Two varieties or two individuals may differ enormously in their relative proportions of foliage, stem, chaff, and seed; but the seeds themselves do not very widely differ. Thus, in the analyses of 67 specimens of the wheat grain, collated by the author, the extreme percentages of ash were 1·35 and 3·13. In 60 specimens out of the 67 the range of variation fell between 1·4 and 2·3 per cent. In 42 the range was from 1·7 to 2·1 per cent.; while the average of the whole was 2·1 per cent.

In the *stems* or *straw* of the grains, the variation is more considerable. Wheat straw ranges from 3·8 to 6·9; pea straw, from 6·5 to 9·4 per cent. In *fleshy roots* the variations are great; thus turnips give, when dried, 6 to 21 per cent. The extremest variations in ash-content are, however, found, in general, in the succulent *foliage*. Turnip tops range from 10·7 to 19·7 ; potato tops vary from 11 to near 20, and tobacco from 19 to 27 per cent.

Average ash-percentage in the different parts of plants.

Wolff (*Die naturgesetzlichen Grundlagen des Ackerbaues*, 3 *Aufl.*, p. 117) has deduced from a large number of analyses the following average ash-percentages for three important classes of agricultural plants, viz. :—

	Grain.	Straw.
Cereal crops	2	5·25 per cent.
Leguminous crops . . .	3	5 ,,
Oil-plants	4	4·5 ,,

More general averages are as follow (Wolff, *loc. cit.*) :—

Annual and Biennial Plants.		Perennial Plants.	
Seeds	3 per cent.	Seeds	3 per cent.
Stems . . .	5 ,,	Wood	1 ,,
Roots . . .	4 ,,	Bark	7 ,,
Leaves . . .	15 ,,	Leaves . . .	10 ,,

We may conclude this section by stating three propositions which are proved in part by the facts that have been already presented, and which are a summing up of the most important points in our knowledge of this subject.

Ash-ingredients are necessary for vegetable increase.

I. *Ash-ingredients are indispensable to the life and growth of all plants.* In mould, yeast, and other plants of the simplest kind, as well as in those of the higher orders, analysis never fails to recognise a proportion of fixed matters. We must hence conclude that these are necessary to the primary actions of vegetation, that atmospheric food cannot be assimilated, that vegetable matter cannot be organized, except with the co-operation of those substances which are found in the ashes of the plant. This proposition is demonstrated further in the most conclusive manner by numerous synthetic experiments. It is, of course, impossible to attempt producing a plant at all without some ash-ingredients, for the latter are present in all seeds, and during germination are transferred to the seedling. By causing seeds to sprout in a totally insoluble medium, we can observe what happens when the limited supply of fixed matters in the seeds themselves is exhausted. Wiegmann and Polstorf (*Preisschrift über die unorganischen Bestandtheile der Pflanzen*) planted 30 seeds of cress in fine platinum wire contained in a platinum vessel. The contents of the vessel were moistened with distilled water, and the whole was placed under a glass shade, which served to shield from dust. Through an aperture in the shade connexion was made with a gasometer, by which the atmosphere in the interior could be renewed with an artificial mixture, consisting, in 100, of 21 parts oxygen, 78 parts nitrogen, and 1 part carbonic acid. In two days 28 of the seeds germinated; afterwards they developed leaves, and grew slowly with a healthy appearance during twenty-six days, reaching a height of two to three inches. From this time on, they refused to grow, began to turn yellow, and died down. The plants were collected, and burned: the ash from them weighed precisely as much as that obtained by burning 28 seeds like those originally sown. Numerous experiments of this kind have shown that a plant cannot grow in the absence of those substances found in its ash. The development of the cresses ceased as soon as the fixed matters of the seed had served their utmost in assisting the organization of new cells. We know from other experiments that, had the ashes of cress been applied to the plants in the above experiment, just as they exhibited signs of unhealthiness, they would have recovered, and developed to a much greater extent.

Plants cannot attain maturity without ash-ingredients.

II. *The proportion of ash-ingredients in the plant is variable within a narrow range, but cannot fall below or exceed certain limits.* The evidence of this proposition is to be gathered both from the table of ash-percentages, and from experiments like that of Wiegmann and Polstorf above described.

Ash-percentages have a limited range of variation.

III. *We have reason to believe that each part or organ (each cell) of the plant contains a certain, nearly invariable*

Part of the ash is essential: part may be accidental.

amount of fixed matters, which is indispensable to the vegetative functions. Each part or organ may contain, besides, a variable and unessential or accidental quantity of the same. What portion of the ash of any plant is essential and what accidental is a question not yet brought to a satisfactory decision. By assuming the truth of this proposition, we account for those variations in the amount of ash which cannot be attributed to the causes already noticed. The evidences of this statement must be reserved for the subsequent section.

§ 3. Special Compositon of the Ash of Agricultural Plants.

The results of the extended inquiries which have been recently made into the subject of this section may be conveniently presented and discussed under a series of propositions, viz. :—

The ash of agricultural plants contains ten constituents.

1. Among the substances which have been described (§ 1) as the ingredients of the ash, *the following are invariably present in all agricultural plants, and in nearly all parts of them*, viz. :

Basic Constituents.	Acid Constituents.
Potash, K_2O,	Chlorine, Cl,
Soda, Na_2O,	Sulphuric trioxide, SO_3,
Lime, CaO,	Phosphoric pentoxide, P_2O_5,
Magnesia, MgO,	Silicic dioxide, SiO_2,
Ferric oxide, Fe_2O_3.	Carbonic dioxide, CO_2.

We give the elements of agricultural plants in those forms of combination in which they appear in the analyses; not necessarily the forms in which they may be presumed to exist in the living plant.

Normal plants do not differ much in ash-percentage.

2. *Different normal specimens of the same kind of plant have a nearly constant composition.* The use of the word *nearly* in the above statement implies what has been already intimated, viz. that some variation is noticed in the relative proportions, as well as in the total quantity, of ash-

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ingredients occurring in plants. This point will shortly be discussed in full. By taking the average of many trustworthy ash-analyses, we arrive at a result which does not differ very widely from the majority of the individual analyses. This is specially true of the seeds of plants, which attain nearly the same development under all ordinary circumstances. It is less true of foliage, stems, and fleshy roots, whose dimensions and character vary to a great extent. In the following table is stated the composition of the ashes of a number of agricultural products, which have been repeatedly subjected to analysis. In most cases, instead of quoting all the individual analyses, a series of averages is given. Of these, the first is the mean of all the analyses on record or obtainable by the writer, while the subsequent ones represent either the results obtained in the examination of a number of samples by one analyst, or are the mean of a number of single analyses. In this way, it is believed, the real variations of composition are pretty truly exhibited, independently of the errors of analysis.

The limits of variation in ash-percentage are shown in the analyses that follow.

The lowest and highest percentages are likewise given. These are doubtless in many cases exaggerated by errors of analysis, or by impurity of the material analysed. Chlorine and sulphuric acid are for the most part too low, because they are liable to be dissipated in combustion, while silica is often too high, from the fact of sand and soil adhering to the plant.

In two cases, single and perhaps incorrect analyses by Bichon, which give exceptionally large quantities of soda, are cited separately.

A number of analyses that came to notice after making out the averages are given as additional.

The following table includes both the grain and straw of Wheat, Rye, Barley, Oats, Maize, Rice, Buckwheat, Beans, and Peas; the tubers of Potatoes; the roots and tops of Sugar Beets, Field Beets, Carrots, Turnips, and various parts of the Cotton Plant.

Fuller details as to ash-percentages are given in the Appendix.

For the average composition of other plants and vegetable products, the reader is referred to a table in the Appendix, compiled by Professor Wolff, of the Royal Agricultural Academy of Würtemburg. That table includes also the averages obtained by Professor Wolff for most of the substances, cotton excepted, whose composition is represented in the pages immediately following. Any discrepancies between Professor Wolff's and the author's figures are for the most part due to the use of fewer analyses by the former.

In both tables the *carbonic dioxide* (*anhydride* or *acid*) which occurs in most ashes, is excluded, from the fact that its quantity varies according to the temperature at which the ash is prepared.

For brevity we shall employ henceforth the *formulæ* of the ash constituents instead of their *names*.

COMPOSITION OF THE ASH OF SOME AGRICULTURAL PLANTS AND PRODUCTS,

Arranged to exhibit the Extent of Variations.

Pr.Ct. of Ash.	K_2O.	Na_2O.	MgO.	CaO.	Fe_2O_3	P_2O_5.	SO_3.	SiO_2.	Cl.	
WHEAT GRAIN.										
...	31·3	3·2	12·3	3·2	...	46·1	...	1·9	...	Average of 79 Analyses.
2·3	30·0	9·0	10·9	2·2	...	48·1	0·1	0·1	0·5	,, 5 ,, by J. Herapath.
1·9	31·4	3·2	12·3	3·5	0·8	45·0	0·5	3·0	0·4	,, 26 ,, ,, Way and Ogston.
2·4	28·0	2·7	11·5	2·4	0·6	50·0	2·2	2·0	0·7	,, 9 ,, ,, Zoeller.
2·0	33·7	2·6	12·7	3·3	...	44·5	...	0·8	...	,, 30 ,, ,, Bibra.
...	27·3	4·3	12·2	3·0	0·7	50·0	0·1	1·6	0·7	,, 9 ,, ,, others.*
1·6	20·0	0·0	6·3	0·9	0·0	34·4	0·0	0·0	0·0	Lowest per cent. in 79 Analyses.
3·1	38·4	15·9	16·3	8·2	3·3	60·4	2·4	7·6	6·1	Highest ,, 79 ,,
2·6	6·4	27·8	12·9	3·9	0·5	46·1	0·3	0·4	...	Old Analysis by Bichon, not included above.
2·5	30·6	2·5	10·0	4·1	1·1	47·4	1·2	5·6	0·7	Recent Analysis by Anderson, not included above.
RYE GRAIN.										
2·0	28·8	4·3	11·6	3·9	...	45·6	...	2·6	...	Average of 21 Analyses.
2·0	29·1	0·3	11·5	3·0	0·9	48·6	2·5	1·5	1·1	,, 8 ,, by Zoeller.
2·1	33·5	2·1	12·2	2·1	...	45·6	...	1·5	...	,, 5 ,, ,, Bibra.
1·9	25·4	8·2	11·3	5·9	1·2	42·2	0·7	4·5	0·5	,, 8 ,, ,, others.†
1·6	9·4	0·0	10·1	1·3	0·5	25·1	0·5	0·6	0·0	Lowest per cent. in 21 Analyses.
2·7	37·5	20·8	14·4	15·3	2·2	51·8	3·0	14·6	2·5	Highest ,, 21 ,,
BARLEY GRAIN WITH HUSK.										
...	21·2	3·5	8·2	2·3	...	32·8	2·0	28·4	...	Average of 43 Analyses.
2·1	26·7	2·1	8·4	2·4	0·8	32·1	1·0	25·3	1·3	,, 13 ,, by Way and Ogston.
2·9	18·5	3·9	7·0	2·7	0·7	32·4	2·8	31·1	1·1	,, 14 ,, ,, Zoeller.
2·2	18·4	2·8	11·7	2·3	...	35·9	3·3	24·6	...	,, 6 ,, ,, Bibra.
2·5	22·3	3·7	8·2	3·8	1·2	28·3	1·9	31·1	...	,, 5 ,, ,, John.
2·5	17·0	7·0	6·8	2·6	1·1	36·4	0·8	30·6	0·9	,, 5 ,, ,, others.‡
1·8	13·8	0·6	4·3	0·7	0·1	26·0	0·2	22·1	0·2	Lowest per cent. in 43 Analyses.
2·8	31·6	8·9	14·7	4·2	2·4	39·8	4·0	36·7	5·2	Highest ,, 43 ,,
2·4	3·9	16·8	10·1	3·4	1·9	40·6	0·3	22·0	...	Old Analysis by Bichon.
2·5	17·0	5·9	7·2	2·7	0·5	30·3	1·4	33·1	0·2	Recent additional Analysis by Veltman.
2·5	17·0	6·3	6·8	3·1	0·5	lost	1·5	33·7	0·3	,, ,, ,, Moesman.

OAT GRAIN, WITH HUSK.

...	15·6	2·5	7·2	3·7	0·5	21·3	1·5	46·4	0·4	Average of 21 Analyses.
3·2	16·6	2·6	7·0	3·8	0·5	22·6	1·6	44·9	0·6	,, 11 ,, by Way and Ogston.
3·4	14·5	2·6	7·5	3·6	0·8	19·8	1·6	48·0	0·8	,, 10 ,, ,, others.§
2·5	9·8	0·3	4·9	1·3	0·1	9·7	0·1	38·0	0·0	Lowest per cent. in 21 Analyses.
4·0	24·3	8·2	9·7	8·4	2·1	32·3	4·0	56·5	1·6	Highest ,, 21 ,,

MAIZE GRAIN.

...	27·8	3·9	15·0	2·5	0·8	46·8	1·5	1·6	...	Average of 8 Analyses.
1·5	28·4	1·7	13·6	0·6	0·5	53·7	...	1·6	...	Way and Ogston.
...	26·6	7·5	15·4	1·6	0·6	36·6	5·5	2·1	...	Fromberg.
...	30·8	0·0	17·0	1·3	...	50·1	...	0·8	...	Letellier.
2·1	26·0	13·2	13·3	1·2	0·9	44·6	...	3·9	0·2	W. H. Brewer.
...	28·8	3·5	14·9	6·3	undet.	45·0	undet.	undet.	undet.	Stepf.‖
1·3	24·3	1·5	16·0	3·2	1·9	49·4	1·0	2·8	trace	Bibra.
1·3	26·7	3·9	15·2	2·6	2·0	47·5	1·2	1·9	trace	,,
...	30·7	...	14·7	3·1	0·8	44·5	4·1	1·8	0·5	Campbell.
1·7	23·7	0·0	11·3	?	1·4	35·0	?	?	3·6	Lowest per cent. in 3 Analyses by Sachse, Schrieber, and Lehmann.¶
1·9	29·6	0·0	16·0	?	9·6	40·4	?	?	4·5	Highest ,, ,, ,, ,, ,, ,,
1·3	23·7	0·0	11·3	0·6	0·5	35·0	0·0	0·8	0·0	Lowest per cent. in 11 Analyses.
2·1	30·8	13·2	17·0	6·3	9·6	53·7	5·5	3·9	4·5	Highest ,, 11 ,,

RICE GRAIN WITHOUT HUSK.

0·5	21·7	5·5	11·2	3·2	...	53·7	...	2·7	...	Average of 5 Analyses.
1·0	18·5	10·7	11·7	1·3	0·5	53·4	...	3·4	0·3	Johnston.
0·4	20·2	2·5	4·2	7·2	2·0	62·3	...	1·4	...	Zedeler.
0·3	22·2	6·3	12·4	5·9	?	46·3	1·3	3·4	0·5	Bibra.
0·2	22·3	4·0	14·3	1·1	?	54·0	0·6	3·0	trace	,,
0·7	25·4	4·1	13·4	0·8	?	52·6	trace	2·5	trace	,,
0·2	18·5	2·5	4·2	0·8	...	46·3	...	1·4	...	Lowest per cent. in 5 Analyses.
1·0	25·4	10·7	14·3	7·2	...	62·3	...	3·4	...	Highest ,, 5 ,,

* Viz. Schmidt, Thon, Will and Fresenius, Boussingault, Weber, Petzholdt, Baer, Fr. Schulze.

† Viz. Herapath, Way and Ogston, Fr. Schulze, Will and Fresenius, Bichon, Geradewohl, Schulz-Fleeth.

‡ Viz. John, Schmidt, Koechlin, Thomson.

§ Viz. Herapath, Boussingault, Porter, Fr. Schulze, Knop and Schnedermann, Bretschneider, Bibra.

‖ Maize meal.

¶ Detailed analyses not accessible.

COMPOSITION OF THE ASH OF SOME AGRICULTURAL PLANTS AND PRODUCTS, &c.—(*continued.*)

Pr. Ct. of Ash.	K_2O.	Na_2O.	MgO.	CaO.	Fe_2O_3	P_2O_5.	SO_3.	SiO_2.	Cl.	
										RICE GRAIN WITH HUSK.
8.2	17.5	5.6	10.7	4.0	...	40.6	...	...	...	Average of 2 Analyses.
9.1	17.7	5.2	10.3	1.0	?	41.4	0.4	trace	0.4	Bibra.
7.3	17.4	5.8	11.2	7.0	?	39.9	1.4	0.5	1.4	"
										BUCKWHEAT SEED.
2.1	8.7	20.1	10.4	6.7	1.1	50.1	2.2	0.7	...	Analysis by Bichon.
1.1	20.8	9.0	12.3	4.8	2.3	46.7	2.1	...	2.0	" Bibra.
1.1	25.4	3.2	14.5	1.8	1.9	49.2	2.1	...	1.9	" "
										PEAS.
...	40.9	3.1	7.6	5.4	0.8	35.3	4.3	0.8	1.4	Average of 31 Analyses.
...	42.3	0.9	8.0	4.8	1.0	37.6	2.7	0.6	1.8	" 14 " for Prussian Landes Oeconomie Collegium.
...	39.5	7.9	7.1	3.6	0.3	31.6	7.1	0.5	0.1	" 5 " by John.
2.7	42.4	1.5	6.7	6.6	0.6	34.0	5.7	1.4	1.7	" 7 " " Way and Ogston.
...	36.3	6.6	8.2	7.0	0.9	34.4	3.9	0.9	1.2	" 5 " " others.*
2.4	34.2	0.0	5.8	2.2	0.0	25.0	0.0	0.2	0.0	Lowest per cent. in 31 Analyses.
2.9	45.7	12.9	12.2	13.2	3.8	44.4	9.4	2.6	6.5	Highest " 31 "
										BEANS.
...	38.5	6.0	7.3	6.3	0.2	34.6	3.2	0.8	1.5	Average of 18 Analyses.
3.7	35.4	1.9	5.7	4.5	...	38.5	3.6	0.4	3.4	" 4 " by Ritter.
3.0	44.7	1.7	6.7	8.3	0.3	32.1	4.4	0.8	1.1	" 7 " " Way and Ogston.
4.3	34.0	12.6	8.9	5.4	0.3	34.9	1.7	0.9	0.8	" 7 " " others.†
2.7	20.8	0.0	5.1	3.1	0.0	27.1	1.3	0.0	0.0	Lowest per cent. of 18 Analyses.
4.3	53.6	22.8	12.0	13.4	1.0	41.2	6.4	2.5	6.0	Highest " 18 "
...	43.1	0.2	...	6.3	...	32.7	3.3	...	...	Recent Analyses by Henneberg and Stohmann, not included above.
										WHEAT STRAW AND CHAFF.
...	11.5	1.6	2.5	5.8	0.7	5.3	2.5	69.1	1.1	Average of 15 Analyses.
...	11.6	0.7	2.4	5.9	0.5	6.0	3.2	69.6	...	" 9 " by Way and Ogston.‡
5.4	11.3	3.0	2.6	5.6	0.9	4.2	1.4	68.4	2.8	" 6 " " others.§
3.8	1.3	0.0	0.0	2.7	0.1	2.2	0.7	60.6	0.0	Lowest per cent. in 15 Analyses.
6.9	16.7	7.8	.2	8.8	1.8	8.9	5.6	73.6	9.4	Highest " 15 "

RYE STRAW.

5·2	15·4	2·6	2·9	7·9	0·8	5·3	1·9	58·8	1·4	Average of 5 Analyses.‖
4·9	9·8	0·0	2·3	5·5	0·2	3·8	0·8	46·5	0·0	Lowest percentage in 5 Analyses.
6·3	30·8	6·3	3·4	9·6	1·9	7·4	2·5	65·2	3·2	Highest " 5 "
4·2	...	...	...	17·0	1·0	4·5	...	50·1	...	Recent incomplete Anal. by Henneberg & Stohmann, not included above.

BARLEY STRAW.

...	21·6	4·1	2·4	7·7	...	4·5	3·7	54·1	...	Average of 17 Analyses.
5·5	12·0	4·6	3·0	7·3	1·9	6·0	2·8	59·7	2·6	" 4 " by Zoeller.
4·9	15·4	3·5	2·6	9·0	0·8	4·1	2·6	59·8	2·6	" 5 " " Way and Ogston.
...	30·6	4·3	1·9	7·1	...	4·0	4·9	47·6	...	" 8 " " Wolff.
3·2	10·8	1·1	1·7	5·3	0·2	2·2	1·1	49·9	1·3	Lowest percentage in 9 Analyses, Wolff's excluded.
5·9	20·9	5·7	3·1	13·1	2·0	7·2	3·3	68·5	3·9	Highest " 9 " " "

OAT STRAW.

...	20·5	6·4	3·8	7·4	1·6	4·1	3·3	49·5	3·6	Average of 5 Analyses.
5·2	21·4	4·3	3·8	7·0	1·5	5·2	3·4	50·2	3·9	" 3 " by Way and Ogston.
...	19·2	9·7	3·8	8·1	1·8	2·6	3·2	48·4	3·3	" 2 " " Levi and Boussingault.
5·0	12·2	2·8	2·3	4·9	0·7	1·9	2·2	42·6	1·5	Lowest percentage in 5 Analyses.
5·4	26·1	14·7	5·5	8·8	2·7	7·3	4·4	54·3	7·0	Highest " 5 "
...	...	...	...	9·6	0·9	3·3	...	31·4	4·0	Recent Analysis by Henneberg & Stohmann, not included above.

MAIZE STALKS.

5·5	36·3	1·25	5·7	10·8	2·4	8·3	5·2	28·0	...	Way and Ogston.

BUCKWHEAT STRAW.

6·15	46·6	2·2	3·6	18·4	?	11·9	5·3	5·5	7·7	Average of 6 Analyses by Wolff.

PEA STRAW.

...	21·4	5·7	7·2	38·8	1·4	7·1	6·1	5·4	6·3	Average of 22 Analyses.
4·8	23·2	5·3	7·6	35·0	1·4	9·0	6·2	5·7	7·3	" 13 " for Prussian Landes Oec. Collegium.¶
7·9	20·7	5·3	8·6	49·5	1·8	4·1	5·3	5·3	3·3	" 6 " by Way and Ogston.
8·1	15·1	8·3	9·5	37·1	0·8	8·3	7·7	4·8	7·7	" 3 " " others.**
3·4	0·4	0·0	3·3	17·3	0·0	1·7	0·8	0·6	0·0	Lowest percentage in 22 Analyses.
1·3	36·5	24·1††	13·9	67·4	3·5	18·2	16·0	21·4	16·2	Highest " 22 "
...	24·1††	0·3	12·9	36·3	1·8	4·7	8·3	3·3	10·9	Analysis by Baer.††

* Viz. Will and Fresenius, Bichon, Thon, Boussingault, Baer.

† Viz. Herapath, Bichon, Boussingault, Büchner, Thon, Levi.

‡ Viz. Chaff included.

§ Viz. Petzholdt, Baer, Weber, Boussingault, Zoeller, Henneberg and Stohmann; whether or not chaff is included is uncertain.

‖ By Will and Fresenius, Schulz-Fleeth, Zoeller, Rautenberg

¶ By Rammelsberg, Nitzsch, Liebig, Marchand, Steinberg, Schulze, Krocker, Weber, Heintz, Erdmann, Stadeler.

** Viz. Boussingault, Baer, Hertwig.

†† The analysis by Heintz for Pr. Landes Col. is like Baer's, except that the per cents. of Potash and Soda in the one are the reverse of those in the other. The analysis was doubtless made by Baer under direction of Heintz, and in one case has been erroneously copied. The next highest per cent. of Soda is 15·1.

COMPOSITION OF THE ASH OF SOME AGRICULTURAL PLANTS AND PRODUCTS, &c.—(*continued.*)

Pr Ct. of Ash.	K_2O.	Na_2O.	MgO.	CaO.	Fe_2O_3	P_2O_5.	SO_3.	SiO_2.	Cl.	
										BEAN STRAW.
...	32·7	8·7	7·3	25·3	1·7	7·9	2·2	5·5	7·3	Average of 9 Analyses.
...	34·6	4·4	9·3	23·0	2·6	8·2	0·2	6·6	6·8	,, 4 ,, by Ritter and Knop.
6·1	31·3	12·1	5·7	27·2	1·1	7·7	3·7	4·6	7·8	,, 5 ,, ,, Way and Ogston.
5·1	5·4	1·9	3·3	9·4	0·6	0·7	0·0	1·6	0·0	Lowest percentage in 9 Analyses.
7·2	52·2	25·3	16·0	38·7	2·9	14·9	7·0	13·6	14·5	Highest ,, 9 ,,
...	15·0	13·6	7·0	35·9	2·4	12·0	2·5	11·3	0·3	Old Analysis by Hertwig, not included above.
										POTATO TUBER
...	60·9	1·7	4·6	2·4	0·9	18·3	7·0	1·9	2·7	Average of 39 Analyses.
4·1	66·1	0·4	3·9	1·4	0·7	18·7	3·3	0·8	5·5	,, 7 ,, by Schulz-Fleeth, and 1 by Wolff.
3·7	62·5	...	4·8	1·8	0·5	17·7	8·8	2·7	1·6	,, 8 ,, ,, Metzdoff.
...	46·0	8·6	3·6	4·0	3·9	23·6	5·0	4·2	1·4	,, 3 ,, ,, Walz.
4·1	67·6	0·3	4·7	3·6	0·0	17·6	5·8	0·0	0·3	,, 5 ,, ,, Herapath.
...	53·9	2·0	4·9	2·0	1·0	23·6	10·2	1·7	1·5	,, 4 ,, ,, Bretschneider.
...	59·5	2·2	5·1	4·0	1·3	18·5	3·0	2·8	3·9	,, 3 ,, ,, Way and Ogston.
4·6	60·2	2·4	4·9	2·1	0·6	14·9	9·5	2·2	3·3	,, 8 ,, ,, others.*
2·6	42·9	0·0	2·5	0·5	0·0	11·2	0·4	0·0	0·0	Lowest percentage in 39 Analyses.
8·0	73·6	12·8	6·6	6·2	6·0	27·1	18·0	6·5	8·7	Highest ,, 39 ,,
4·5	64·8	1·4	4·3	2·0	1·9	16·8	4·7	1·4	3·4	Average of 4 recent Analyses by Heiden, not included above.
										SUGAR BEET-ROOT.
...	48·0	10·4	9·5	6·4	1·0	14·4	4·7	3·8	2·3	Average of 40 Analyses.
4·1	51·2	10·0	9·1	5·8	0·8	13·6	4·4	3·5	2·6	,, 13 ,, by Ritthausen.
4·8	46·9	9·5	0·2	6·3	1·2	15·9	5·4	3·3	3·1	,, 11 ,, ,, Bretschneider.
4·2	45·4	12·3	10·2	6·9	1·0	14·0	4·4	4·6	1·0	,, 14 ,, ,, Bretschneider and Küllenberg.
5·2	50·9	5·8	6·7	9·8	1·1	16·3	4·0	3·4	1·9	Additional Analysis by Hoffmann.
2·9	51·8	6·7	7·5	7·0	2·2	12·9	2·8	3·2	5·9	,, ,, Karmrodt.
2·9	22·0	5·1	4·5	3·9	0·3	10·2	2·1	1·6	0·5	Lowest percentage in 40 Analyses.
6·0	58·9	29·8	13·8	23·3	2·2	18·5	8·9	9·0	10·8	Highest ,, 40 ,,

FIELD BEET-ROOT.

...	46·6	18·4	4·8	5·9	0·8	8·3	3·7	4·0	9·9	Average of 12 Analyses.
9·5	30·2	35·6	2·6	2·4	0·7	3·8	4·1	3·2	21·3	,, 3 ,, by Way and Ogston.
5·3	51·4	15·1	6·4	5·3	0·6	10·7	3·1	2·7	5·0	,, 3 ,, ,, Ritthausen.
...	57·6	6·3	3·9	5·5	1·0	13·0	2·9	5·1	4·9	,, 2 ,, ,, Wolff.
8·1	49·9	13·9	5·8	9·3	0·9	7·4	4·2	5·1	7·6	,, 4 ,, ,, others.†
2·8	25·2	5·2	2·1	2·2	0·0	1·9	2·1	0·2	2·0	Lowest percentage in 12 Analyses.
11·3	59·2	38·9	12·1	20·2	3·1	13·1	12·3	9·6	34·8	Highest ,, 12 ,,

CARROT ROOT.

7·5	37·0	20·7	5·2	10·9	1·0	11·2	6·9	2·0	4·9	Average of 10 Analyses.
6·6	39·1	20·4	4·8	10·7	1·3	10·3	7·9	1·4	4·8	,, 5 ,, by Way and Ogston.
8·3	35·0	21·0	5·6	11·0	0·6	12·1	5·8	2·5	4·9	,, 5 ,, ,, others.‡
5·1	17·0	10·1	1·3	6·6	0·0	8·2	3·3	0·9	2·1	Lowest percentage in 5 Analyses.
10·9	50·9	34·8	9·1	16·5	2·0	15·0	11·7	4·8	6·4	Highest ,, 5 ,,

TURNIP ROOT

8·1	48·6	8·7	2·6	12·1	0·4	10·6	12·3	0·7	5·1	Average of 43 Analyses.
10·8	46·2	9·6	4·4	9·0	1·2	14·3	11·4	1·6	3·0	,, 6 ,, by Wunder.
11·8	43·7	12·4	4·7	10·0	0·8	10·2	12·1	0·9	6·5	,, 5 ,, ,, Anderson.
7·5	38·3	13·7	2·9	11·3	0·5	11·2	14·7	2·0	5·5	,, 6 ,, ,, Way and Ogston.
6·9	52·7	6·4	1·7	13·3	0·0	9·2	12·4	0·0	5·1	,, 24 ,, ,, Gilbert.
7·2	50·6	3·9	2·0	13·9	0·4	16·4	6·3	1·2	7·0	,, 2 ,, ,, others.§
6·0	26·3	0·0	1·7	5·5	0·0	6·8	2·6	0·0	1·5	Lowest percentage of 19 Analyses, exclusive of Gilbert's.
20·9	58·3	20·5	6·4	16·2	1·8	16·9	17·9	3·5	12·8	Highest ,, 19 ,, ,, ,,

FIELD BEET TOPS.

...	25·1	20·5	10·4	9·8	1·2	5·4	7·2	3·3	17·6	Average of 4 Analyses.
17·0	22·6	23·0	9·2	9·2	1·0	5·5	6·2	2·1	21·8	,, 3 ,, by Way and Ogston.
21·8	32·7	13·1	13·9	11·3	1·6	5·0	10·1	6·8	5·1	Analyses by Wolff.
14·0	9·0	13·1	7·5	8·7	0·5	4·7	4·9	1·4	5·1	Lowest percentage in 4 Analyses.
21·8	32·7	23·9	13·9	11·3	1·6	6·4	10·1	6·8	24·6	Highest ,, 4 ,,

* Viz. Moser, Fromberg, Boussingault, Cameron, John, Griepenkerl.
† Etti, Griepenkerl, Herapath, Boussingault.
‡ Bretschneider, Richardson, Fromberg (2), Herapath.
§ Herapath, Stammer.

COMPOSITION OF THE ASH OF SOME AGRICULTURAL PLANTS AND PRODUCTS, &c.—(*continued.*)

Pr. Ct. of Ash.	K_2O.	Na_2O.	MgO.	CaO.	Fe_2O_3	P_2O_5.	SO_3.	SiO_2.	Cl.	
					SUGAR BEET TOPS.					
22·0	22·3	18·8	16·2	19·7	1·3	7·6	6·5	3·5	4·7	Average of 4 Analyses.*
16·3	15·2	12·9	11·0	17·8	0·7	5·4	4·6	1·5	2·8	Lowest percentage in 4 Analyses.
29·2	27·2	31·2	19·2	23·2	2·3	9·2	8·3	5·6	7·2	Highest „ 4 „
					CARROT TOPS.					
...	17·0	19·8	5·0	32·7	2·0	3·1	8·4	3·7	10·2	Average of 6 Analyses.
18·2	8·7	22·2	3·6	39·7	2·9	2·0	7·3	5·5	9·3	„ 3 „ by Way and Ogston.
15·5	25·3	17·3	6·4	25·7	1·1	4·2	9·5	1·9	11·0	„ 3 „ „ others.†
15·0	7·7	10·9	3·0	23·1	0·6	1·4	6·9	1·6	2·7	Lowest percentage in 6 Analyses.
21·3	30·9	29·0	7·5	41·8	4·9	6·4	11·1	8·8	16.2	Highest „ 6 „
					TURNIP TOPS.					
10·9	28·1	6·0	2·5	34·8	0·8	6·7	13·3	1·5	8·7	Average of 36 Analyses.
13·0	21·0	12·4	3·2	32·4	1·9	7·2	9·6	4·6	13·5	„ 6 „ by Way and Ogston.
15·3	25·2	6·1	5·0	32·8	3·3	9·1	8·5	4·0	7·6	„ 4 „ „ Wunder.
9·4	30·5	4·2	1·0	37·0	0·0	6·1	15·2	0·0	7·8	„ 24 „ „ Campbell.
16·3	27·6	7·9	12·7	20·0	1·6	7·6	10·7	6·0	7·6	„ 2 „ „ others.‡
9·5	12·1	4·0	1·0	7·9	0·0	2·0	5·0	0·0	2·5	Lowest percentage in 12 Analyses, exclusive of Campbell's.
19·7	37·2	19·9	16·1	39·6	5·5	15·1	16·3	9·5	11·9	Highest „ 12 „ „ „
					COTTON STALKS.					
...	33·7	...	8·1	42·1	0·6	12·6	1·8	...	1·1	J. Lawrence Smith. Report to Black Oak Agricultural Society, 1846.
3·1	29·6	...	3·7	24·3	...	34·9	3·5	3·2	0·7	O. Judd. Proceedings American Association of Science, 1852, p. 219.
...	29·4	1·7	6·9	23·3	9·5	18·3	1·7	8·6	0·5	T. J. Summer. Proceedings Philadelphia Academy, Dec. 1852.
					COTTON SEED.					
3·8	27·8	2·7	10·6	10·9	3·3	35·4	3·2	trace	4·8	T. J. Summer. Analysis imperfect (*loc. cit.*).
4·0	36·0	1·0	14·2	6·2	0·6	37·2	4·1	trace	0·5	Higgins and Bickell. Turner's Cotton Planter's Manual, p. 207.
					COTTON FIBRE.					
1·3	41·8	6·1	11·2	19·8	2·4	6·4	4·2	0·3	7·8	Higgins and Bickell (*loc. cit.*).

* Hoffman, Eylerts, Bretschneider (2). † Fromberg (2), Bretschneider. ‡ Namur, Anderson.

The average composition of the ash of a number of ordinary crops is concisely exhibited in the subjoined statement:

	K_2O and Na_2O.	MgO.	CaO.	P_2O_5.	SiO_2.	SO_3.	Cl.
CEREALS—							
Grain*	30	12	3	46	2	2·5	1
Straw	13—27	3	7	5	50—70	2·5	2
LEGUMES—							
Seed	44	7	5	35	1	4	2
Straw	27—41	7	25—39	8	5	2—6	6—7
ROOT CROPS—							
Roots	60	3—9	6—12	8—18	1—4	5—12	3—9
Tops	37	3—16	10—35	3—8	3	6—13	5—17
GRASSES—							
In flower	33	4	8	8	35	4	5

The composition of the ash differs in different parts of the same plant.

3. *Different parts of the same plant usually exhibit decided differences in the composition of their ash.* This fact is made evident by a comparison of the figures of the table above, and is more fully illustrated by the following analyses of the parts of the mature oat-plant, by Arendt, 1 to 6 (*Die Haferpflanze*, p. 107), and Norton, 7 to 9 (*Am. Jour. Sci.* 2 Ser. 3, 318).

	1 Lower Stem.	2 Middle.	3 Upper Stem.	4 Lower Leaves.	5 Upper Leaves.	6 Ears.	7 Chaff.	8 Husk.	9 Kernel husked.
K_2O	81·2	68·3	55·9	36·9	24·8	13·0	10·6	12·4	31·7
Na_2O	0·4	1·5	1·0	0·9	0·4	0·1			
MgO	2·1	3·6	3·9	3·8	3·9	8·9	11·2	2·3	8·6
CaO	3·6	5·3	8·6	16·7	17·2	7·3		4·3	5·3
Fe_2O_3	1·0	0·0	0·2	2·7	0·5	trace		0·3	0·8
P_2O_5	2·7	1·4	2·7	1·7	1·5	36·5		0·6	49·1
SO_3	0·0	1·3	1·1	3·2	7·5	4·9	5·3	4·3	0·0
SiO_2	4·1	9·3	20·4	34·0	41·8	26·0	68·0	74·1	1·8
Cl	8·6	11·7	7·4	1·6	2·4	3·8	3·1	1·4	0·2

The results of Arendt and Norton are not in all respects strictly comparable, having been obtained by different methods, but serve well to establish the fact in question.

We see from the above figures that the ash of the lower stem consists chiefly of potash (81 per cent.). This alkali is predominant throughout the stem, but in the upper parts,

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* Exclusive of husk

where the stem is not covered by the leaf sheaths, silica and lime occur in large quantity. In the ash of the leaves, silica, potash, and lime are the principal ingredients. In the chaff and husk, silica constitutes three-fourths of the ash; while in the grain, phosphoric pentoxide appears as the characteristic ingredient, existing there in connexion with a large amount of potash (32 per cent.) and much magnesia. Chlorine acquires its maximum (11·7 per cent.) in the middle stem, but in the seed is present in small quantity, while sulphuric trioxide is totally wanting in the lower stem, and most abundant in the upper leaves.

The composition of the ash differs in leaves of different ages

Again, the unequal distribution of the ingredients of the ash is exhibited in the leaves of the sugar beet, which have been investigated by Bretschneider (*Hoff. Jahresbericht*, 4, 89). This experimenter divided the leaves of six sugar beets into five series or circles, proceeding from the outer and older leaves inward. He examined each series separately, with the following results:—

	1	2	3	4	5
Potash	18·7	25·9	32·8	37·4	50·3
Soda	15·2	14·4	15·8	15·0	11·1
Sodium chloride	5·8	6·4	5·8	6·0	6·5
Lime	24·2	19·2	18·2	15·8	4·7
Magnesia	24·5	22·3	13·0	8·9	6·7
Ferric oxide	1·4	0·5	0·6	0·6	0·5
Phosphoric pentoxide	3·3	4·8	5·8	8·4	12·7
Sulphuric trioxide	5·4	5·6	5·6	5·2	5·9
Silica	1·5	0·8	2·7	2·1	1·5

From these data we perceive that in the ash of the leaves of the sugar beet, potash and phosphoric pentoxide regularly and rapidly increase in relation to the other ingredients from without inward, while lime and magnesia as rapidly diminish in the same direction. The per cent. of the other ingredients—viz. soda, chlorine, ferric oxide, sulphuric trioxide, and silica—remains nearly invariable throughout.

Another illustration is furnished by the following analyses of the ashes of the various parts of the horse-chestnut tree made by Wolff (*Ackerbau*, 2 Auf. 134):—

The composition of the ash of different parts of the same plant varies greatly.

	Bark.	Wood.	Leaf Stems.	Leaves.	Flower Stems.	Calyx.
Potash	12·1	25·7	46·2	27·9	63·6	61·7
Lime	76·8	42·9	21·7	29·3	9·3	12·3
Magnesia	1·7	5·0	3·0	2·6	1·3	5·9
Sulphuric trioxide .	trace	trace	3·8	9·1	3·5	trace
Phosphoric pentoxide	6·0	19·2	14·8	22·4	17·1	16·6
Silica	1·1	2·6	1·0	4·9	0·7	1·7
Chlorine	2·8	6·1	12·2	5·1	4·7	2·4

	Stamens	Petals.	Green Fruit.	Ripe Fruit.		
				Seed.	Green Shell.	Brown Shell.
Potash	60·7	61·2	58·7	61·7	75·9	54·6
Lime	13·8	13·6	9·8	11·5	8·6	16·4
Magnesia	3·1	3·8	2·4	0·6	1·1	2·4
Sulphuric trioxide .	trace	trace	3·7	1·7	1·0	3·6
Phosphoric pentoxide	19·5	17·0	20·8	22·8	5·3	18·6
Silica	0·7	1·5	0·9	0·2	0·6	0·8
Chlorine	2·8	3·8	4·8	2·0	7·6	5·2

4. *Similar kinds of plants, and especially the same parts of similar plants, exhibit a close general agreement in the composition of their ashes; while plants which are unlike in their botanical characters are also unlike in the proportions of their fixed ingredients.*

Similar plants give similar ashes.

The three plants, wheat, rye, and maize, belong, botanically speaking, to the same natural order, *gramineæ*, and their ripe seeds yield ashes almost identical in composition. Barley and the oat are also graminaceous plants, and their seeds should give ashes of similar composition. That such is not the case is chiefly due to the fact, that, unlike the grains of wheat, rye, and maize, those of barley and oats are closely invested with a husk, which forms a part of the seed as ordinarily seen. This husk yields an ash which is rich in silica, and we can only properly compare barley and oats

The ashes of cereal grain compared.

with wheat and rye when the former are hulled, or the ash of the hulls is taken out of the account. There are varieties of both oats and barley whose husks separate from the seed—the so-called naked or skinless oats and naked or skinless barley—and the ashes of these grains agree quite nearly in composition with those of wheat, rye, and maize, as may be seen from the following table:—

	Wheat. Average of 79 Analyses.	Rye. Average of 21 Analyses.	Maize. Average of 7 Analyses.	Naked Oats. Analysis by Fr. Schulz.	Naked Barley. Analysis by Fr. Schulz.
Potash	31·3	28·8	27·7	33·4	35·9
Soda	3·2	4·3	4·0	—	1·0
Magnesia . . .	12·3	11·6	15·0	11·8	13·7
Lime	3·2	3·9	1·9	3·6	2·9
Ferric oxide . .	0·7	0·8	1·0	0·8	0·7
Phosphoric pentoxide . . .	46·1	45·6	47·1	46·9	45·0
Sulphuric trioxide	1·2	1·9	1·7	—	—
Silica	1·9	2·6	2·1	2·4	0·7
Chlorine . . .	0·2	0·7	0·1	—	—

By reference to the table (p. 138) it will be observed that the pea and bean kernel, together with the allied vetch and lentil, also nearly agree in ash-composition.

So, too, the ashes of the root-crops, turnips, carrots, and mangolds, or beets, exhibit a general similarity of composition, as may be seen in the table (pp. 140–142).

The seeds of the oil-bearing plants likewise constitute a group whose members agree in this respect.

5. *The ash of the same species of plant is more or less variable in composition, according to circumstances.*

The several conditions which cause variation in ashes noted.

The conditions that have already been noticed as influencing the proportion of ash are in general the same that affect its quality. Of these we may specially notice:

a. The stage of growth of the plant.

b. The vigour of its development.

c. The variety of the plant or the relative development of its parts.

d. The soil or the supplies of food, both natural and artificial.

e. The season and climate.

The stage of growth influences the ash.

a. The stage of growth.—The facts that the different parts of a plant yield ashes of different composition, and that the different stages of growth are marked by the development of new organs or the unequal expansion of those already formed, are sufficient to sustain the point now in question, and render it needless to cite analytical evidence. In a subsequent chapter, wherein we shall attempt to trace some of the various steps in the progressive development of the plant, numerous illustrations will be adduced (p. 192).

The vigour of growth influences the ash.

b. Vigour of development.—Arendt (*Die Haferpflanze*, p. 18) selected from an oat-field a number of plants in blossom, and divided them into three parcels—1, composed of very vigorous plants; 2, of medium; and 3, of very weak plants. He analysed the ashes of each parcel, with results as below:

	1.	2.	3.
Silica	27·0	39·9	42·0
Sulphuric trioxide	4·8	4·1	5·6
Phosphoric pentoxide	8·2	8·5	8·8
Chlorine	6·7	5·8	4·7
Ferric oxide	0·4	0·5	1·0
Lime	6·1	5·4	5·1
Magnesia, Potash, and Soda	45·3	34·3	30·4

Here we notice that the ash of the weak plants contains 15 per cent. less of alkalies, and 15 per cent. more of silica, than that of the vigorous ones, while the proportion of the other ingredients is not greatly different.

Zoeller (*Liebig's Ernährung der Vegetabilien*, p. 340) examined the ash of two specimens of clover which grew on the same soil and under similar circumstances, save that one, from being shaded by a tree, was less fully developed than the other.

Six weeks after the sowing of the seed the clover was cut, and gave the following results on partial analysis :—

	Shaded Clover.	Unshaded Clover.
Alkalies	54·9	36·2
Lime	14·2	22·8
Silica	5·5	12·4

Different varieties of the same species differ as to ash.

c. The variety of the plant or the relative development of its parts must obviously influence the composition of the ash taken as a whole, since the parts themselves are unlike in composition.

Herapath (*Quar. Jour. Chem. Soc.* ii. p. 20) analysed the ashes of the tubers of five varieties of potatoes, raised on the same soil and under precisely similar circumstances. His results are subjoined :—

	White Apple.	Prince's Beauty.	Axbridge Kidney.	Magpie.	Forty-fold.
Potash	69·7	65·2	70·6	70·0	62·1
Sodium chloride . .	—	—	—	—	2·5
Lime	3·0	1·8	5·0	5·0	3·3
Magnesia	6·5	5·5	5·0	2·1	3·5
Phosphoric pentoxide	17·2	20·8	14·9	14·4	20·7
Sulphuric trioxide .	3·6	6·0	4·3	7·5	7·9
Silica	—	—	0·2	—	—

The ash is greatly modified by soil and manure

d. The soil, or the supplies of food, manures included, have the greatest influence in varying the proportions of the ash-ingredients of the plant. It is to a considerable degree the character of the soil which determines the vigour of the plant and the relative development of its parts. This condition then, to a certain extent, includes those already noticed.

It is well known that oats have a great range of weight per bushel, being nearly twice as heavy when grown on rich land as when gathered from a sandy inferior soil. According to the agricultural statistics of Scotland for the year 1857 (*Trans. Highland and Agr. Soc.* 1857–59, p. 213), the bushel of oats produced in some districts weighed 44 pounds per bushel, while in other districts it was as low as 35 pounds, and in one instance but 24 pounds per bushel. Light oats have a thick and bulky husk, and an ash-analysis gives a result quite unlike that of good oats. Herapath (*Jour. Roy. Agr. of Eng.* xi. p. 107) has published analyses of light oats from sandy soil, the yield being six bushels per acre, and of heavy oats from the same soil, after "warping,"* where the produce was 64 bushels per acre. Some of his results per cent. are as follow :—

Ashes of oats grown in different soils vary.

	Light Oats.	Heavy Oats.
Potash	9·8 . . .	13·1
Soda	4·6 . . .	7·2
Lime	6·8 . . .	4·2
Phosphoric pentoxide .	9·7 . . .	17·6
Silica	56·5 . . .	45·6

Wolff (*Jour. für prakt. Chem.* 52, p. 103) has analysed the ashes of several plants, cultivated in a poor soil, with the addition of various mineral fertilizers. The influence of the added substances on the composition of the plant is very striking. The following figures comprise his results on the ash of buckwheat straw which grew on the unmanured soil, and on the same after application of the substances specified below :—

Ashes of buckwheat variously manured differ in composition.

	1. Without Manure.	2. Sodium Chloride.	3. Potassium Nitrate.	4. Potassium Carbonate.	5. Magnesium Sulphate.	6. Calcium Carbonate.
Potash	31·7	21·6	39·6	40·5	28·2	23·9
Potassium chloride .	7·4	26·9	0·8	3·1	6·9	9·7
Sodium chloride . .	4·6	3·0	3·2	3·8	3·4	1·7
Lime	15·7	14·0	12·8	11·6	14·1	18·6
Magnesia	1·7	1·9	3·3	1·4	4·7	4·2
Sulphuric trioxide .	4·7	2·8	2·7	4·3	7·1	3·5
Phosphoric pentoxide	10·3	9·5	6·5	8·9	10·9	10·0
Carbonic dioxide . .	20·4	16 1	27·1	22·2	20·0	23·2
Silica	3·6	4·2	4·2	4·2	4·8	5·2
	100·0	100·0	100·0	100·0	100·0	100·0

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* Thickly covering with sediment from muddy water.

It is seen from these figures that all the applications employed in this experiment exerted a manifest influence, and, in general, the substance added, or at least one of its ingredients, is found in the plant in increased quantity.

In 2, chlorine, but not sodium; in 3 and 4, potash; in 5, sulphuric trioxide and magnesia, and in 6, lime, are present in larger proportion than in the ash from the produce of the unmanured soil.

Season and climate affect the ash.

e. A wet season or a moist climate reduces the absolute as well as the relative percentage of ash in most plants, the volatile matters being, on the other hand, relatively, but not absolutely increased. Differences in climate and variations in season influence also the relative percentages of the particular ash materials of plants, but it is not as yet possible to draw any very complete set of general conclusions from the observations made on this subject.

6. *What is the normal composition of the ash of a plant?*—It is evident from the foregoing facts and considerations that to pronounce upon the normal composition of the ash of a plant, or, in other words, to ascertain what ash-ingredients and what proportions of them are proper to any species of plant or to any of its parts, is a matter of much difficulty and uncertainty.

The best that can be done is to adopt the average of a great number of trustworthy analyses as the approximate expression of ash-composition. From such data, however, we are still unable to decide what are the absolutely essential, and what are really accidental ingredients, or what amount of any given ingredient is essential, and to what extent it is accidental. Wolff, who appears to have first suggested that a part of the ash of plants may be accidental, endeavoured to approach a solution of this question by comparing together the ashes of samples of the same plant, cultivated under the same circumstances in all respects, save that they were supplied with unequal quantities of readily available ash-ingredients. The analyses of the

Effect of different manures on the ash may be eliminated.

ashes of buckwheat stems, just quoted, belong to this investigation. Wolff showed that, by assuming the presence in each specimen of buckwheat straw of a certain excess of certain ingredients, and deducting the same from the total ash, the residuary ingredients closely approximated in their proportions to those observed in the crop which grew in an unmanured soil. The analyses just quoted (p. 149) are here " corrected" in this manner, by recalculation after the subtraction of a certain percentage of those ingredients which in each case were furnished to the plant by the fertilizer applied to it. The numbers of the analyses correspond with those on page 149.

After deduction of. . . .	1. No-thing.	2. 20 p. c. Potassium Chloride.	3. 20 p. c. Potassium Carbonate.	4. 25 p. c. Potassium Carbonate.	5. 8·5 p. c. Magnesium Sulphate.	6. 16·6 p.c. Calcium and Magnesium Carbonates.
Potash	31·7	27·0	32·5	33·5	30·6	28·0
Potassium chloride .	7·4	9·1	1·0	3·9	7·4	11·3
Sodium chloride . .	4·6	3·8	4·0	4·7	3·7	1·9
Lime	15·7	17·3	16·0	14·5	15·3	14·6
Magnesia	1·7	2·4	4·1	1·7	2·3	2·9
Sulphuric trioxide .	4·7	3·5	3·4	5·4	2·1	4·1
Phosphoric pentoxide	10·3	11·7	8·1	11·2	11·8	11·7
Carbonic dioxide .	20·4	20·1	25·9	19·8	21·6	19·3
Silica	3·6	5·2	5·2	5·3	5·2	6·1
	100·0	100·0	100·0	100·0	100·0	100·0

The correspondence in the above analyses thus "corrected," already tolerably close, might, as Wolff remarks (*loc. cit.*), be made much more exact by a further correction, in which the quantities of the two most variable ingredients, viz. chlorine and sulphuric acid, should be reduced to uniformity, and the analyses then be recalculated to per cent.

In the first place, however, we are not warranted in assuming that the " excess" of chloride of potassium, carbonate of potash, &c., deducted in the above analyses respectively, was *all* accidental and unnecessary to the plant; for, under the influence of an increased amount of a nutritive ingredient, the plant may not only mechanically contain more, but may chemically employ more in the vegetative processes. It is well proved that vegetation grown under the influence of large supplies of nitrogenous manures contains an increased proportion of nitrogen in the truly assimilated state of albumen, gluten, &c. The same may be equally true of the various ash-ingredients.

Again, in the second place, we cannot say that in any instance the *minimum quantity* of any ingredient necessary to the vegetative act is present, and no more.

Effect of manures on ash best studied with poor soils.

It must be remarked that these great variations are only seen when we compare together plants produced on *poor soils*, i.e. on those which are relatively deficient in some one or several ingredients. If a fertile soil had been employed to support the buckwheat plants in these trials, we should doubtless have had different and far less striking results.

In 1859, Metzdorf (*Wilda's Centralblatt*, 1862, 2, p. 367) analysed the ashes of eight samples of the red-onion potato, grown on the same field in Silesia, but differently manured.

Without citing the analyses, we may state some of the most striking results. The extreme range of variation in potash was 5½ per cent. The ash containing the highest percentage of potash was not, however, obtained from potatoes that had been manured with a compound containing 50 pounds of this substance, but from a parcel to which had been applied a poudrette containing less than 3 pounds of potash for the quantity used.

The *unmanured* potatoes were relatively the richest in lime, phosphoric acid, and sulphuric acid, although several parcels were copiously treated with manures containing considerable quantities of these substances. These facts are of great interest in reference to the theory of the action of manures.

7. *To what extent is each ash-ingredient essential, and how far may it be accidental?*—Before the art of chemical analysis had arrived at much perfection, it was believed by many men of science that the ashes of the plant were either unessential to growth or else were the products of growth—were generated by the plant.

What ash-ingredients are indispensable to the plant?

Since the substances found in ashes are universally distributed over the earth's surface, and are invariably present in all soils, it is not possible by analysis of the ash of plants growing under natural conditions to decide whether any or several of their ingredients are indispensable to vegetative life. For this purpose it is necessary to institute experimental inquiries, and these have been prosecuted with great painstaking, though not with results that are in all respects satisfactory.

Experiments in Artificial Soils.—The Prince Salm-Horstmar has been a most laborious student of this question. His plan of experiment was the following:—The seeds of a plant were sown in a soil-like medium (sugar-charcoal, pulverized quartz, purified sand), which was as thoroughly as possible freed from the substance whose special influence on growth was the subject of study. All other substances presumably necessary were supplied, and the experiments were conducted under all the usual external conditions of growth, light, warmth, moisture, &c.

The results of 195 trials thus made with oats, wheat, barley, and colza, subjected to the influence of a great variety of artificial mixtures, have been published; the most important of these results will shortly be given.

Plants may be grown in solutions.

Experiments in Solutions.—Water-Culture.—Sachs, W. Knop, Stohmann, Nobbe, Siegert, and others have likewise studied this subject. Their method was like that of Prince Salm-Horstmar, except that the plants were made to germinate and grow independently of any soil; and, throughout the experiment, had their roots immersed in water, containing in solution or suspension the substances whose action was to be observed.

The method of growing plants in solutions.

Water-Culture has recently contributed so much to our knowledge of the conditions of vegetable growth, that some account of the mode of conducting it may be properly given in this place. Cause a number of seeds of the plant it is desired to experiment upon to germinate in moist cotton or coarse sand, and when the roots have become an inch or two in length, select the strongest seedlings, and support them, so that the roots shall be immersed in water, while the seeds themselves shall be just above the surface of the liquid.

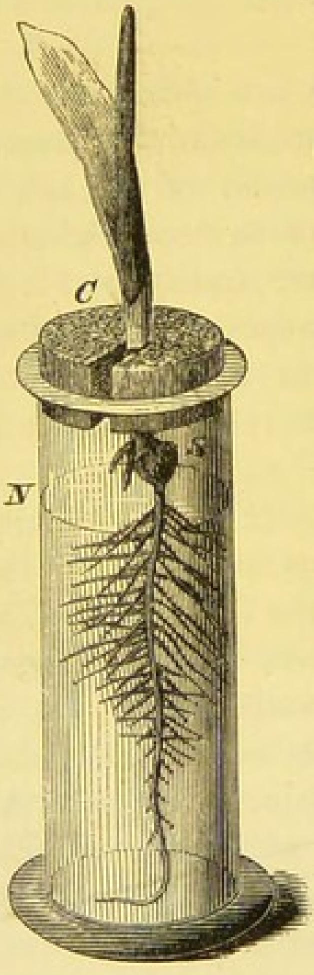

Fig. 19.

For this purpose, in case of a single maize plant, for example, provide a quart cylinder or bottle, with a wide mouth, to which a cork is fitted, as in Fig. 19. Cut a vertical notch in the cork to its centre, and fix therein the stem of the seedling by packing with cotton. The cork thus serves as a support of the plant. Fill the jar with pure water to such a height that when the cork is brought to its place, the seed, *S*, shall be a little above the liquid. If the endosperm or cotyledons dip into the water, they will speedily mould and rot; they require, however, to be kept in a moist atmosphere. Thus arranged, suitable warmth, ventilation, and illumination alone are requisite to continue the growth until the nutriment of the seed is nearly exhausted. As regards illumination, this should be as full as possible, for the foliage; but the roots should be protected from it, by enclosing the vessel in a shield of black paper, as, otherwise, minute parasitic algæ would in time develop upon the roots, and disturb their functions.

For the first days of growth, pure distilled water may advantageously surround the roots, but when the first green leaf appears they should be placed in the solution whose nutritive power is to be tested. The temperature should be properly proportioned to the light, in imitation of what is observed in the skilful management of conservatory or house plants.

Preparation of a normal solution for water-culture.

The experimenter should first learn how to produce large and well-developed plants, by aid of an appropriate liquid, before attempting the investigation of other problems. For this purpose, a solution or mixture must be prepared, containing in proper proportions all that the plant requires, save what it can derive from the atmosphere. The recent experience of Nobbe, Siegert, Wolff, and others, supplies valuable information on this point. Professor Wolff has obtained striking results with a variety of plants in using a solution made essentially as follows :—

Place 20 grams (300 grains) of the fine powder of well-burnt bones with half a pint of water in a large glass flask, heat to boiling, and add nitric acid cautiously in quantity just sufficient to dissolve the bone-ash. In order to remove any injurious excess of nitric acid, pour into the hot liquid a solution of carbonate of potash until a slight permanent turbidity is produced; then add 11 grams (170 grains) of nitrate of potash, 7 grams (107 grains) of crystallized sulphate of magnesia, and 3 grams (46 grains) of chloride of potassium, with water enough to make the solution up to the bulk of one litre (or quart). Mix 30 cubic cent. (one fluid ounce) of this liquid with a litre (or quart) of water and a single drop of strong solution of ferric chloride (the perchloride of iron), and employ this diluted solution to feed the plant.

Constituents of a normal solution for water-culture.

Wolff's solution, thus prepared, contained in 1,000 parts as follows, exclusive of iron :—

Phosphoric pentoxide	8·234
Lime	10·370
Potash	9·123
Magnesia	1·403
Sulphuric trioxide	2·254
Chlorine	0·885
Nitric pentoxide	29·703
Solid matters	61·972
Water	938·028
	1000·000

This solution was diluted to a liquid containing but one part of solid matters to 1,000 or 2,000 parts of water.

Precautions in water-culture experiments.

The solution should be changed every week, and as the plants acquire greater size, their roots should be transferred to a larger vessel, filled with solution of the same strength.

It is important that the water which escapes from the jar by evaporation and by transpiration through the plant, should be daily or oftener replaced, by filling it with pure water up to the original level. The solution, whose preparation has been described, may be turbid from the separation of a little white calcic sulphate before the last dilution, as well as from the precipitation of ferric phosphate on adding ferric chloride. The former deposit may be dissolved, though this is not needful ; the latter will not dissolve, and should be occasionally put into suspension by stirring the liquid. When the plant is half grown, further addition of iron is unnecessary.

In this manner, and with this solution, Wolff produced a maize plant 5¾ feet high, and equal, in every respect, as regards size, to plants from similar seed cultivated in the field. The ears were not, however, fully developed when the experiment was interrupted by the plant becoming unhealthy.

With the oat his success was better. Four plants were brought to maturity, having 46 stems and 1,535 well-developed seeds (*Vs. St.* viii. 190—215).

In similar experiments, Nobbe obtained buckwheat plants, six to seven feet high, bearing three hundred plump and perfect seeds, and barley stools with twenty grain-bearing stalks (*Vs. St.* vii. 72).

Plants decompose the salts of a solution.

In water-culture, the composition of the solution is suffering continual alteration, from the fact that the plant makes, to a certain extent, a selection of the matters presented to it, and does not necessarily absorb them in the proportions in which they originally existed. In this way, disturbances arise which impede or become fatal to growth. In the early experiments of Sachs and Knop, in 1860, they frequently observed that their solutions suddenly acquired the odour of hydrosulphuric acid, and black ferrous sulphide formed upon the roots, in consequence of which they were shortly destroyed. This reduction of a sulphate to a sulphide takes place only in an alkaline liquid, and Stohmann was the first to notice that an acid liquid might be made alkaline by the action of living roots. The plant, in fact, has the power to decompose salts; and by appropriating the acid constituents more abundantly than the bases, the latter accumulate in the solution in the free state, or as carbonates with alkaline properties.

To prevent the reduction of sulphates, the solution must be kept *slightly acid*, best by the addition of a very little free nitric acid; and if the roots blacken, they must be washed with a dilute acid, and, after rinsing with water, must be transferred to a fresh solution.

On the other hand, Kühn has shown that when ammonium chloride is employed to supply maize with nitrogen, this salt is decomposed, its ammonia assimilated, and its chlorine, which the plant cannot use, accumulates in the solution in the form of hydrochloric acid, to such an extent as to prove fatal to the plant (*Henneberg's Journal*, 1864, pp.

116 and 135). Such disturbances are avoided by employing large volumes of solution, and by frequently renewing them.

The solutions in water-culture should usually be weak.

The concentration of the solution is by no means a matter of indifference. While certain aquatic plants, as sea-weeds, are naturally adapted to strong saline solutions, agricultural land plants rarely succeed well in water-culture, when the liquid contains more than $\frac{2}{1000}$ of solid matters, and will thrive in considerably weaker solutions.

Simple well-water is often rich enough in plant-food to nourish vegetation perfectly, provided it be renewed sufficiently often. Sachs' earliest experiments were made with well-water.

Birner and Lucanus, in 1864 (*Vs. St.* viii. 154), raised oat plants in well-water, and these, in respect to entire weight, were more than half as heavy as plants that grew simultaneously in garden soil, and, as regards seed-production, fully equalled the latter. The well-water employed contained in 100,000 parts:

Potash	2·10
Lime	15·10
Magnesia	1·50
Phosphoric pentoxide	0·16
Sulphuric trioxide	7·50
Nitric pentoxide	6·00
Silica, Chlorine, Ferric oxide	traces
Solid matters	32·36
Water	99,967·64
	100,000·00

Nobbe (*Vs. St.* viii. 337) found that in a solution containing but $\frac{1}{10,000}$ of solid matters, *which was continually renewed*, barley made no progress beyond germination; and a buckwheat plant, which at first grew rapidly, was soon arrested in its development, and yielded but a few ripe seeds, and but 1·746 grm. of total dry matter.

While water-culture does not provide all the normal conditions of growth—the soil having important functions that cannot be performed by any liquid medium—it is a method of producing highly-developed plants, under circumstances which admit of accurate control and great variety of alteration, and is therefore of the utmost value in vegetable physiology. It has taught important facts which no other means of study could reveal, and promises to enrich our knowledge in a still more eminent degree.

Five out of ten of the ash-ingredients are absolutely requisite.

Potash, Lime, Magnesia, Phosphoric Protoxide, and Sulphuric Trioxide, are absolutely necessary for the life of Agricultural Plants, as is demonstrated by all the experiments hitherto made for studying their influence.

The necessity of sodium for plants has been doubted.

Is Soda essential to Agricultural Plants?—This question has occasioned much discussion.

By glancing over the table of ash-analyses in the Appendix, it will be observed that its range of variation is very great. Among the earlier analysts, Bichon found in the ash of the pea 13, in that of the bean 19, in that of rye 19, in that of wheat 27 per cent. of soda. Herapath found 15 per cent. of this substance in wheat-ash, and 20 per cent. in ash of rye; and Brewer found 13 per cent. in the ash of maize. In a few other analyses of the grains, we find similar high percentages. In most of the analyses, however, soda is present in much smaller quantity. The average in the ashes of the grains is less than 3 per cent., and in not a few of the analyses it is *entirely wanting*.

It is not needful to recount here the evidence to this effect that is furnished by the investigations of Salm-Horstmar, Sachs, Knop, and others (see especially Birner and Lucanus, *Vs. St.* viii. 128—161).

In the older analyses of other classes of agricultural plants, especially in root crops, similarly great variations occur.

Some uncertainty exists as to these older data, for the reason that the estimation of soda by the processes custom-

Some of the older analyses not to be relied on;

arily employed is liable to great inaccuracy, especially with the inexperienced analyst. On the one hand, it is not easy (or has not been easy until lately) to detect, much less to estimate, minute traces of soda, when mixed with much potash; while on the other hand, soda, if present to the extent of a per cent. or more, is very liable to be estimated too high. It has therefore been doubted if these high percentages in the *ash of grains* are correct.

Again, furthermore the processes formerly employed for preparing the ash of plants for analysis were such as, by too elevated and prolonged heating, might easily occasion a partial or total expulsion of soda from a material which properly should contain it, and we may hence be in doubt whether the older analyses, in which soda is not mentioned, are to be altogether depended upon.

but they are partially confirmed by the newest results.

The later analyses—especially those by Bibra, Zoeller, Arendt, Bretschneider, Ritthausen, and others, who have employed well-selected and carefully cleaned materials for their investigations, and who have been aware of all the various sources of error incident to such analyses—must therefore be appealed to in this discussion. From these recent analyses we are led to precisely the same conclusions as were warranted by the older investigations. Here follows a statement of the range of percentages of soda in the ash of several field crops, according to the newest analyses:—

	Per cent.			Per cent.	
Ash of Wheat kernel .	none	Bibra . .	to	5	Bibra.
" Potato tuber .	none	Cameron . Metzdorf .	"	4	Wolff.
" Barley grain .	1	Bibra . .	"	6	Bibra. Veltmann.
	2	Zoeller . .	"	7	Zoeller.
" Sugar-beet . .	4·7	Ritthausen	"	29·8	Ritthausen.
	5·7	Bretschneider	"	16·6	Bretschneider.
" Turnip root .	7·7	Anderson .	"	17·1	Anderson.

Although, as just indicated, soda has been found wanting in wheat grains and in potato tubers, in some instances, it is not certain that it was absent from other parts of the same plants, nor has it been proved, so far as we know, that soda is wanting in any *entire plant* which has grown on a natural soil.

Weinhold found in the ash of the stem and leaves of a species of stonecrop (*Sedum telephium*) no trace of soda detectable by ordinary means; while in the ash of the roots of the same plant there occurred 1·8 per cent. of this substance (*Vs. St.* iv. p. 190).

It is possible, then, that in the above instances soda really existed in the plants, though not in those parts which were subjected to analysis. It should be added that in ordinary analyses, where soda is stated to be absent, it is simply implied that it is present in *unweighable quantity,** if at all, while in reality a minute amount may be present in all such cases.†

The amount of sodium in plants varies greatly.

The grand result of all the analytical investigations hitherto made with regard to cultivated agricultural plants, then, is that *soda is an extremely variable ingredient of the ash of plants, and though generally present in some proportion, and often in large proportion, has been observed to be absent in weighable quantity in the seeds of grains and in the tubers of potatoes.*

Salm-Horstmar, Stohmann, Knop, Cloez, Péligot, and Nobbe and Siegert, have contributed certain synthetical data that bear on the question before us.

The investigations of Salm-Horstmar were made with the greatest nicety, and especial attention was bestowed on the influence of very minute quantities of the various substances employed. He gives, as the result of numerous experiments, that for wheat, oats, and barley, *in the early vegetative stages of growth, soda, while advantageous, is not*

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* Unweighable quantities are designated as "trace" or "traces."

† The newly discovered methods of spectrum analysis, by which $\frac{1}{100000000}$ of a grain of sodium may be detected, have demonstrated that this element is so universally distributed that it is next to impossible to find or make anything that is free from it.

essential, but that for the perfection of fruit an appreciable though minute quantity of this substance is indispensable. (*Versuche und Resultate über die Nahrung der Pflanzen*, pp. 12, 27, 29, 36.)

Stohmann's single experiment led to the similar conclusion, that maize may dispense with soda in the earlier stages of its growth, but requires it for a full development. (*Henneberg's Jour. für Landwirthschaft*, 1862, p. 25.)

Knop, on the other hand, succeeded in bringing the maize plant to full perfection of parts, if not of size, in a solution which was intended and asserted to contain no soda. (*Vs. St.* iii. p. 301.) Nobbe and Siegert came to the same results in similar trials with buckwheat. (*Vs. St.* iv. p. 339.)

The experiments of Knop, and of Nobbe and Siegert, while they prove that much soda is not needful to maize and buckwheat, do not, however, satisfactorily demonstrate that *a trace of soda* is not necessary, because the solutions in which the roots of the plants were immersed stood for months in glass vessels, and could scarcely fail to dissolve some soda from the glass. Again, slight impurity of the substances which were employed in making the solution could scarcely be avoided without extraordinary precautions, and, finally, the seeds of these plants might originally have contained enough soda to supply this substance to the plants in appreciable quantity.

Sodium is contained in all plants.

To sum up, it appears from all the facts before us :

1. That soda is never *totally* absent from plants ; but that,

2. If indispensable, but a minute amount of it is requisite.

3. That the foliage and succulent portions of the plant may include a considerable amount of soda that is not necessary to the plant—that is, in other words, accidental.*

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* Soda is essential to animal life : since all the food of animals is derived, indirectly at least, from the vegetable kingdom, it is a wise provision that soda is *contained in*, even if it be not indispensable to, plants.

Can Soda replace Potash ?—The close similarity of potash and soda, and the variable quantities in which the latter especially is met with in plants, has led to the assumption that one of these alkalies can take the place of the other.

Sodium cannot wholly replace potassium in plants.

Salm-Horstmar, and, more recently, Knop and Schreber, have demonstrated that soda cannot *entirely* take the place of potash—in other words, potash is indispensable to plant life. Cameron concludes, from a series of experiments which it is unnecessary to describe, that soda can *partially* replace potash. A partial replacement of this kind would appear to be indicated by many facts.

Thus, Herapath has made two analyses of asparagus, one of the wild, the other of the cultivated plant, both gathered in flower. The former was rich in soda, the latter almost destitute of this substance, but contained correspondingly more potash. Two analyses of the ash of the beet, one by Wolff (1), the other by Way (2), exhibit similar differences :—

Cultivated plants contain less sodium and more potassium than wild.

	Asparagus.		Field Beet.	
	Wild.	Cultivated.	1.	2.
Potash	18·8	50·5	57·0	25·1
Soda	16·2	trace	7·3	34·1
Lime	28·1	21·3	5·8	2·2
Magnesia	1·5	—	4·0	2·1
Chlorine	16·5	8·3	4·9	34·8
Sulphuric trioxide .	9·2	4·5	3·5	3·6
Phosphoric pentoxide	12·8	12·4	12·9	1·9
Silica	1·0	3·7	3·7	1·7

These results go to show—it being assumed that only a very minute amount of soda, if any, is absolutely necessary to plant life—that the soda which appears to replace potash is accidental, and that the replaced potash is accidental also, or in excess above what is really needed by the plant, and leaves us to infer that the quantity of these bodies absorbed depends to some extent on the composition of the soil, and is to the same degree independent of the wants of vegetation.

The alkalies in maritime and marine plants.

Alkalies in Strand and Marine Plants.—The above conclusions cannot as yet be accepted in case of plants which grow only near or in salt water. Asparagus, the beet and carrot, though native to saline shores, are easily capable of inland cultivation, and indeed grow wild in the almost complete absence of soda compounds.

The common saltworts, *Salsola*, and the samphire, *Salicornia*, are plants which, unlike those just mentioned, never stray inland. Göbel, who has analysed these plants as occurring on the Caspian steppes, found in the soluble part of the ash of the *Salsola brachiata*, 4·8 per cent. of potash and 30·3 per cent. of soda, and in the *Salicornia herbacea* 2·6 per cent. of potash and 36·4 per cent. of soda; the soda constituting in the first instance no less than $\frac{1}{15}$ and in the latter $\frac{1}{24}$ of the entire weight, not of the ash, but of the *air-dry plant*. Potash is never absent from these forms of vegetation (*Agricultur-Chemie*, 3te Auf. p. 66).

According to Cadet (*Liebig's Ernährung der Veg.*, p. 100), the seeds of the *Salsola kali*, sown in common garden soil, gave a plant which côntained both soda and potash; from the seeds of this, sown also in garden soil, grew plants in which only potash-salts with traces of soda could be found.

Another class of plants—the sea-weeds (*algæ*)—derive their nutriment exclusively from the sea-water in which they are immersed. Though the quantity of potash in sea-water is but $\frac{1}{30}$ that of the soda, it is yet a fact, as shown by the analyses of Forchhammer (*Jour. für Prakt. Chem.* 36, p. 391) and Anderson (*Trans. High. and Agr. Soc.* 1855–7, p. 349), that the ash of sea-weeds is, in general, as rich (or even richer) in potash than in soda. In fourteen analyses, by Forchhammer, the average amount of soda in the dry weed was 3·1 per cent.; that of potash 2·5 per cent. In

Anderson's results, the percentage of potash is invariably higher than that of soda.*

Analogy with land plants would lead to the inference that the soda of the sea-weeds is in a great degree accidental, although, necessarily, special investigations are required to establish a point like this.

Iron is essential to plants.

Oxide of Iron is essential to Plants.—It is abundantly proved that a minute quantity of *ferric oxide*, Fe_2O_3, is essential to growth, though the agricultural plant may be perfect if provided with so little as to be discoverable in its ash only by sensitive tests. Knop asserts that maize, which refuses to grow in entire absence of ferric oxide, flourishes when the ferric phosphate, which is exceedingly insoluble, is simply suspended in the solution that bathes its roots for the first four weeks only of the growth of the plant (*Vs. St.* v. p. 101).

We find that the quantity of oxide of iron given in the analyses of the ashes of agricultural plants is small, being usually less than *one* per cent.

Here, too, considerable variations are observed. In the analyses of the seeds of cereals, ferric oxide ranges from an unweighable trace to 2 and even 3 per cent.; in root crops it has been found as high as 5 per cent. Kekulé found in the ash of gluten from wheat 7·1 per cent. of ferric oxide (*Jahresbericht der Chem.* 1851, p. 715). Schulz-Fleeth found 17·5 per cent. in the ash of the albumen from the juice of the potato tuber. The proportion of *ash* is, however, so small that, in case of potato albumen, the ferric oxide amounts to but 0·12 per cent. of the dry substance (*Der Rationelle Ackerbau*, p. 82).

In the wood, and especially in the bark of trees, oxide of iron often exists to the extent of 5—10 per cent. The largest percentages have been found in aquatic plants. In the ash of the duckweed (*Lemna trisulca*) Liebig found

* Doubtless due to the fact that the material used by Anderson was freed by washing from adhering common salt.

7·4 per cent. Gorup-Besanez found in the ash of the leaves of the *Trapa natans* 29·6 per cent., and in the ash of the fruit-envelope of the same plant 68·6 per cent. (*Ann. Ch. Ph.* 118, p. 223).

Probably much of the iron of agricultural and land plants is accidental. In case of the *Trapa natans* we cannot suppose all the ferric oxide to be essential, because the larger part of it exists in the tissues as a brown powder, which may be extracted by acids, and has the appearance of having accumulated there mechanically.

Doubtless a portion of the oxide of iron encountered in analyses of agricultural vegetation has never at any time existed within the vegetable tissues, but comes from the soil which adheres with great tenacity to all parts of plants.

It is not quite certain that manganese is essential to plants.

Oxide of Manganese, Mn_3O_4, is perhaps unessential to Agricultural Plants.—This oxide is commonly less abundant than oxide of iron, and is often, if not usually, as good as wanting in agricultural plants. It generally accompanies oxide of iron where the latter occurs in considerable quantity. Thus, in the ash of *Trapa* it was found to the extent of 7·5—14·7 per cent. Sometimes it is found in much larger quantity than oxide of iron; *e.g.* C. Fresenius found 11·2 per cent. of oxide of manganese in ash of leaves of the beech tree (*Fagus sylvatica*) that contained but 1 per cent. of oxide of iron. In the ash of oak leaves (*Quercus robur*) Neubauer found, of the former 6·6, of the latter but 1·2 per cent.

In ash of the wood of the larch (*Larix Europæa*) Böttinger found 13·5 per cent. Mn_3O_4, and 4·2 per cent. Fe_2O_3; and in ash of wood of *Pinus sylvestris*, 18·2 per cent. Mn_3O_4, and 3·5 per cent. Fe_2O_3. In ash of the seed of colza, Nitzsch found 16·1 per cent. Mn_3O_4, and 5·5 Fe_2O_3. In case of land plants these high percentages are accidental, and specimens of most of the plants just named have been analysed which were free from all but traces of oxide of manganese.

Salm-Horstmar concluded from his experiments that oxide of manganese is indispensable to vegetation. Sachs, Knop, and most other experimenters in water-culture, make no mention of this substance in the mixtures, which in their hands have served for the more or less perfect development of a variety of agricultural plants. But it must be recollected that the magnesium sulphate, or Epsom salts, used in preparing these mixtures, is seldom or never free from considerable traces of manganese. According to Birner and Lucanus, manganese is not needful to the oat plant, and cannot take the place of iron (*Vs. St.* viii. p. 43).

Chlorine is probably present in all plants, and appears essential.

Is Chlorine indispensable to Crops?—What has been written of the occurrence of soda in plants appears to apply in most respects equally well to chlorine. In nature, soda, or rather *sodium*, is generally associated with chlorine as common salt. It is most probably in this form that the two substances usually enter the plant, and in the majority of cases, when one of them is present in large quantity, the other exists in corresponding quantity. Less commonly, the chlorine of plants is in combination with potassium almost exclusively.

Chlorine is doubtless never absent from the perfect agricultural plant, as produced under natural conditions, though its quantity is liable to great variation, and is often very small—so small as to be overlooked, except by the careful analyst. In many analyses of grain chlorine is not mentioned. Its absence, in many cases, is due without doubt to the fact that chlorine is readily dissipated from the ash of substances rich in phosphoric, silicic, or sulphuric compounds, on prolonged exposure to a high temperature. In the later analyses—in which the vegetable substance, instead of being at once burned to ashes at a high red heat, is first charred at a heat of low redness, and then extracted with water, which dissolves the chlorides, and separates them from the unburned carbon and other matters—chlorine is invariably mentioned. In the tables of analyses, the averages of chlorine are undeniably too low. This is especially true of the grains.

The average of chlorine in the twenty-six analyses of wheat by Way and Ogston (p. 136) is but 0·08 per cent., it not being found at all in the ash of twenty-one samples. In Zoeller's later analyses, chlorine is found in every instance, and averages 0·7 per cent. Weber's analysis, as compared with the others, would indicate a considerable range of variability. Weber extracted the charred ash with water, and found 6 per cent. of chlorine, which is six times as much as is given in any other recorded analysis of the wheat grain. This result is in all probability erroneous.

Like soda, chlorine is particularly abundant in the stems and leaves of those kinds of vegetation which grow in soils or other media containing much common salt. It accompanies sodium in strand and marine plants, and, in general, the amount of chlorine in any plant may be largely increased or diminished by supplying its compounds to, or withholding them from, the roots.

Data as to the necessity of chlorine are not complete.

As to the indispensableness of chlorine, we have somewhat conflicting data. Salm-Horstmar concludes that a trace of it is needful to the wheat plant, though many of his experiments in reference to the importance of this element he himself regards as unsatisfactory. Nobbe and Siegert, who have made an elaborate investigation on the nutritive relations of chlorine to buckwheat, were led to conclude that while the stems and foliage of this plant are able to attain a considerable development in the absence of chlorine (the minute amount in the seed itself excepted), the presence of chlorine is essential to the perfection of the grain.

On the other hand, Knop excludes chlorine from the list of necessary ingredients of maize, and from not yet fully described experiments doubts that it is necessary for buckwheat.

Leydhecker, in a more recent investigation, has come to the same conclusions as Nobbe and Siegert regarding the indispensableness of chlorine to the perfection of buckwheat (*Vs. St.* viii. 177).

From a series of experiments in water-culture, Birner and Lucanus (*Vs. St.* viii. 160) conclude that chlorine is not indispensable to the oat plant, and has no specific effect on the production of its fruit. Chloride of potassium increased the weight of the crop, chloride of sodium gave a larger development of foliage and stem, chloride of magnesium was positively deleterious, *under the conditions of their trials.*

Lucanus (*Vs. St.* vii. 363–71) raised clover by water-culture without chlorine, the crop (dry) weighing in the most successful experiments 240 times as much as the seed. Addition of chlorine gave no better result.

Nobbe (notes to above paper) has produced normally developed vetch and pea plants, but only in solutions containing chlorine. Knop, still more recently (*Lehrbuch der Agricultur-Chemie*, p. 615), gives his reasons for not crediting the justness of the conclusions of Nobbe and Siegert and Leydhecker.

Until further more decisive results are reached, we are warranted in adopting, with regard to chlorine as related to *agricultural plants*, the following conclusions, viz.:—

It may be concluded that chlorine is essential to plants.

1. Chlorine is never *totally* absent.
2. If indispensable, but a minute amount is requisite in case of the cereals and clover.
3. Buckwheat, vetches, and perhaps peas, require a not inconsiderable amount of chlorine for full development.
4. The foliage and succulent parts of a plant may include a considerable quantity of chlorine that is not indispensable to the life of the plant.

Necessity of Chlorine for Strand Plants.—A single observation of Wiegmann and Polstorff indicates that *Salsola kali* requires chlorine, though whether it be united to potassium or sodium is indifferent. These experimenters transplanted young saltworts into a pot of garden soil which contained but traces of chlorine, and watered them with a weak solution of chloride of potassium. The plants grew most luxuriantly, blossomed, and completely filled the pot. They were then put out into the earth, without receiving further applications of chlorine compounds, but the next year they became unhealthy, and perished at the time of blossoming.

Silica is a variable element of plants.

Silica is probably indispensable to Crops.—The numerous analyses we now possess indicate that this substance is always present in the ash of all parts of agricultural plants *when they grow in natural soils.*

In the ash of the wood of trees it usually ranges from 1 to 3 per cent., but is often found to the extent of 10—20 per cent., or even 30 per cent., especially in the pine. In leaves, it is usually more abundant than in stems. The ash of turnip-leaves contains 3—10 per cent.; of tobacco-leaves, 5—18 per cent.; of the oat, 11—58 per cent. (Arendt, Norton.) In ash of lettuce, 20 per cent.; of beech-leaves, 26 per cent.; in those of oak, 31 per cent. have been observed (Wicke, *Henneberg's Jour.* 1862, p. 156).

Silica is very abundant in some plants.

The bark or cuticle of many plants contains an extraordinary amount of silica. The Cauto tree of South America (*Hirtella silicia*) is most remarkable in this respect. Its bark is very firm and harsh, and is difficult to cut, having the texture of soft sandstone. In Trinidad, the natives mix its ashes with clay in making pottery. The bark of the Cauto yields 34 per cent. of ash, and of this 96 per cent. is silica (Wicke, *Henneberg's Jour.* 1862, p. 143).

Another plant, remarkable for its content of silica, is the bamboo. The ash of the rind contains 70 per cent., and in the joints of the stem are often found concretions of hydrated silica resembling opal—the so-called *Tabasheer.*

The ash of the common scouring rush (*Equisetum hyemale*) has been found to contain 97·5 per cent. of silica.

The straw of the cereal grains, and the stems and leaves of grasses, both belonging to the botanical family *Gramineæ*, are specially characterised by a large amount of silica, ranging from 40 to 70 per cent. The sedge and rush families likewise contain much of this substance.

Silica is not uniformly distributed in plants.

The *position* of silica in the plant would appear, from the percentages above quoted, to be, in general, at the surface. Although it is found in all parts of the plant, yet the *cuticle* is usually richest, and this is especially true in cases where the amount of silica is large. Davy, in 1799, drew attention to the deposition of silica in the cuticle, and advanced the idea that it serves the plant an office of support similar to that enacted in animals by the bones.

The oldest parts of plants contain most silica.

In the ash of the pine (*Pinus sylvestris*) Wittstein has obtained results which indicate that the *age* of wood or bark greatly influences the amount of silica. He found in

	Per cent.
Wood of a tree, 220 years old . . .	32·5
,, ,, 170 ,, . . .	24·1
,, ,, 135 ,, . . .	15·1

And in—

Bark of a tree, 220 years old . . .	30·3
,, ,, 170 ,, . . .	14·4
,, ,, 135 ,, . . .	11·9

In the ash of the straw of the oat, Arendt found the percentage of silica to increase as the plant approached maturity. So the leaves of forest trees, which in autumn are rich in silica, are nearly destitute of this substance in spring-time. Silica accumulates then, in general, in the older and less active parts of the plants, whether these be external or internal, and is relatively deficient in the younger and really growing portions.

This rule is not without exceptions. Thus, the chaff of wheat, rye, and oats, is richer in silica than any other part of these plants, and Böttinger found the seeds of the pine richer in silica than the wood.

In numerous instances silica is so deposited in or upon the cell-wall, that when the organic matters are destroyed by burning, or removed by solvents, the form of the cell is preserved in a silicious skeleton. This has long been known in case of the Equisetums and Deutzias. Here, the roughnesses of the stems or leaves, which make these plants useful for scouring, are fully incrusted or interpenetrated by silica, and the ashes of the cuticle present the same appearance under the microscope as the cuticle itself.

Lately, Kindt, Wicke, and Mohl have observed that the hairs of nettles, hemp, hops, and other rough-leaved plants, are highly silicious.

The permanence of the bark of some trees has been attributed to the silica, which is often present in abundance. The best textile materials, which are bast-fibres of various plants, viz. common hemp, Manilla hemp (*Musa textilis*), aloe-hemp (*Agave Americana*), common flax, and New Zealand flax (*Phormium tenax*), have been found to contain much silica. In jute (*Corchorus textilis*) some cells are partially incrusted, while cotton fibre is almost free from silica. Wicke (*loc. cit.*) suggests that the durability of textile fibres is to a degree dependent on their content of silica.

Silica seems in part an accidental ingredient of plants.

The great variableness observed in the same plant, and in the same part of the plant, as to the percentage of silica, would indicate that this substance is at least in some degree accidental.

In the ashes of ten samples of tobacco-leaves, Fresenius and Will found silica to range from 5·1 to 18·4 per cent. The analyses of the ash of thirteen samples of pea-straw, grown on different soils from the same seed during the same year, under direction of the "Landes Oeconomie Collegium" of Prussia, gave the following percentages of silica, viz. 0·56; 0·75; 2·30; 2·32; 2·80; 3·29; 3·57; 5·15; 5·82; 8·03; 8·32; 9·77; 21·35. Analyses of the ash of nine samples of colza straw, all produced from the same seed on different soils, gave the following percentages: 1·00; 1·14; 3·02; 3·57; 4·65; 5·08; 7·81; 11·88; 17·12 (*Journal für Prakt. Chem.* xlviii. 474–7). Such instances might be greatly multiplied.

The idea that a part of the silica is accidental is further sustained by the fact observed by Saussure, the earliest investigator of the composition of the ash of plants (*Recherches sur la Végétation*, p. 282), that crops raised on a silicious soil are in general richer in silica than those grown on a calcareous soil. Norton found in the ash of the chaff of the Hopeton oat from a light loam 56·7 per cent., from a poor peat soil 50·0, of silica, while the chaff of the potato oat from a sandy soil gave 70·9 per cent.

Salm-Horstmar obtained some remarkable results in the course of his synthetical experiments on the mineral food of plants, which fully confirmed him in the opinion that silica is indispensable to vegetation. He found that an oat plant, having for its soil pure quartz (insoluble silica), with addition of the other constituents of plant-food, soluble silica excepted, not only grew well, but contained in its ash 23 per cent. of silica, or as great a proportion as exists in the plant raised under normal conditions. This silica may, however, have been mostly derived from the husk of the seed, for the plant was a very small one.

Silica seems of little importance to some plants.

Sachs, in 1862, was the first to publish evidence indicating strongly that silica is not a necessary ingredient of maize. He obtained in his early essays in water-culture a maize plant of considerable development, whose ashes contained but 0·7 per cent. of silica. Shortly afterwards Knop produced a maize plant with 140 ripe seeds, and a dry-weight of 50 grammes (nearly 2 oz. Av.), in a medium so free from silica that a mere trace of this substance could be found in the root, but half a milligramme in the stem, and 22 milligrammes in the fifteen leaves and sheaths. It was altogether absent from the seeds. The ash of the leaves of this plant thus contained but 0·54 per cent. of silica, and the stem but 0·07 per cent. Way and Ogston found in the ash of maize, leaf and stem together, 27·98 per cent. of silica.

Knop was inclined to believe that the little silica he found in his maize plant was due to dust, and did not belong to the tissues of the plant. He remarked, "I believe that silica is not to be classed among the nutritive elements of the Gramineæ, since I have made similar observations in the analysis of the ashes of barley."

Plants have been successfully grown almost without silica.

In the numerous experiments that have been made more recently upon the growth of plants in aqueous solutions, by Sachs, Knop, Nobbe and Siegert, Stohmann, Rautenberg and Kühn, Birner and Lucanus, Leydhecker, Wolff, and Hampe, silica, in nearly all cases, has been excluded, so far as it is possible to do so in the use of glass vessels. This has been done without prejudice to the development of the plants. Nobbe and Siegert and Wolff especially have succeeded in producing buckwheat, maize, and the oat, in full perfection of size and parts, with this exclusion of silica.

The silica of a plant may be diminished or increased artificially.

Wolff (*Vs. St.* viii. p. 200) obtained in the ash of maize thus cultivated, 2 to 3 per cent. of silica, while the same two varieties from the field contained in their ash 11½—13 per cent. The proportion of ash was essentially the same in both cases, viz. about 6 per cent. Wolff's results with the oat plant were entirely similar.

Birner and Lucanus (*Vs. St.* viii. 141) found that the supply of soluble silicates to the oat made its ash very rich in silica (40 per cent.), but diminished the growth of straw, without affecting that of the seed, as compared with plants nearly destitute of silica.

While it is not thus demonstrated that utter absence of silica is no hindrance to the growth of plants which are ordinarily rich in this substance, it is certain that very little will suffice their needs, and highly probable that it is in no way essential to their physiological development.

Other experiments, by Pierre, have shown that the notion attributing the "laying" of corn to a deficiency of silica in the straw, is erroneous.

All the ash-ingredients of a plant may be in excess.

The Ash-ingredients, which are indispensable to Crops, may be taken up in larger quantity than is essential.—More than sixty years ago Saussure described a simple experiment which is conclusive on this point. He gathered a number of peppermint plants, and in some determined the amount of dry matter, which was 40·3 per cent. The roots of others were then immersed in pure water, and the plants were allowed to vegetate 2½ months in a place exposed to air and light, but sheltered from rain.

At the termination of the experiment, the plants, which originally weighed 100, had increased to 216 parts, and the total dry matter of these plants, which at first was 40·3, had become 62 parts. The plants could have acquired from the glass vessels and pure water no considerable quantity of mineral matters. It is plain, then, that the ash-ingredients which were contained in two parts of the peppermint were sufficient for the production and existence of three parts. We may assume, therefore, that at least one-third of the ash of the original plants was in excess, and accidental.

The fact of excessive absorption of essential ash-ingredients is also demonstrated by the precise experiments of Wolff on buckwheat, already described (see p. 149), where the point in question is incidentally alluded to, and the difficulties of deciding how much excess may occur are brought to notice. (See also pp. 163 and 165 in regard to potash and ferric oxide.)

As a further striking instance of the influence of the nourishing medium on the quantity of mineral matters in the plant, the following is adduced, which may serve to put in still stronger light the fact that a plant does not always require what it contains.

The ash-ingredients of a plant may be increased artificially.

Nobbe and Siegert have made a comparative study of the composition of buckwheat, grown on the one hand in garden soil, and on the other in an aqueous solution of saline matters. (The solution contained magnesium sulphate, calcium chloride, potassium phosphate and nitrate, with ferric phosphate, which together constituted 0·316 per cent. of the liquid.) The ash-percentage was much higher in the water plants than in the garden plants, as shown by the subjoined figures (*Vs. St.* v. p. 132):—

	Per cent. of Ash in			
	Stems and Leaves.	Roots.	Seeds.	Entire Plant.
Water plant	18·6	15·3	2·6	16·7
Garden plant	8·7	6·8	2·4	7·1

We have seen that well-developed plants contain a larger proportion of ash than feeble ones, when they grow side by side in the same medium. In disregard of this general rule, the water plant in the present instance has an ash-percentage double that of the land-plant, although the former was a dwarf compared with the latter, yielding by one-sixth as much dry matter. The *seeds*, however, scarcely differ in composition.

Superfluous ash-ingredients are variously disposed of.

Disposition by the Plant of excessive or superfluous Ash-ingredients.—The ash-ingredients taken up by a plant in excess beyond its actual wants may be disposed of in three ways. The soluble matters—those soluble by themselves, and also incapable of forming insoluble combinations with other ingredients of the plant—viz. the alkaline chlorides, sulphates, carbonates, and phosphates, the calcium and magnesium chlorides, may—

1. Remain dissolved in, and diffused throughout, the juices of the plant; or,

2. May exude upon the surface as an efflorescence, and be washed off by rains.

Exudation to the surface has been repeatedly observed in case of cucumbers and other kitchen vegetables, growing in the garden as well as with buckwheat and barley in water-culture (*Vs. St.* vi. p. 37).

Saussure found in the white incrustations upon cucumber leaves, besides an organic body insoluble in water and alcohol, some calcium chloride, with a trace of magnesium chloride. The organic substance so enveloped the calcium chloride as to prevent deliquescence of the latter (*Recherches sur la Vég.* p. 265).

The removal of salts from plants.

Saussure proved that foliage readily yields up saline matters to water. He placed hazel leaves eight successive times in renewed portions of pure water, leaving them therein fifteen minutes each time, and found that by this treatment they lost $\frac{1}{15}$ of their ash-ingredients. The portion thus dissolved was chiefly alkaline salts; but consisted in part of earthy phosphates, silica, and ferric oxide (*Recherches*, p. 287).

Ritthausen has shown that clover which lies exposed to rain after being cut may lose by washing more than one-third of its ash-ingredients.

Mulder (*Chemie der Ackerkrume*, ii. p. 305) attributes to loss by rain a considerable share of the variations in percentage and composition of the fixed ingredients of plants. We must not, however, forget that all the experiments which indicate great loss in this way, have been made on the cut plant, and their results may not hold good to the same extent for uninjured tissues of plants. Further investigations are needed to decide this point.

The segregation of saline matters in plants.

3. The insoluble or nearly insoluble matters, or those which become so in the plant, viz. the calcium sulphate, the oxalates, phosphates, and carbonates of calcium and magnesium, the oxides of iron and manganese and silica, may be deposited as crystals or concretions in the cells, or may incrust the cell-walls, and thus be set aside from the sphere of vital action.

In the denser and comparatively juiceless tissues, as in bark, old wood, and ripe seeds, we find little variation in the amount of soluble matters. These are present in large and variable quantity only in the succulent organs.

The separation of insoluble salts within the plant.

In bark (cuticle), wood, and seed envelopes (husks, shells, chaff), we often find silica, the oxides of iron and manganese, and calcium carbonate—all insoluble substances —accumulated in considerable amount. In bran—the coverings of the seeds of cereals—magnesium phosphate exists in comparatively large quantity. In the dense teak wood, concretions chiefly consisting of hydrocalcic phosphate, $CaHPO_4$, aq., have been noticed. Of a certain species of cactus (*Cactus senilis*) 80 per cent. of the dry matter of the parenchyma consists of crystals, and these are nearly pure calcium oxalate and phosphate.

That the quantity of matters thus segregated is in some cases, and in some degree, proportionate to the excess of them in the nourishing medium in which the plant grows, has been observed by Nobbe and Siegert, who remark that two portions of buckwheat, cultivated by them in a solution and in a garden soil respectively, both contained crystals and globular crystalline masses, consisting probably of calcium and magnesium oxalates and phosphates, but that *these were more abundant in the "solution"-plants, the ash of which was twice as great as that of the "soil"-plants.*

These insoluble substances may either be entirely non-essential, as often appears to be the case with silica, or, having once served the wants of the plant, may be rejected as no longer useful, and by assuming the insoluble form are removed from the sphere of vital action, and become virtually dead matter. They are, in fact, excreted, though not, in general, formally expelled beyond the limits of the plant. They are, to some extent, thrown off into the bark, or into the older wood or pith, or else are encysted in the living cells.

The occurrence of crystallized salts thus segregated in the cells of plants is illustrated by the following cuts. Fig. 20 represents a crystallized concretion of calcium

CHAP. II.

The forms of the saline concretions in plants.

oxalate, having a basis or skeleton of cellulose, from a leaf of the walnut. This concretion, which is attached to the cell-wall, is called a *cystolith* (Payen, *Chimie Industrielle*, Pl. XII.). Fig. 21 is a mass of crystals of the same salt, from the leaf-stalk of rhubarb. Fig. 22 represents similar crystals from the beet-root. In the root of the young bean, Sachs found a ring of cells, containing crystals of calcium sulphate (*Sitzungsberichte der Wien. Akad.* 37, p. 106). Bailey observed in certain parts of the inner bark of the locust tree a series of cells, each of which contained a crystal. In the onion bulb, and many other plants, crystals are abundant (*Gray's Struct. Botany*, 5th ed. p. 59).

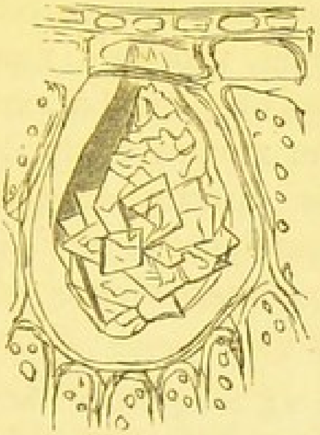

Fig. 20.

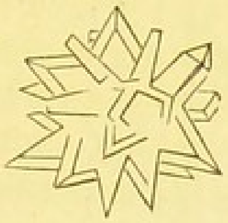

Fig. 21.

Fig. 22.

Some plants excrete mineral matters.

Instances are not wanting in which there is an obvious excretion of mineral matters, or at least a throwing of them off to the surface. Silica, as we have seen, is often found in the cuticle, but it is usually imbedded in the cell-wall. In certain plants, other substances accumulate in considerable quantity without the cuticle. A striking example is furnished by the *Saxifraga incrustata*, a low-growing European plant, which is found in lime soils. The leaves of this saxifrage are entirely coated with a scaly incrustation of calcium carbonate mixed with some magnesium carbonate. At the edges of the leaf, this incrustation acquires a con-

CHAP. II.

Incrustations on leaves.

siderable thickness, as is illustrated by Fig. 23 *a*. In an analysis made by Unger, to whom these facts are due, the fresh (undried) leaves yielded to a dilute acid 4·14 per cent. of calcium carbonate, and 0·82 per cent. of magnesium carbonate.

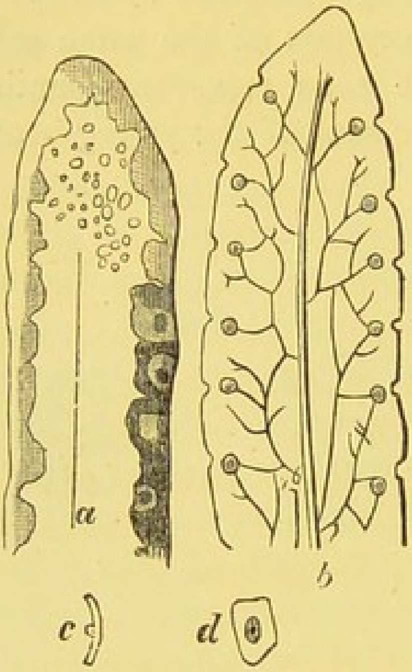

Fig. 23.

Unger learned by microscopic investigation that this excretion of carbonates proceeds mostly from a series of glandular expansions at the margin of the leaf, which are directly connected with the sap-ducts of the plant (*Sitzungsberichte der Wiener Akad.* 43, p. 519).

In Figure 23, *a* represents the appearance of a leaf, magnified 4½ diameters. Around the borders are seen the scales of calcium carbonate; some of these have been detached, leaving round pits on the surface of the leaf; *c*, *d*, exhibit the scales themselves, *c* in profile; *b* shows a leaf, freed from its incrustation by an acid, and from its cuticle by potash solution, so as to exhibit the veins (ducts) and glands, whose course the carbonate of lime chiefly takes in its passage through the plant.

The state of the ash-matters, as they exist in the plant, is not wholly known.

The Ash-ingredients as they exist in the Plant.—It is by no means true that the ash-ingredients always exist in plants in the condition and in the forms which present themselves in our analyses.

Arendt and Hellriegel have studied one aspect of this question, the proportions of soluble and insoluble matters, the former in the ripe oat plant, and the latter in clover at various stages of growth.

Arendt extracted from the leaves and stems of the oat plant, after thorough grinding, the whole of the soluble matters by repeated washings with water.* He found that

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* To extract the soluble parts of the *grain* in this way was impossible.

Much ash-matter in the oat is in a soluble form.

all the sulphuric trioxide and all the chlorine were soluble. Nearly all the phosphoric pentoxide was removed by water. The larger part of the lime, magnesia, soda, and potash, was soluble, though a portion of each escaped solution. Ferric oxide was found in both the soluble and insoluble state. In the leaves, iron was found among the insoluble matters after all phosphoric pentoxide had been removed. Finally, as has been mentioned already, silica was mostly insoluble, though in all cases a small quantity occurred in the soluble condition, viz. 3—8 parts in 10,000 of the dry plant (*Wachsthum der Haferpflanze*, pp. 168, 183-4).

Weiss and Wiesner conclude from their microchemical investigations that iron exists as insoluble compounds of protoxide and sesquioxide, both in the cell-membrane and in the cell-contents (*Sitzungsberichte der Wiener Akad.* 40, p. 278).

The ash-matters of clover are more soluble in the young than in the old plant.

Hellriegel found that a larger proportion of the various bases was soluble in young clover than in the mature plant. As a rule, the leaves gave most soluble matters, the leaf-stalks less, and the stems least. He obtained, among others, the following results (*Vs. St.* iv. p. 59).

Of 100 parts of the following fixed ingredients of clover the percentages dissolved in the sap, and undissolved, were as follow:—

		In young leaves.	In full-grown leaves.
Potash	dissolved	75·2	37·3
	undissolved	24·8	62·7
Lime	dissolved	69·5	72·4
	undissolved	30·5	27·6
Magnesia	dissolved	43·6	78·3
	undissolved	56·4	21·7
Phosphoric pentoxide.	dissolved	20·9	19·9
	undissolved	79·1	80·1
Silica	dissolved	26·8	16·1
	undissolved	73·2	83·9

These researches demonstrate that potassium and sodium —elements, all of whose commonly occurring salts, certain silicates excepted, are readily soluble in water—enter into insoluble combinations in the plant; while phosphoric pentoxide, which forms insoluble salts with lime, magnesia, and ferric oxide, is freely soluble in connexion with these bases in the sap.

Sulphates in the ash do not always represent sulphates in the plant,

It should be added, that *sulphates* may be absent from the plant, or some parts of it, although they are found in the *ashes*. Thus Arendt discovered no sulphates in the lower joints of the stem of oats after blossom, though in the upper leaves, at the same period, sulphuric trioxide (SO_3) formed nearly 7 per cent. of the sum of the fixed ingredients (*Wachsthum der Haferpf.* p. 157). Ulbricht found that sulphates were totally absent from the lower leaves and stems of red clover, at a time when they were present in the upper leaves and blossom (*Vs. St.* iv. p. 30, *Tabelle*). Both Arendt and Ulbricht observed that sulphur existed in all parts of the plants they experimented upon; in the parts just specified, it was, however, no longer combined with oxygen, but had, doubtless, become an integral part of some albuminoid or other complex organic body. Thus the oat stem, at the period above cited, contained a quantity of sulphur, which, had it been converted into sulphuric trioxide, would have amounted to 14 per cent. of the fixed ingredients. In the clover leaf, at a time when it was totally destitute of sulphates, there existed an amount of sulphur, which, in the form of sulphuric trioxide, would have made 13·7 per cent. of the fixed ingredients, or 1 per cent. of the dry leaf itself.*

but, partly, the sulphur of albuminoids.

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* *Arendt* was the first to estimate sulphuric trioxide in vegetable matters with accuracy, and to discriminate it from the sulphur in organic compounds. This chemist determined the sulphates of the oat plant by extracting the pulverized material with acidulated water. He likewise estimated the total sulphur by a special method, and, by subtracting the sulphur of the sulphates from the total, he obtained as a difference that portion of sulphur which belonged to the albuminoids, &c. In his analyses of clover, *Ulbricht* followed a similar plan (*Vs. St.* iii. p. 147). As has already been stated, many of the older analyses are wholly untrustworthy as regards sulphur and sulphates.

The fluorine of the ash.

Other Ash-ingredients.—Salm-Horstmar has described some experiments, from which he infers that *a minute amount of Lithium* and *Fluorine* (the latter as fluoride of potassium) are indispensable to the fruiting of barley (*Jour. für Prakt. Chem.* 84, p. 140). The same observer, some years ago, was led to conclude that a trace of *Titanic acid* is a necessary ingredient of plants. The later results of water-culture would appear to demonstrate that these conclusions are erroneous; but it must not be forgotten that fluorine, for instance, is an essential element of the bones and teeth of the higher animals, and must be present therefore in their vegetable food.

Exhaustion of soils may sometimes be due to the absence of an overlooked ash-ingredient.

It is, moreover, possible, as Mulder has suggested (*Chemie der Ackerkrume*, ii. 341), that the failure of certain crops, after long-continued cultivation in the same soil, may be due to the exhaustion of some of these less abundant and usually overlooked substances. Land not unfrequently becomes "clover-sick," *i.e.* refuses to produce good crops of clover, even with the most copious manurings. In Vaucluse, according to Mulder, the madder crop has suffered a deterioration in quality—the colouring effect of the root having diminished one-fourth—as an apparent result of long cultivation on the same soil, although the seed is annually renewed from Asia Minor, and great care is bestowed on its culture.

The rarer and occasional constituents of plant-ashes.

The newly discovered element, *Rubidium*, has been found in the sugar-beet, in tobacco, coffee, tea, and the grape. It doubtless occurs, perhaps together with *Cæsium*, in many other plants, though in very minute quantity. It is not unlikely that small quantities of these alkali-metals may be found to be of decided influence on the growth of plants. Yet Birner and Lucanus seem to have determined that these bodies, when potash is absent, act as poison to the oat (*Vs. St.* viii. p. 147).

The late investigations of A. Braun and of Risse (Sachs, *Exp. Physiologie*, 153) show that *Zinc* is a usual ingredient

Some plants near zinc mines contain zinc.

of plants growing about zinc mines, where the soil contains carbonate or silicate of this metal. Certain marked varieties of plants are peculiar to, and appear to have been developed by, such soils, viz. a violet (*Viola tricolor*, var. *calaminaris*)* and a penny-cress (*Thlaspi alpestre*, var. *calaminaris*). In the ash of the leaves of the latter plant Risse found 13 per cent. of zinc oxide; in other plants he found from 0·3 to 3·3 per cent.

Copper and other elements occur occasionally in plants.

Copper is often or commonly found in the ashes of plants: and other elements, viz. *Arsenic*, *Baryta*, and *Lead*, have been discovered therein; but as yet we are not fairly warranted in assuming that any of these substances are of importance to agricultural vegetation. The same is true of *Iodine*, which, though an invariable and probably a necessary constituent of many algæ, is not known to exist to any considerable extent in, or to be essential to, any cultivated plants.

The whole subject of the occasional elements of plants requires investigation. Our knowledge on this point is far from complete.

§ 4. FUNCTIONS OF THE ASH-INGREDIENTS.

But little is known with certainty as to the subject of this section.

Sulphates help to produce the albuminoids and the sulphurized oils.

Sulphates.—The albuminoids, which contain sulphur as an essential ingredient, obviously cannot be produced in absence of sulphuric acid, which, so far as we know, is the single source of sulphur to plants. The sulphurized oils of the onion, mustard, horse-radish, turnip, &c., likewise require sulphates for their production.

Phosphates.—The phosphorized oils require phosphates for their elaboration. The physiological function of

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* By some botanists ranked as a distinct species.

The functions of phosphates.

the phosphates, so abundant in the cereals, admits of partial explanation. The soluble albuminoids which are formed in the foliage must pass thence through the cells and ducts of the stem into growing parts of the plant and into the seed, where they accumulate in large quantity. But the albuminoids penetrate membranes with great difficulty and slowness when in the pure state. According to Schumacher (*Physik der Pflanze*, p. 128), potassium phosphate considerably increases the diffusive rate of albumen, and thus facilitates its translocation in the plant.

The alkalies are concerned in the formation of organic acids, &c.

Alkalies and Alkali-earths.—The organic acids, viz. oxalic, malic, tartaric, citric, &c., require alkalies and alkali-earths to form the salts which exist in plants, *e.g.* hydric potassic tartrate in the grape, calcium oxalate in beet leaves, calcium malate in tobacco; and without these bases it is, perhaps, in most cases impossible for the acids to be formed, though in the orange and lemon citric acid exists in the partly free state; and in various plants, as *Sempervirum arboreum* and *Cacalia ficoides*, acids are formed during the night which disappear in the day. The leaves of these plants are sour in the morning, tasteless at noon, and bitter at night. (Heyne and Link.)

The function of silica doubtful.

Silica.—The function of silica might appear to be, in case of the grasses, sedges, and equisetums, to give rigidity to the slender stems of these plants, and enable them to sustain the often heavy weight of the fruit. Two circumstances, however, embarrass the unqualified acceptance of this notion. The first is, that the proportion of silica is not greatest in those parts of the plant which, on this view, would most require its presence. Thus Norton (*Am. Jour. of Sci.* [2] vol. iii. pp. 235–6) found that in the sandy oat the upper half of the dry leaf yielded 16·2 per cent. ash, while the lower half gave but 13·6 per cent. The ash of the upper part contained 52·1 per cent. of silica, while that from the bottom part had but 47·8 per cent. of this ingredient. According to Arendt (*Das Wachsthum der Hafer-*

pflanze, p. 180), the different parts of the oat contain the following quantities of silica respectively :—

	Amount of Silica in 1000 parts of dry substance.		
	Removed by water.	Insoluble in water.	Total.
Lower part of the stem	0·33	1·4	1·7
Middle part of the stem	0·30	4·8	5·1
Upper part of the stem	0·36	13·0	13·3
Lower leaves	0·86	34·3	35·2
Upper leaves	0·52	43·3	43·8

Stiffness of straw does not seem dependent on silica.

We see then plainly that the upper part of the stem and leaves contains more silica than the lower parts, while the lower parts certainly need to possess the greatest degree of strength.

We must not forget, however, as Knop has remarked, that the lower part of the leaf of most cereals and grasses, which envelopes the stem like a sheath, is really the support of the plant as much as or even more than the stem itself.

The results of the many experiments in water-culture by Sachs, Knop, Wolff, and others (see p. 173), in which the supply of silica has been reduced to an extremely small amount, without detriment to the development of plants commonly rich in this substance, would seem to demonstrate that silica does not essentially contribute to the stiffness of the stem.

Wolff distinctly informs us that the maize and oat plants produced by him, in solutions nearly free from silica, were as firm in stalk, and as little inclined to lodge or "lay," as those which grew in the field.

The recommendation to supply silex to grain crops, in order to stiffen the straw and prevent falling of the crop before it ripens, either by directly applying alkali-silicates, or by the use of fertilizers and processes which may render the silica of the soil soluble, must accordingly be considered entirely futile from the point of view of the needs of the crop, as it is from that of the resources of the soil.

Supposed functions of chlorine.

Chlorine.—As has been mentioned, both Nobbe and Leydhecker found that buckwheat grew quite well up to the time of blossom without chlorine. From that period on, in absence of chlorine, remarkable anomalies appeared in the development of the plant. In the ordinary course of growth, starch, which is organized in the mature leaves, does not remain in them to a great extent, but is transferred to the newer organs, and especially to the fruit, where it also accumulates in large quantities. In absence of chlorine, according to the experiments of Nobbe and Leydhecker, the terminal leaves became thick and fleshy, from extraordinary development of cell-tissue, at the same time they curled together, and finally fell off upon slight disturbance. The stem became knotty, transpiration of water was suppressed, the blossoms withered without fructification, and the plant prematurely died. The fleshy leaves were full of starch-grains, and it appeared that, in absence of chlorine, the transfer of starch from the foliage to the flower and fruit was rendered impossible; in other words, chlorine (in combination with potassium or calcium) was concluded to be necessary to, was in fact the agent of, this transfer. Knop believes, however, that these phenomena are due to some other cause, and that chlorine is not essential to the perfection of the fruit of buckwheat (see p. 169).

Intimate connexion between iron and chlorophyll.

Iron.—We are in possession of some interesting facts, which appear to throw light upon the function of this metal in the plant. In case of the deficiency of this element, foliage loses its natural green colour, and becomes pale or white even in the full sunshine. In absence of iron a plant may unfold its buds at the expense of already organized matters, as a potato-sprout lengthens in a dark cellar, or in the manner of fungi and white vegetable parasites; but the leaves thus developed are incapable of assimilating carbon, and actual growth or increase of total weight is impossible. Salm-Horstmar first showed that plants which grow in soils or media destitute of iron are very pale

CHAP. II.

Marked effects of iron on plants.

in colour, and that addition of iron-salts very speedily gives them a healthy green. Sachs found that maize-seedlings, vegetating in solutions free from iron, had their first three or four leaves green; several following were white at the base, the tips being green, and afterwards perfectly white leaves unfolded. On adding a few drops of ferric sulphate or chloride to the nourishing medium, the foliage was plainly altered within twenty-four hours, and in three to four days the plant acquired a deep, lively green. Being afterwards transferred to a solution destitute of iron, perfectly white leaves were again developed, and these were brought to a normal colour by addition of iron.

E. Gris was the first to trace the reason of these effects, and first found, in 1843, that watering the roots of plants with solutions of iron, or applying such solutions externally to the leaves, shortly developed a green colour where it was previously wanting. By microscopic studies he found that in the absence of iron, the protoplasm of the leaf-cells remains a colourless or yellow mass, destitute of visible organization. Under the influence of iron, grains of *chlorophyll* begin at once to appear, and pass through the various stages of normal development. We know that the power of the leaf to decompose carbonic acid and assimilate carbon, resides in the cells that contain chlorophyll, or, we may say, in the chlorophyll-grains themselves. We understand at once, then, that in the absence of iron, which is essential to the formation of chlorophyll, there can be no proper growth, no increase at the expense of the external atmospheric food of vegetation.

Risse, under Sachs' direction (*Exp. Physiologie*, 143), demonstrated that *manganese* cannot take the place of iron in the office just described.

Relation of the ash ingredients of plants to animal life.

Functions of other Ash-ingredients. — As to the special uses of the other fixed matters we know little. It is certain that potash, lime, and magnesia are indispensable to the life and health of animals; and since all

Some ash-ingredients are directly, others indirectly, concerned in the building-up of plants.

animals derive directly, or indirectly, their sustenance from the vegetable world, it is obvious that these substances must be ingredients of plants in order to fit the latter for their nutritive office; but why no vegetable cell can be elaborated without potash, why lime and magnesia are imperative necessities to plants, we are as yet unable fully to comprehend. But these bases without doubt determine the production of certain vegetable acids, and contribute in their saline combinations, as phosphates, sulphates, nitrates, &c. &c., to the formation of complex organic bodies, containing the various non-metallic constituents of plants. We have already described, with some minuteness, the most important of these direct and indirect functions of the ash-ingredients in building up the various structures and constituents of plants. Further experiments, however, are required in this direction.

CHAPTER III.

§ 1. QUANTITATIVE RELATIONS AMONG THE INGREDIENTS OF PLANTS.

Chap. III.

Quantitative relations between ash-ingredients rarely observed.

VARIOUS attempts have been made to exhibit definite numerical relations between certain different ingredients of plants.

Equivalent Replacement of Bases.—In 1840, Liebig, in his *Chemistry applied to Agriculture*, suggested that the various bases might displace each other in equivalent quantities, *i.e.* in the ratio of their molecular weights; and that were such the case, the discrepancies to be observed among analyses should disappear, if the latter were interpreted on this view. Liebig instanced two analyses of the ashes of fir-wood and two of pine-wood made by Berthier and Saussure, as illustrations of the correctness of this theory. In the fir of Mont Breven, magnesium carbonate was present; in that of Mont La Salle, it was absent. In the former existed but half as much potassium carbonate as in the latter. In both, however, the same total percentage of alkaline and earthy carbonates was found, and the amount of oxygen in these bases was the same in both instances.

Since the unlike but equivalent quantities of potash, lime, and magnesia, contain the same quantity of oxygen, these bases, in the case in question, do displace each other in equivalent proportions. The same was true for the ash

This is due to the acci-dental occurrence of ash-matters in plants.

of pine-wood, from Allevard and from Norway. On applying this principle to other cases it has, however, signally failed. The fact that the plant can contain accidental or unessential ingredients, renders it obvious that, however truly such a law as that of Liebig may in any case apply to those substances which are really concerned in the vital actions, it will be impossible to read the law in the results of the majority of analyses.

Attempts to establish definite relations between phosphates and albuminoids fail.

Relation of Phosphates to Albuminoids.—Liebig likewise considers that a definite relation must and does exist between the phosphoric acid and the albuminoids of the ripe grains. That this relation is not constant, is evident from the following statement of the data that have been as yet obtained, bearing on the question. In the table, the amount of nitrogen representing the albuminoids (see p. 94) found in various analyses of rye and wheat grain, is compared with that of phosphoric pentoxide (P_2O_5), the latter being taken as unity.

							P_2O_5.		N.
In	7	Samples of	Rye-grain	Fehling & Faiszt	found the	ratio of P_2O_5 to N to range from	1	:	1·97—3·06
	11	do.	do.	Mayer	do.	do.	1	:	2·04—2·38
	5	do.	do.	Bibra	do.	do.	1	:	1·68—2·81
	6	do.	do.	Siegert	do.	do.	1	:	2·35—2·96
	28	do.	do.	the extreme range was from			1	:	1·68—3·06
In	2	Samples of	Wheat-grain	Fehling & Faiszt	found	the ratio of P_2O_5 to N to range from	1	:	2·71—2·86
	11	do.	do.	Mayer	do.	do.	1	:	1·83—2·19
	2	do.	do.	Zoeller	do.	do.	1	:	2·02—2·16
	30	do.	do.	Bibra	do.	do.	1	:	1·87—3·55
	6	do.	do.	Siegert	do.	do.	1	:	2·30—3·33
	51	do.	do.	the extreme range was from			1	:	1·83—3·55

Siegert, who collected these data (*Vs. St.* iii. 147), and who experimented on the influence of phosphatic and nitrogenous fertilizers upon the composition of wheat and rye, gives, as the general results of his special inquiries, that *Phosphoric acid and Nitrogen stand in no constant* *relation to each other. Nitrogenous manures increase the per cent. of nitrogen and diminish that of phosphoric acid.*

Other Relations.—All attempts to trace simple and constant relations between other ingredients of plants, viz. between starch and alkalies, cellulose and silica, &c. have proved fruitless.

It has, on the other hand, been demonstrated that the proportions of the constituents are constantly changing from day to day as the relative mass of the individual organs themselves undergoes perpetual variation.

In adopting the above conclusions, it is not asserted that such definite relations between phosphates and albuminoids, or between starch and alkalies, as Liebig first suggested and as various observers have laboured to show, do not exist, but simply that they do not appear from the analyses of plants.

§ 2. The Composition of the Plant in successive Stages of Growth.

Plants alter in composition as they develop.

We have hitherto regarded the composition of the plant mostly in a *relative* sense, and have instituted no comparisons between the absolute quantities of its ingredients at different stages of growth. We have obtained a series of isolated views of the entire plant, or of its parts, at some certain period of its life, or when placed under certain conditions, and have thus sought to ascertain the peculiarities of these periods, and to estimate the influence of these conditions. It now remains to attempt in some degree the combination of these sketches into a panoramic picture—to give an idea of the composition of the plant *at the successive steps of its development.* We shall thus gain some insight into the rate and manner of its growth, and acquire data that have an important bearing on the requisites for its perfect nutrition. For this purpose we need to study not only the relative percentage or composition of the plant and of its parts at various stages of its existence, but we must also inform ourselves as to the total quantities of each ingredient at these periods.

We shall select from the data at hand those which illustrate the composition of the oat plant. Not only the ash-ingredients, but also the organic constituents, will be noticed, so far as our information and space permit.

The composition of the oat at different periods of growth

The Composition and Growth of the Oat Plant may be studied as a type of an important class of agricultural plants, viz. the *annual cereals*—plants which complete their existence in one summer, and which yield a large quantity of nutritious seeds—the most valuable result of culture. The oat plant was first studied in its various parts and at different times of development by Professor John Pitkin Norton, of Yale College. His laborious research, published in 1846 (*Trans. Highland and Agr. Soc.* 1845–7, also *Am. Jour. of Sci. and Arts*, vol. iii. 1847), was the first step in advance of the single and disconnected analyses which had previously been the only data of the agricultural physiologist. For several reasons, however, the work of Norton was imperfect. The analytical methods employed by him, though the best in use at that day and handled by him with great skill, were not adapted to furnish results trustworthy in all particulars. Fourteen years later, Arendt,* at Moeckern, and Bretschneider,† at Saarau, in Germany, at the same time, but independently of each other, resumed the subject, and to their labours the subjoined figures and conclusions are due.

has been studied by Norton, Arendt, and Bretschneider.

Here follows a statement of the periods at which the plants were taken for analysis.

1st Period	June 18, Arendt—Three lower leaves unfolded, two upper still closed. „ 19, Bretschneider—Four to five leaves developed.

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[*] *Wachsthumsverhältnisse der Haferpfl.*, *Jour. für Prakt. Chem.* 76, 193.

[†] *Das Wachsthum der Haferpflanze.* Leipzig, 1859.

2d Period { June 30 (12 days), Arendt—Shortly before the plants were fully headed.
„ 29 (10 days), Bretschneider—The plants were headed.

3d Period { July 10 (10 days), Arendt—Immediately after bloom.
„ 8 (9 days), Bretschneider—Full bloom.

4th Period { July 21 (11 days), Arendt—Beginning to ripen.
„ 28 (20 days), Bretschneider—Beginning to ripen.

5th Period { July 31 (10 days), Arendt—Fully ripe.
Aug. 6 (9 days), Bretschneider—Fully ripe.

Conditions of the experiment similar but not identical.

It will be seen that the periods, though differing somewhat as to time, correspond almost perfectly in regard to the development of the plants. It must be mentioned that Arendt carefully selected luxuriant plants of equal size, so as to analyse a uniform material (see p. 99), and took no account of the yield of a given surface of soil. Bretschneider, on the other hand, examined the entire produce of a square rod. The former procedure is best adapted to study the composition of the well-nourished *individual plant;* the latter gives a truer view of the *crop.*

The unlike character of the material as just indicated is but one of the various causes which might render the two series of observations discrepant. Thus, differences in soil, weather, and seeding, would necessarily influence the relative as well as the absolute development of the two crops. The results are, notwithstanding, strikingly accordant in many particulars. In all cases the roots were not, and could not be, included in the investigation, as it is impossible to free them from adhering soil.

The total weight of crops increases in the first three periods, then lessens.

The Total Weight of Crop per English Acre, at the end of each period, was as follows:

TABLE I.—*Bretschneider.*

1st Period	6,358 lbs. Avoirdupois.
2d „	10,603 „ „
3d „	16,523 „ „
4th „	14,981 „ „
5th „	10,622 „ „

The Total Weights of Water and Dry Matter for all but the second period—the material of which was accidentally lost—were:

The total weight of dry matter increases through the whole season.

TABLE II.—*Bretschneider*.

	Dry Matter. lbs. Av. per acre.	Water. lbs. Av. per acre.
1st Period	1,284	5,074
3d ,,	4,383	12,240
4th ,,	5,427	14,983
5th ,,	6,886	3,736

1.—From Table I. it is seen: That the weight of the live crop is greatest at or just before the time of blossom.* After this period the total weight diminishes as it had previously increased.

2.—From Table II. it becomes manifest: That the organic tissue (dry matter) continually increases in quantity up to the maturity of the plant; and

The water of the crop lessens during the fifth period only.

3.—The loss after the third period falls exclusively upon the water of vegetation. At the time of blossom the plant has its greatest absolute quantity of water, while its least absolute quantity of this ingredient is found when it is fully ripe.

By taking the difference between the weights of any two periods, we obtain:

The Increase or Loss of Dry Matter and Water during each period.

TABLE III.—*Bretschneider*.

	Dry Matter. lbs. per acre.	Water. lbs. per acre.
1st Period	1,284 gain	5,073 gain.
2d ,,	3,099 ,,	7,166 ,,
4th ,,	1,044 ,,	2,684 loss.
5th ,,	1,459 ,,	5,820 ,,

On dividing the above quantities by the number of days of the respective periods, there results:—

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* In Arendt's experiment at the time of "heading out," third period.

The Average Daily Gain or Loss per Acre during each period.

TABLE IV.—*Bretschneider.*

	Dry Matter.	Water.
1st Period	22 lbs. gain	87 lbs. gain.
3d ,,	163 ,, ,,	382 ,, ,,
4th ,,	65 ,, ,,	167 ,, loss.
5th ,,	112 ,, ,,	447 ,, ,,

The period of blossoming is the period of most active growth.

4.—Table III., and especially Table IV., show that the gain of organic matter in Bretschneider's oat crop went on most rapidly at or before the time of blossom (according to Arendt, at the time of heading out). This was, then, the period of most active growth. Afterward the rate of growth diminished by more than one-half, and at a later period increased again, though not to the maximum.

Absolute Quantities of Carbon, Hydrogen, Oxygen, Nitrogen, and Ash, in the dry oat crop at the conclusion of the several periods (*lbs. per acre*):

TABLE V.—*Bretschneider.*

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.*
1st Period	593	80	455	46	110
3d ,,	2,137	286	1,575	122	263
4th ,,	2,600	343	2,043	150	291
5th ,,	3,229	407	2,713	167	372

The proportion of volatile to non-volatile matters varies slightly with growth.

Relative Quantities of Carbon, Hydrogen, Oxygen, Nitrogen, usually called **Organic Matter, and of Ash** in the dry oat crop, at the end of the several periods (*per cent.*):

TABLE VI.—*Bretschneider.*

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Organic Matter.	Ash.
1st Period	46·22	6·23	35·39	3·59	91·43	8·57
3d ,,	48·76	6·53	35·96	2·79	94·04	5·96
4th ,,	47·91	6·33	37·65	2·78	94·67	5·33
5th ,,	46·89	5·88	39·40	2·43	94·60	5·40

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[*] In Bretschneider's analyses, "ash" signifies the residue left after carefully burning the plant. In Arendt's investigation the sulphur and chlorine were determined in the unburnt plant.

Relative Quantities of Carbon, Hydrogen, Oxygen, and Nitrogen, in dry substance, after deducting the somewhat variable amount of ash (*per cent.*):

TABLE VII.—*Bretschneider.*

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.
1st Period	50·55	6·81	38·71	3·93
3d ,,	51·85	6·95	38·24	2·86
4th ,,	50·55	6·96	39·83	2·93
5th ,,	49·59	6·21	41·64	2·56

5.—The Tables V., VI., and VII. demonstrate that while the absolute quantities of the elements of the dry oat plant continually increase to the time of ripening, they do not increase in the same proportion. In other words, the plant requires, so to speak, a change of diet as it advances in growth. They further show that Nitrogen and Ash are relatively more abundant in the young than in the mature plant; in other words, the rate of assimilation of Nitrogen and fixed ingredients falls behind that of Carbon, Hydrogen, and Oxygen. Still otherwise expressed, the plant as it approaches maturity organizes relatively more amyloids and relatively less albuminoids.

Plants produce more amyloids and less albuminoids as they mature.

The relations just indicated appear more plainly when we compare **the Quantities of Nitrogen, Hydrogen, and Oxygen, assimilated during each period,** calculated upon the amount of Carbon assimilated in the same time and assumed at 100.

TABLE VIII.—*Bretschneider.*

	Carbon.	Nitrogen.	Hydrogen.	Oxygen.
1st Period	100	7·8	13·4	73·6
3d ,,	100	4·9	13·3	72·5
4th ,,	100	6·1	12·3	100·8
5th ,,	100	2·6	10·6	106·5

From Table VIII. we see that the ratio of Hydrogen to Carbon regularly diminishes as the plant matures; that of Nitrogen falls greatly from the infancy of the plant to the period of full bloom, then strikingly increases during the first stages of ripening, but falls off at last to minimum. The ratio of Oxygen to Carbon is the same during the first and third periods, but increases remarkably from the period of full blossom until the plant is ripe.

As already stated, the largest absolute assimilation of all ingredients—most rapid growth—takes place at the time of heading out, or blossom. At this period all the volatile elements are assimilated at a nearly equal rate, and at a rate equal to that at which the fixed matters (ash) are absorbed. In the first period, Nitrogen and Ash; in the fourth period, Nitrogen and Oxygen; in the fifth period, Oxygen and Ash, are assimilated in largest proportion.

The daily increase is most marked when "heading out."

This is made evident by calculating for each period **the Daily Increase of each Ingredient,** the amount of the ingredients in the ripe plant being assumed at 100 as a point of comparison. The figures resulting from such a calculation are given in

TABLE IX.—*Bretschneider.*

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.
1st Period	0·31	0·33	0·28	0·47	0·50
3d ,,	2·51	2·68	2·17	2·39	2·13
4th ,,	0·89	0·88	1·07	1·06	0·47
5th ,,	1·49	1·16	1·89	0·75	1·70

The increased assimilation of the fifth over the fourth period is in all probability only apparent. The results of analysis, as before mentioned, refer only to those parts of the plant that are above ground. The activity of the foliage in gathering food from the atmosphere is doubtless greatly diminished before the plant ripens, as evidenced by the leaves turning yellow and losing water of vegetation. The increase of weight in the plant above ground probably proceeds from matters previously stored in the roots, which now are transferred to the fruit and foliage, and maintain the growth of these parts after their power of assimilating inorganic food (CO_2, H_2O, P_2O_5, N_2O_5) is lost.

The following statement exhibits the **Average Daily Increase of Carbon, Hydrogen, Oxygen, Nitrogen, and Ash** (in lbs. per acre) during the several periods :—

TABLE X.—*Bretschneider.*

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.
1st Period	8·43	1·13	6·30	0·65	1·56
3d ,,	66·95	8·94	48·06	3·30	6·55
4th ,,	23·84	2·95	24·06	1·47	1·44
5th ,,	39·85	3·89	42·44	1·04	5·23

Turning now to Arendt's results, which are carried more into detail than those of Bretschneider, we will notice

Arendt's study of the oat.

A.—The Relative (*percentage*) **Composition of the Entire Plant and of its Parts,**[*] during the several periods of vegetaion.

1. *Fibre*[†] is found in greatest relative quantity—40 per cent.—in the lower joints of the stem, and from the time when the grain "heads out" to the period of bloom. Relatively considered, there occur great variations in the same part of the plant at different stages of growth. Thus, in the ear, which contains the least fibre, the quantity of this substance regularly diminishes, not absolutely, but only relatively, as the plant becomes older, sinking from 27 per cent. at "heading out" to 12 per cent. at maturity. In the leaves which, as regards fibre, stand intermediate between the stem and ear, this substance ranges from 22 per cent. to 38 per cent. Previous to blossom, the upper leaves, after-

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[*] Arendt selected large and well-developed plants, divided them into six parts, and analysed each part separately. His divisions of the plants were—1, the three lowest joints of the stem; 2, the two middle joints; 3, the upper joint; 4, the three lowest leaves; 5, the two upper leaves; 6, the ear. The stems were cut just above the nodes, the leaves included the sheaths, the ears were stripped from the stem. Arendt rejected all plants which were not perfect when gathered. When nearly ripe, the cereals, as is well known, often lose one or more of their lower leaves. For the numerous analyses on which these conclusions are based we must refer to the original.

[†] I.e. *Crude cellulose* (see p. 41, et seq.).

wards the lower leaves, are the richest in fibre. In the lower leaves, the maximum (33 per cent.) is found in the fourth; in the upper leaves, 38 per cent. in the second period.

The apparent diminution in amount of fibre is due in all cases to increased production of other ingredients.

Fat is unequally distributed.

2. *Fat and Wax* are least abundant in the stem. Their proportion increases, in general, in the upper parts of the stem, as well as in the later stages of its growth. The range is from 0·2 per cent. to 3 per cent. In the ear the proportion increases from 2 per cent. to 3·7 per cent. In the leaves the quantity is much larger and is mostly in the form of wax. The smallest proportion is 4·8 per cent., which is found in the upper leaves, when the plant is ripe. The largest proportion (10 per cent.) exists in the lower leaves, at the time of blossom. The relative quantities found in the leaves undergo considerable variation from one stage of growth to another.

Great variations in sugar, starch, &c., occur during growth.

3. *Non-nitrogenous matters, other than fibre—starch, sugar, &c.**—undergo great and irregular variation. In the stem the largest percentage (57 per cent.) is found in the young lower joints; the smallest (43 per cent.) in ripe upper straw. Only in the ear occurs a regular increase, viz. from 54 to 63 per cent.

4. *The Albuminoids*,† in Arendt's investigation, exhibit a somewhat different relation to the vegetable substance from what was observed by Bretschneider, as seen from the subjoined comparison of the percentages found at the different periods:

	PERIODS.				
	I.	II.	III.	IV.	V.
Arendt	20·93	11·65	10.86	13·67	14·30
Bretschneider	22·73	—	17·67	17·61	15·39

These differences may be variously accounted for. They are due, in part, to the fact that Arendt analysed only

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* What remains after deducting fat and wax, albuminoids, fibre, and ash, from the dry substance, is here included.

† Calculated by multiplying the percentage of nitrogen by 6·33.

large and perfect plants. Bretschneider, on the other hand, examined all the plants of a given plot, large and small, perfect and injured. The differences illustrate what has been already insisted on, viz. that the development of the plant is greatly modified by the circumstances of its growth, not only in reference to its external figure, but also as regards its chemical composition.

Nitrogen is differently distributed during growth.

The relative distribution of nitrogen in the parts of the plant at the end of the several periods is exhibited by the following table, simple inspection of which shows the relative fluctuations in the percentage of this element. The *percentages* are arranged for each period separately, proceeding from the highest to the lowest :

PERIODS.

I.	II.	III.	IV.	V.
Upper leaves. 3·74	Lower leaves. 2·39	Upper leaves. 2·27	Ears. 2·85	Ears. 3·04
Lower leaves. 3·38	Upper leaves. 2·19	Lower leaves. 2·18	Upper leaves. 1·91	Upper leaves. 1·74
Lower leaves. 2·15	Ears. 2·06	Ears. 1·85	Lower leaves. 1·62	Upper stem. 1·56
—	Middle stem. 1·52	Upper stem. 1·34	Upper stem. 1·60	Lower leaves. 1·43
—	Upper stem. 0·87	Middle stem. 0·98	Middle stem. 1·20	Middle stem. 1·17
—	Lower stem. 0·80	Lower stem. 0·88	Lower stem. 0·83	Lower stem. 0·79

Ash is greatest during Period I.

5. *Ash.*—The agreement of the percentages of ash in the entire plant in corresponding periods of the growth of the oat in the independent examinations of Bretschneider and Arendt is remarkably close, as appears from the figures below :

PERIODS.

	I.	II.	III.	IV.	V.
Bretschneider	8·57	—	5·96	5·33	5·40
Arendt	8·03	5·24	5·44	5·20	5·17

The diminution at the second, increase at the third, and subsequent diminution at the fourth period, are observed to run parallel in both cases.

As regards the several parts of the plant, it was found by Arendt that of the *stem* the upper portion was richest in ash throughout the whole period of growth. Of the *leaves*, on the contrary, the lower contained most fixed matters. In the *ear* there occurred a continual decrease from its first appearance to its maturity, while in the stem and leaves there was, in general, a progressive increase towards the time of ripening. The greatest percentage (10·5 per cent.) was found in the ripe leaves; the smallest (0·78 per cent.) in the ripe lower straw.

Far more interesting and instructive than the relative proportions are

The absolute quantities of constituents in the (dry) oat plant.

B.—The Absolute Quantities of the Ingredients found in the Plant at the conclusion of the several periods of growth.—These absolute quantities, as found by Arendt, in a given number of carefully selected and vigorous plants, do not accord with those obtained by Bretschneider from a given area of ground, nor could it be expected that they should, because it is next to impossible to cause the same amount of vegetation to develop on a number of distinct plots.

Though the results of Bretschneider more nearly represent the crop as obtained in farming, those of Arendt give a truer idea of the plant when situated in the best possible conditions, and attaining a uniformly high development. We shall not attempt to compare the two sets of observations, since, strictly speaking, in most points they do not admit of comparison.

From a knowledge of the absolute quantities of the substances contained in the plant at the ends of the several periods, we may at once estimate the *rate of growth*, i.e. *the rapidity with which the constituents of the plant are either taken up or organized.* The accompanying table, which gives in successive columns the *total weights of* 1,000 *oat plants at the end* of the several periods, and (by subtracting the first from the second, the second from the third, &c.) the *gain from matters absorbed or produced during* each period, will serve to justify the deductions that follow, which are taken from the treatise of Arendt, and which apply, of course, only to the plants examined by this investigator.

Chap. III.

The absolute quantities of each ingredient of 1,000 dry oat plants.

1,000 ENTIRE OAT PLANTS (WATER-FREE).

	(1) Contain at end of. (2) *Absorb or produce within.*								
	Period I. 3 leaves open.*	Period II. Heading out.		Period III. Blossoming.		Period IV. Beginning to ripen.		Period V. Ripe.	
	1 & 2	1	2	1	2	1	2	1	2
Fibre	103.3	459·7	356·4	564·8	105·1	545·0	*Loss*	550·6	*Loss*
Fat	20.1	48.9	28·8	82·9	34·0	97·6	14·7	89·8	*Loss*
Other non-nitrogenous matters	201·4	624·6	423·2	916·7	292·1	1242·6	325·9	1340·0	97·4
Albuminoids	95·4	158·9	63·5	202·8	43·9	317·8	115·0	351·6	34·2
Organic matter	419·2	1292·2	873·0	1767·2	475·1	2203·0	435·8	2331·6	128·6
Silica	6·39	15·82	9·43	25·45	9·63	34·66	9·21	36·32	1·66
Sulphuric trioxide	1·06	2·71	1·65	2·68	0	4·83	2·12	5·34	0·41
Phosphoric pentoxide	3·27	5·99	2·72	10·32	4·33	12·90	2·58	14·23	1·33
Ferric oxide	0·20	0·46	0·26	0·61	0·15	0·83	0·22	0·58	*Loss*
Lime	4·48	8·50	4·02	11·60	3·10	14·49	2·89	14·71	0·22
Magnesia	1·53	2·71	1·18	3·71	1·01	5·42	1·71	6·45	1·03
Chlorine	2·28	3·62	1·34	5·32	1·70	5·96	0·64	5·78	*Loss*
Soda	0·86	1·28	0·42	1·47	0·19	1·12	*Loss*	0·87	*Loss*
Potash	17·05	31·11	14·06	40·20	9·09	44·33	4·13	43·76	*Loss*
Ash	36·60	70·08	33·48	100·41	30·33	120·75	20·34	126·93	7·18
Dry Matter	455·8	1363·6	907·8	1867·6	504·0	2323·8	456·2	2458·5	134·7

* The weights in this table are *grams*. One gram = 15·434 grains. As the weights have mostly a comparative value, reduction to the English standard is unnecessary.

1. The plant increases in *total weight* (dry matter) through all its growth, but to unequal degrees in different

The greatest growth at "heading out,"

periods. The greatest growth occurs at the time of heading out; the slowest, within ten days of maturity.

We may add that the increase of the oat after blossom takes place mostly in the seed, the other organs gaining but little. The lower leaves almost cease to grow after the second period.

when fibre also is chiefly found.

2. *Fibre* is produced most largely during the time of heading out (second period). When the plant has finished blossoming (end of third period), the formation of fibre entirely ceases. Afterwards there appears to occur a slight diminution of this substance, probably due to unavoidable loss of lower leaves, but not to a resorption or metamorphosis in the plant.

3. *Fat* is formed most largely at the time of blossom. It ceases to be produced some weeks before ripening.

Formation of albuminoids irregular.

4. The formation of *Albuminoids* is irregular. The greatest amount is organized during the fourth period (after blossoming). The gain in albuminoids within this period is two-fifths of the total amount found in the ripe plant, and also is nearly two-fifths of the entire gain of organic substance in the same period. The absolute amount organized in the first period is not much less than in the fourth; but in the second, third, and fifth periods, the quantities are considerably smaller.

Bretschneider gives the data for comparing the production of albuminoids in the oat crop examined by him with Arendt's results. Taking the quantity found at the conclusion of the first period as 100, the amounts gained during the subsequent periods are related as follow :—

	PERIODS.						
	I.	II.	III.	(II. & III.)	IV.	(II. III. & IV.)	V.
Arendt . .	100 . .	67 . .	46 . .	(113) . .	120 . .	(233) . .	36
Bretschneider	100 . .	? . .	? . .	(165) . .	62 . .	(227) . .	35

We perceive striking differences in the comparison. In Bretschneider's crop, the increase of albuminoids goes on most rapidly in the third period, and sinks rapidly during

The production of albuminoids is easily affected.

the time when in Arendt's plants it attained the maximum. Curiously enough, the gain in the second, third, and fourth periods, taken together, is in both cases as good as identical (233 and 227), and the gain during the last period is also equal. This coincidence is doubtless, however, merely accidental. Comparisons with other crops of oats, examined, though very incompletely, by Stöckhardt (*Chemischer Ackersmann*, 1855,) and Wolff (*Die Erschöpfung des Bodens durch die Cultur*, 1856), *demonstrate that the rate of assimilation is not related to any special times or periods of development, but depends upon the stores of food accessible to the plant, and the favourableness of the weather to growth.*

Ratio of gain of amyloids to albuminoids indeterminate.

The following figures, which exhibit for each period of both crops a comparison of the gain in albuminoids with the increase of the other organic matters, further demonstrate that in the act of organization, the nitrogenous principles have no close quantitative relations to the non-nitrogenous bodies (amyloids and fats).

The quantities of albuminoids gained during each period being represented by 10, the amounts of amyloids, &c., are seen from the subjoined ratios:

	PERIODS.				Ratio in Ripe Plant.
	I.	II. & III.	IV.	V.	
Arendt . .	10 : 34	10 : 114	10 : 28	10 : 25	10 : 66
Bretschneider	10 : 30	10 : 50	10 : 46	10 : 120	10 : 51

Ash-ingredients are less freely absorbed towards maturity.

5. The *Ash-ingredients* of the oat are absorbed throughout its entire growth, but in regular diminishing quantity. The gain during the first period being 10, that in the second period is 9, in the third 8, in the fourth 5½, in the fifth 2 nearly.

The ratios of gain in ash-ingredients to that in entire dry substance, are as follow, ash-ingredients being assumed as 1, in the successive periods:

1 : 12½ 1 : 27 1 : 16 1 : 23 1 : 19

Accordingly, the absorption of ash-ingredients is not proportional to the growth of the plant, but is to some degree accidental, and independent of the wants of vegetation.

The constituents during each period tabulated.

Recapitulation.—Assuming the quantity of each proximate element in the ripe plant as 100, it contained at the end of the several periods the following amounts :—

	Fibre. Per cent.	Fat. Per cent.	Amyloids. Per cent.	Albuminoids. Per cent.	Ash. Per cent.
I. Period	18	20	15	27	29
II. ,,	81	50	47	45	55
III. ,,	100	85	70	57	79
IV. ,,	100	100	92	90	95
V. ,,	100	100	100	100	100

The gain during each period tabulated.

The *gain* during each period was accordingly as follows :—

	Fibre. Per cent.	Fat. Per cent.	Amyloids. Per cent.	Albuminoids. Per cent.	Ash. Per cent.
I. Period	18	20	15	27	29
II. ,,	63	30	32	18	26
III. ,,	19	35	23	12	24
IV. ,,	0	15	22	33	16
V. ,,	0	0	8	10	5
	100	100	100	100	100

The results of Arendt and Bretschneider as to ash ingredients tabulated.

6. As regards the *individual ingredients of the ash*, the plant contained at the end of each period the following amounts, the total quantity in the ripe plant being taken at 100. Corresponding results from Bretschneider enclosed in ( ) are given for comparison :

Period.	Silica. Per cent.	Sulphuric Trioxide. Per cent.	Phosphoric Pentoxide. Per cent.	Lime. Per cent.	Magnesia. Per cent.	Potash. Per cent.
I.	18 (22)	20 (42)	23 (23)	30 (31)	24 (31)	39 (42)
II.	41 (57)	52 (44)	42 (63)	58 (83)	42 (73)	70 (89)
III.	70	52	73	79	58	91
IV.	93 (72)	90 (39)	91 (74)	99 (74)	84 (77)	100 (100)
V.	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (95*)

The *gain* (or *loss*, indicated by the minus sign −) in these ash-ingredients during each period is given below.

Period.	Silica.	Sulphuric Trioxide.	Phosphoric Pentoxide.	Lime.	Magnesia.	Potash.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
I.	18 (22) . .	20 (42) . .	23 (23) . .	30 (31) . .	24 (31) . .	39 (42)
II.	23 } (35) . .	32 } (2) . .	19 } (40) . .	28 } (52) . .	18 } (42) . .	31 } (47)
III.	29 . .	0 . .	31 . .	21 . .	16 . .	21
IV.	23 (15) . .	38 (−5*) . .	18 (10) . .	20 (−9*) . .	26 (4) . .	9 (11)
V.	7 (28) . .	10 (56) . .	9 (27) . .	1 (17) . .	16 (23) . .	0 (−5*)
	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)

The discordant results of these two experiments considered.

These two independent investigations could hardly give all the discordant results observed on comparing the above figures, as the simple consequence of the unlike mode of conducting them. We observe, for example, that in the last period Arendt's plants gathered less *silica* than in any other—only 7 per cent. of the whole. On the other hand, Bretschneider's crop gained more silica in this than in any other single period, viz. 28 per cent. A similar statement is true of *phosphoric pentoxide.* It is obvious that Bretschneider's crop was taking up fixed matters much more vigorously in its last stages of growth than were Arendt's plants. As to *potash*, we observe that its accumulation ceased in the fourth period in both cases.

It is, on the whole, plain that we cannot safely draw from these interesting researches any very definite conclusions as to the rate and progress of assimilation and growth in the oat plant beyond what have been already pointed out.

Migrations of ash-ingredients and organic matters within the plants.

C.—Translocation of substances in the Plant.—The translocation of certain matters from one part of the plant to another is revealed by the analyses of Arendt, and since such changes are of interest from a physiological point of view, we may recount them here briefly.

It has been mentioned already that the growth of the stem, leaves, and ear of the oat plant in its later stages, *probably* takes place to a great degree at the expense of the

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* In these instances Bretschneider's later crops contained less sulphuric acid, lime, and potash than the earlier. This result may be due to the washing of the crop by rains, but is probably caused by unequal development of the several plots.

roots. It is also probable that a transfer of *amyloids*, and certain that one of *albuminoids*, goes on from the leaves through the stem into the ear.

Silica appears not to be subject to any change of position after it has once been fixed by the plant. *Chlorine* likewise reveals no noticeable mobility.

Migrations of phosphorus in the oat.

On the other hand, *phosphoric pentoxide* passes rapidly from the leaves and stem towards or into the fruit in the earlier as well as in the later stages of growth, as shown by the following figures.

One thousand plants contained in the various periods quantities (grams) of phosphoric pentoxide as follow:—

	I. Period.	II. Period.	III. Period.	IV. Period.	V. Period.
Three lower joints of stem	0·47	0·20	0·21	0·20	0·19
Two middle ,, ,,	—	0·39	1·14	0·46	0·18
Upper joint ,,	—	0·66	1·73	0·31	0·39
Three lower leaves ,,	1·05	0·70	0·69	0·51	0·35
Two upper leaves ,,	1·75	1·67	1·18	0·74	0·59
Ear	—	2·36	5·36	10·67	12·52

Observe that these absolute quantities diminish in the stem and leaves after the first or third period in all cases, and increase very rapidly in the ear.

Migration and change of the sulphur of the oat.

Arendt found that *sulphuric trioxide* existed to a much greater degree in the leaves than in the stem throughout the entire growth of the oat plant, and that after blossoming the lower stem no longer contained sulphur in the form of sulphuric trioxide at all, though its total in the plant considerably increased. It is almost certain, then, that sulphuric trioxide *originates*, either partially or wholly, by oxidation of sulphur or some sulphurized compound in the upper organs of the oat.

Magnesia is translated from the lower stem into the upper organs, and in the fruit especially it constantly increases in quantity.

There is no evidence that *lime* moves upward in the plant. On the contrary, Arendt's analyses go to show that in the ear, during the last period of growth, it diminishes in quantity, being, perhaps, replaced by magnesia.

Data, as to movements of ash-ingredients in plant, imperfect.

As to *potash*, no transfer is fairly indicated except from the ears. These contained at blossoming (Period III.) a maximum of potash. During their subsequent growth the amount of potash diminished, being probably displaced by magnesia.

The data furnished by Arendt's analyses, while they indicate a transfer of matters in the cases just named, and in most of them with great certainty, do not, and cannot, from their nature, disprove the fact of other similar changes, and cannot fix the real limits of the movements which they point out.

DIVISION II.

The Structure of the Plant and Offices of its Organs.

CHAPTER I.

GENERALITIES.

Chap. I.

A knowledge of the structure as well as chemical constitution of plants necessary.

*We have given a brief description of those elements and compounds which constitute the plant in a chemical sense. They are the materials—the stones and timber, so to speak —out of which the vegetable edifice is built. It is important in the next place to learn how these building materials are put together, and on what plan the edifice is constructed.

It is hardly possible for the farmer with certainty to contribute in any great, especially in any new degree, to the upbuilding of the plant, unless he is acquainted with the mode of its structure and the elements that form it. It is the happy province of science to add, to the vague and general information which the observation and experience of generations has taught, a more definite and particular knowledge acquired by study purposely and carefully directed to special ends.

An acquaintance with the parts and structure of the plant is indispensable for understanding the mode by which it derives its food from external sources, while the ingenious methods of propagation practised in fruit and flower culture are only intelligible by its help.

The term organism explained.

PLANT ORGANISM.—We have at the outset spoken of organic matter, of organs and organization. The vegetable and animal consist of numerous parts, differing greatly from each other, but each essential to the whole. The root, stem, leaf, flower, and seed, are each instruments or *organs* whose co-operation is needful to the perfection of the plant. The plant (or animal) being thus an assemblage of organs, is called an *Organism;* it is an *Organized Structure.* The atmosphere, the waters, the rocks and soils of the earth, do not possess distinct co-operating parts; they are *Inorganic matter.*

In inorganic nature, chemical affinity rules over the transformations of matter. A plant or animal that is dead, under ordinary circumstances, soon loses its form and characters; it is gradually consumed by the atmospheric oxygen, and virtually burnt up to gases and ash.

In the organic world, a special condition which we call *vitality* modifies the affinities of oxygen, and ensures the existence of a continuous and perpetual succession of living forms.

Organized structure distinguished from inorganic matter.

An Organism or Organized Structure is characterised and distinguished from Inorganic matter by two particulars:

1. It builds up and increases its own mass by appropriating external matter, which is *assimilated* by it, and *interstitially* deposited among the particles of the previously existing substance. When growth occurs in Inorganic matter, in a crystal for example, it is merely by *juxtaposition* of new matter to an external surface.

2. It *reproduces* itself. It is *developed* by a series of changes from a germ or rudiment, which is always derived from a similar previously existing organism.

Minute and naked-eye anatomy of plants.

ULTIMATE AND COMPLEX STRUCTURE.—In our account of the Structure of the Plant we shall first consider the elements of that structure—the Cells—which cannot be divided or wounded without extinguishing their life, and by whose expansion or multiplication all growth takes place. Then will follow an account of the complex parts of the plant—its Organs—which are built up by the juxtaposition of numerous cells. Of these we have one class, viz. the Roots, Stems, and Leaves, whose office is to sustain and nourish the individual Plant. These may be distinguished as the *Organs of Nutrition.* The other class, comprising the Flower and Fruit, are not essential to the existence of the individual, but their function is to maintain the race. They are the *Organs of Reproduction.*

Classification of organs.

CHAPTER II.

PRIMARY ELEMENTS OF ORGANIZED STRUCTURE.

§ 1. The Vegetable Cell.

Chap. II.

Assemblages of cells form the earliest states of all organisms.

One of the most interesting discoveries that the microscope has revealed is, that all organized matter originates in the form of minute vesicles or cells. If we examine by the microscope a seed or an egg, we find nothing but a cell-structure—an assemblage of little globular bags or vesicles, lying closely together, and more or less filled with solid or liquid matters. From these cells, then, comes the frame or structure of the plant, or of the animal. In the process of maturing, the original vesicles are enormously multiplied, and often greatly modified in shape and appearance, to suit various purposes; but, still, it is always easy, especially in the plant, to find cells of the same essential characters as those occurring in the seed.

the whole structure of the lower and

Cellular Plants.—In those tribes of plants which exhibit the lowest type of vegetable existence, and which possess no distinct organs or parts adapted to separate offices, the organism consists of an aggregation of similar cells, and may even consist of a single one. The phenomenon of red snow frequently observed in Alpine and Arctic regions is due to a microscopic one-celled plant (an *Alga, Protococcus nivalis*) which propagates with great rapidity, and gives its colour to the surface of the snow. In the chemist's laboratory it is often observed that, in the clearest solutions of salts, like the sulphates of soda and magnesia, a flocculent growth, sometimes red, sometimes green, most often white, is formed, which, under the microscope, is seen to be a vegetation consisting of single cells. This is the mycelium, or vegetative part of a kind of mould : one form of it is very troublesome in electrotyping (Berkeley, *Cryptog Bot.* p. 300). Brewers' yeast, Fig. 24, is nothing more than a mass of similar one or few-celled plants.

In sea-weeds, mushrooms, the moulds that grow on damp walls, or upon bread, cheese, &c., and in the brand or blight which infests many of the farmer's crops, we have examples of plants of simple structure formed almost exclusively of similar cells.

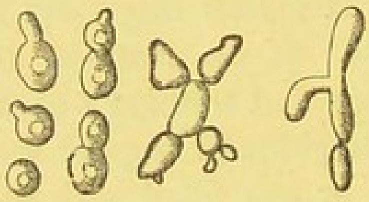

Fig. 24.

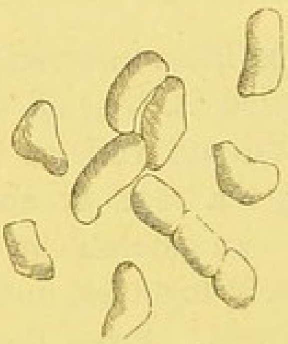

Fig. 25.

the soft and growing parts of the higher plants.

The plants of higher classes we find likewise to consist chiefly of globular or angular cells, which may be seen best in the soft and growing parts.

If we examine the pulp of fruits, as that of a ripe apple or tomato, we are able, by means of a low magnifier, to distinguish the cells of which it almost entirely consists. Fig. 25 represents a bit of the flesh of a ripe pippin, magnified fifty diameters. The cells mostly cohere together, but readily admit of separation.

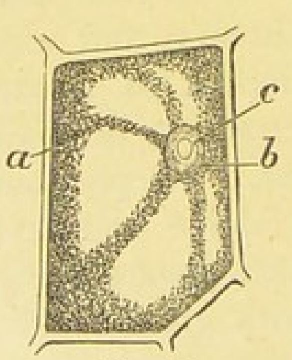

Fig. 26.

Structures composing the cell.

Structure of the Cell.—By the aid of the microscope it is possible to learn something with regard to the internal structure of the cell itself. Fig. 26 exhibits the appearance of a cell from the flesh of the Jerusalem artichoke, magnified 230 diameters : externally the membrane, or wall of the cell, is seen in section. This membrane is filled and distended by a transparent liquid or sap. Within the cell is observed a round body, *b*, which is called the *nucleus*, and upon this is seen a smaller *nucleolus*, *c*. Lining the interior of the cell-membrane, and connected with the nucleus, is a yellowish, turbid, semi-fluid substance of a mucilaginous consistence, *a*, which is designated the *protoplasm*, or *formative layer*. This, when more highly magnified, is found to contain a vast number of excessively minute granules.

Action of reagents on cells.

By the aid of chemistry the microscopist is able to dissect these cells, which are hardly perceptible to the unassisted eye, and ascertain to a good degree how they are constituted. On moistening them with solution of iodine, and afterwards with sulphuric acid, the outer membrane, or *cell-wall*, which consists of *cellulose*, becomes violet blue. The thicker cell-membranes, however, only become yellow or brown. At the same time we observe that the interior, half-liquid *protoplasm*, has coagulated and shrunk together,—has therefore separated from the cell-wall,—and, including with it the nucleus and the smaller granules, lies in the centre of the cell like a collapsed bladder. It has also assumed a deep yellow or brown colour. If we moisten one of these cells with nitric acid, the cell-wall is not affected, but the liquid penetrates it, coagulates the protoplasm, and colours it yellow. In the same way it is often tinged violet blue by hydrochloric acid. These reactions leave no room to doubt that the slimy inner lining of the cell is chiefly an *albuminoid*. The protoplasm is not miscible with or soluble in water. In young cells it exhibits regular circulatory movements, producing ultimately a network of currents over the inside of the cell-wall, which are rendered visible by the suspended granules.

If we examine the cells of any other plant, we find almost invariably the same structure as above described, provided the cells are young, *i.e.* belong to *growing* parts. In some cases cells consist only of protoplasm and nucleus, being destitute of cell-walls during a portion or the whole of their existence.

Cells often modified.

In studying many of the maturer parts of plants, viz. such as have ceased to enlarge, as the full-sized leaf, the perfectly formed wood, &c., we find the cells do not correspond to the description just given. In external shape, thickness, and appearance of the cell-wall, and especially in the character of the contents, there is indefinite variety. But this is the result of change in the original cells, which are always, at first, formed closely on the pattern that has been explained.

Tissue, a coherent mass of cells.

Vegetable Tissue.—It does not, however, usually happen that the individual cells of the higher orders of plants admit of being obtained separately. They are attached together more or less firmly by their outer surfaces, so as to form a coherent mass of cells—a *tissue*, as it is termed. In the accompanying cut, Fig. 27, is shown a highly magnified view of a portion of a very thin slice across a young cabbage stalk. It exhibits the outline of the irregular empty cells, the walls of which are, for the most part, externally united and appear as one, *a*. At the points indicated by *b*, cavities between the cells are seen, called *intercellular spaces*, in most cases filled with air. A slice across the potato tuber has a similar appearance, except that the cells are filled with starch, and it would be scarcely possible to dissect them apart; but when a

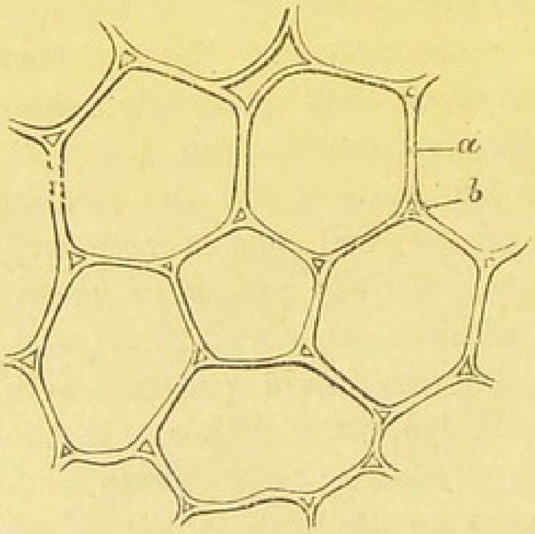

Fig. 27.

potato is boiled, the starch grains swell, and the cells, in consequence, separate from each other, a practical result of which is to make the potato mealy. A thin slice of vegetable ivory (the seed of *Phytelephas macrocarpa*), under the microscope, dry or moistened with water, presents no trace of cell-structure, the cells being blended together: however, upon soaking in sulphuric acid, the mass softens and swells, and the individual cells are at once revealed, their surfaces separating in six-sided outlines.

Form of cells

Form of Cells.—In the soft, succulent parts of plants, the cells lie loosely together, often with considerable intercellular spaces, and have mostly a rounded outline. In denser tissues, the cells are crowded together in the least possible space, and hence often appear six-sided when seen in cross section, or twelve-sided if viewed entire. A piece of honeycomb is an excellent illustration of the appearance of many forms of vegetable cell-tissue.

dodecahedral from pressure,

The pulp of an orange is the most evident example of cell-tissue. The individual cells of the ripe orange may be easily separated from each other. Being mature and incapable of further growth, they possess neither protoplasm nor nucleus, but are filled with a sap or juice containing, among other secondary products found in the mature fruit, citrates and sugar.

stellate,

In the pith of the rush star-shaped cells are found. In common mould the cells are long and thread-like. In the *Confervaceæ*, one of the lowest tribes of Algæ, they are cylindrical, and attached end to end. In the bark of many trees, in the stems and leaves of grasses, they are square or rectangular.

elongated.

Cotton fibre, flax and hemp, consist of long and slender cells (Fig. 28). Wood is mostly made up of elongated cells, tapered at the ends and adhering together by their sides.

Each cotton fibre is a single cell which forms an external appendage to the epidermis of the seed of the cotton plant (various species of *Gossypium*). When it has lost its water and becomes dry, its sides collapse, and it resembles a twisted strap. *a*, in Fig. 28, exhibits a portion of a cotton fibre highly magnified. The flax fibre, from the inner bark of the flax stem, *b*, Fig. 28, is a tube of thicker walls and smaller bore than the cotton fibre, and hence is more durable than cotton. It is very flexible, and even when crushed or bent short retains much of its original tenacity. Hemp fibre closely resembles flax fibre in appearance.

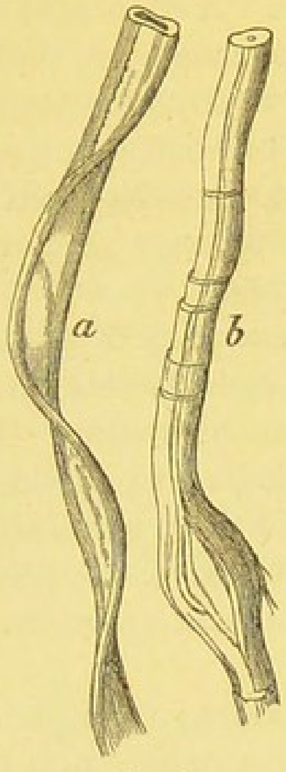

Fig. 28.

Cell-membrane may be thickened by deposition of cellulose and lignine.

Thickening of the Cell-Membrane.—The growth of the cell, which, when young, always has a very delicate outer membrane, often results in the thickening of its walls by the interior disposition of cellulose and lignine. This thickening may take place regularly and uniformly, or interruptedly. The flax fibre, *b*, Fig. 28, is an example of nearly uniform thickening. The irregular deposition of cellulose is shown in Fig. 29, which exhibits a section from the seeds (cotyledons) of the common nasturtium (*Tropæolum majus*). The original membrane is coated interiorly with several distinct and successively-formed linings, which are not continuous, but are irregularly developed. Seen in section, the thickening has a waved outline, and at points the original cell-membrane is bare. Were these cells viewed entire, we should see at these points, on the exterior of the cell, dots or circles appearing like orifices, but being simply the unthickened portions of the cell-wall. The cells in Fig. 29 exhibit each a central nucleus surrounded by a grain of aleurone.

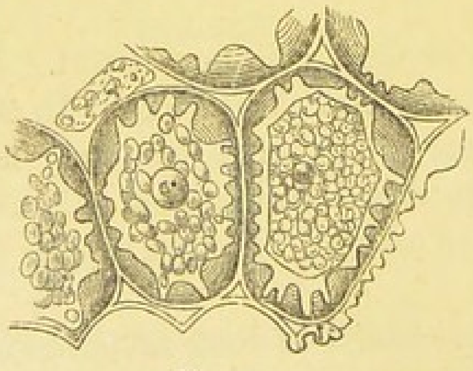

Fig. 29.

Cell contents

Cell Contents. — Besides the protoplasm and nucleus, the cell usually contains a variety of bodies, which have been, indeed, noticed already as ingredients of the plant, but which may be here recapitulated. Many cells are altogether empty, and consist of nothing but the cell-wall. Such are found in the bark or

absent in some old cells

epidermis of most plants, and often in the pith; and although they remain connected with the actually living parts, they have no longer any proper life in themselves.

include both organic and mineral substances.

All living or active cells are distended with liquid. This consists of water, which holds in solution gum, dextrine, inuline, the sugars, salts of organic acids, and other less important vegetable principles, together with mineral matters, and constitutes the sap of the plant. In oil plants minute transparent globules of oil exist in certain cells (Fig. 14, p. 75); while, in numerous plants, coloured and milky juices are found in certain spaces or channels between the cells.

The water of the cell comes partly from the soil, and partly from atmospheric moisture. The matters, which are dissolved in the sap or juices of the plant, together with the semi-solid protoplasm, undergo transformations resulting in the production of secondary substances. By observing the various parts of a plant at the successive stages of its development, under the microscope, we are able to trace within the cells the formation and growth of starch grains, of crystalline bodies, and granules consisting chiefly of vegetable caseine (aleurone in part), and of the various matters which give colour to leaves and flowers.

The circumstances under which a cell develops determine the character of its contents. The outer cells of the potato tuber are incrusted with corky matter; the inner ones are chiefly entirely occupied with starch. In oats, wheat, and other cereals, we find, just within the skin or epidermis of the grain, which is nearly destitute of albuminoids, a few layers of cells that contain scarcely anything but albuminoids, with a little fat; while the interior cells are chiefly filled with starch (Fig. 15, p. 92).

Transformations in Cell Contents.—The same cell may exhibit a great variety of aspect and contents at different periods of growth. The constituents of the substances contained in the cell at one period may be separated subsequently and redistributed with additional material so as

Cell contents undergo change.

to form others. This is especially to be observed in the seed while developing on the mother plant. Hartig has traced these changes in numerous plants under the microscope. According to this observer, the cell contents of the seed (cotyledons) of the common nasturtium (*Tropæolum majus*) run through the following metamorphoses. Up to a certain stage in its development the interiors of the cells are nearly devoid of recognisable solid matters, other than the nucleus and the adhering protoplasm. Shortly, as the growth of the seed advances, green grains of chlorophyll make their appearance about the nucleus, completely covering it from view. At a later stage, these grains, which have enlarged and multiplied, are seen to have mostly become detached from the nucleus, and lie near to and in contact with the cell wall. After a short time the green colour due to the chlorophyll disappears, and granules exhibiting the characteristic structure and reactions of starch make their appearance. Subsequently, as the seed hardens and becomes firmer in its tissues, the microscope shows that the starch grains, which were situated near the cell wall, have vanished, while the cell wall itself has thickened internally—the starch having been replaced by cellulose. Again, later, the nucleus, about which in the meantime more starch grains have been formed, undergoes a change and disappears; then the starch grains, some of which have enlarged while others have vanished, are found to be imbedded in a pasty matter, which has the reactions of an albuminoid. From this time on, the starch-grains are gradually replaced by smaller grains of aleurone, which, finally, when the seed is mature, completely occupy the cells.

In the sprouting of the seed similar changes occur, but in reversed order. Oxygen is absorbed, and the insoluble starch and oil are broken up and pass into solution to serve as food for the young plant.

The Dimensions of Vegetable Cells are very various. A creeping marine plant is known—(the *Caulerpa*

Dimensions of cells very various.

prolifera, Fig. 30)—which consists of a single cell, though it is often a foot in length, and is branched with what have the appearance of leaves and roots. Many of the cells of the lemon are more than half an inch in length; in the shaddock they are much larger. (Quekett's *Histology*, p. 18.)

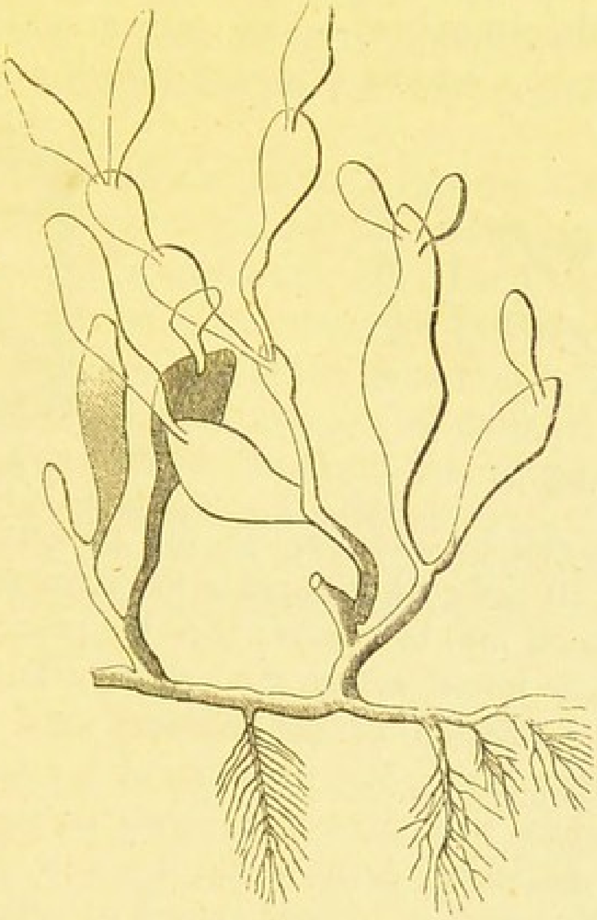

Fig. 30.

Cotton consists of single filamentous cells, which may measure 1 to 2 inches. In most cases, however, the cells of plants are so small as to require a powerful microscope to distinguish them,—are, in fact, no more than 1-1200th to 1-200th of an inch in diameter; the spores of Fungi afford examples of cells still more minute.

Cylindrical cells, such as those of wood, are often remarkable for their great length compared with their transverse diameter.

Growth, the result of

Growth.—The growth of a plant is nothing more than the aggregate result of the enlargement and multiplication of the cells which compose it. In most cases the cells attain their full size in a short time. The continuous growth of plants depends, then, chiefly on the constant and rapid formation of new cells.

cell multiplication,

Cell-multiplication.—The young and active cell always contains a *nucleus* (Fig. 31). Such a cell may produce a new cell by *division*. In this process the nucleus, from which all cell-growth appears to originate, is observed to resolve itself into two parts; then the protoplasm begins to contract or infold across the cell in a line corresponding with the division of the nucleus, until the opposite infolded edges meet—like the skin of a sausage where a string is tightly tied around it,—thus separating the two nuclei and enclosing each within its new cell, which is completed by a further external growth of cellulose.

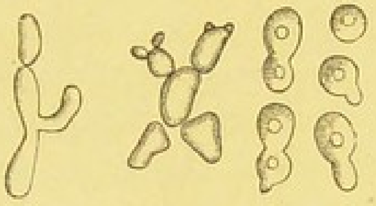

Fig. 31.

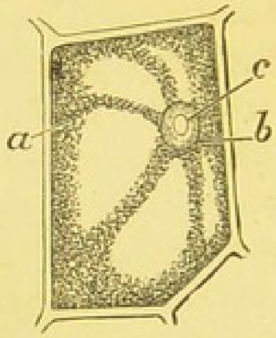

Fig. 32.

takes place by division,

In one-celled plants, like yeast (Fig. 32), the new cells thus formed bud out from the side of the parent cell, and before they obtain full size become entirely detached from it, or, as in higher plants, the new cells remain adhering to the old, forming a tissue.

or free formation of nuclei,

In *free cell-formation* nuclei are observed to develop in the protoplasm of a parent cell, which enlarge, surround themselves with their own protoplasm and cell-membrane, and by the absorption or death of the parent cell become independent of the latter.

The rapidity with which the vegetable cells may multiply and grow is illustrated by many familiar facts. The most striking cases of quick growth are met with in the mushroom family. A species of Puff-ball has been known to grow to the size of a large gourd in a single night. In such sudden growth it has been estimated that the cells are produced at the rate of three or four hundred millions per hour. It is in part, however, probably due to the expansion of cells already formed.

often with great rapidity.

Permeability of Cells to Liquids.—Although the membranes of the vegetable cell are completely continuous and imperforate, they are nevertheless readily permeable to liquids. This fact may be elegantly shown by placing a delicate slice from a potato tuber, immersed in water, under the microscope, and then bringing a drop of solution of iodine in contact with it. Instantly this reagent penetrates the walls of the unbroken cells without perceptibly affecting their appearance, and, being absorbed by the starch grains, at once colours them intensely purplish blue.

Cell-membrane permeable to liquids.

§ 2. THE VEGETABLE TISSUES.

As already stated, the cells of the higher kinds of plants are united together more or less firmly, and thus constitute what are known as VEGETABLE TISSUES. Of these, a large number have been distinguished by vegetable anatomists, the distinction being based either on peculiarities of form or of function. For our purpose it will be necessary to define but a few varieties, viz. *Cellular Tissue*, *Woody Tissue*, *Bast Tissue*, and *Vascular Tissue*.

Tissue, a coherent mass of cells.

Cellular Tissue, or *Parenchyma*, is the simplest of all, being a mere aggregation of globular or polyhedral cells whose walls are in close adhesion. Cellular tissue is abundant throughout all classes of plants. It is the only kind of tissue in the simpler forms, and the soft parts of the higher forms are chiefly composed of it.

Different kinds of tissue described. Parenchyma.

CHAP. II.

Prosenchyma.

Prosenchyma is a name applied to all tissues composed of elongated cells, like those of wood and bast. Parenchyma and prosenchyma insensibly shade into each other.

Wood.

Wood Tissue, in its simplest form, consists of cells that are several or many times as long as they are broad, and that taper at each end to a point. These spindle-shaped cells cohere firmly together by their sides, and their ends overlap each other, in this way forming the tough fibres of wood. Wood cells are often more or less thickened in their walls by depositions of cellulose, lignine, and colouring matters, according to their age and position, and are variously dotted and perforated, as will be explained hereafter.

Bast.

Bast Tissue is made up of long and slender cells similar to those of wood tissue, but commonly more delicate and flexible. The name is derived from the occurrence almost of this tissue in the bast, or inner bark. Flax, hemp, and all textile materials of vegetable origin, cotton excepted, consist of bast fibres. Bast cells occupy a place in rind, corresponding to that held by wood cells in the interior of the stem (Fig. 28 *b*, p. 218).

Ducts.

Vascular Tissue is the term applied to those unbranched *Tubes* and *Ducts* which are found in all the higher orders of plants, interpenetrating the cellular tissue. There are several varieties of ducts, viz. *dotted ducts*, *ringed or annular ducts*, and *spiral ducts*, of which illustrations will be given when the minute structure of the stem comes under notice.

The formation of vascular tissue takes place by a simple alteration in cellular tissue. A longitudinal series of adhering cells represents a tube, save that the bore is obstructed, with numerous transverse partitions. By the removal or perforation of these partitions a tube is developed. This removal or perforation actually takes place in the living plant by a process of absorption.

CHAPTER III.

THE ORGANS OF NUTRITION.

§ 1. The Root.

The growth of roots requires moisture, is usually downwards,

The Roots of plants, with few exceptions, from the first moment of their development grow downward. In general, they require a moist medium, and their downward descent is probably due to the greater supply of moisture which they receive in that direction. They will form in water or in moist cotton, and in many cases originate from branches, or even leaves, when these parts of the plant are buried in the earth or immersed in water. It cannot be assumed that they seek to avoid the light, because they may attain a full development without being kept in darkness. The action of light upon them, however, appears to be unfavourable to their functions.

and takes place near the extremities.

The Growth of Roots occurs mostly by lengthening, and very little or very slowly by increase of thickness. The lengthening is chiefly manifested toward the outer extremities of the roots, as was neatly demonstrated by Wigand, who divided the young root of a sprouted pea into four equal parts by ink-marks. After three days, the first two divisions next the seed had scarcely lengthened at all, while the third was double, and the fourth eight times its previous length. Ohlerts made precisely similar observations on the roots of various kinds of plants. The growth is confined to a space of about one-sixth of an inch from the tip (*Linnea*, 1837, pp. 609—631). This peculiarity adapts the roots to extend through the soil in all directions, and to occupy its smallest pores, or rifts. It is likewise

Chap. III.

the reason that a root, which has been cut off in transplanting or otherwise, never afterwards extends in length.

Although the older parts of the roots of trees and of the so-called root-crops acquire a considerable diameter, the roots by which a plant feeds are usually thread-like and often exceedingly slender.

Structure of extremities.

Spongioles.

Spongioles.—The tips of the rootlets have been termed spongioles, or spongelets, from the idea that their texture adapts them especially to collect food for the plant, and that the absorption of matters from the soil goes on exclusively through them. In this sense, spongioles do not exist. The real living apex of the root is not, in fact, the outmost extremity but is situated a little within that point.

Root-Cap.

Root-Cap.—The extreme end of the root usually consists of cells that have become loosened and in part detached from the proper cell-tissue of the root, which, therefore, shortly perish, and serve merely as an elastic cushion or cap to protect the true termination or living point of the root in its act of penetrating the soil. Fig. 33 represents a magnified section of part of a barley root, showing the loose cells which slough off from the tip. These cells are filled with air instead of sap.

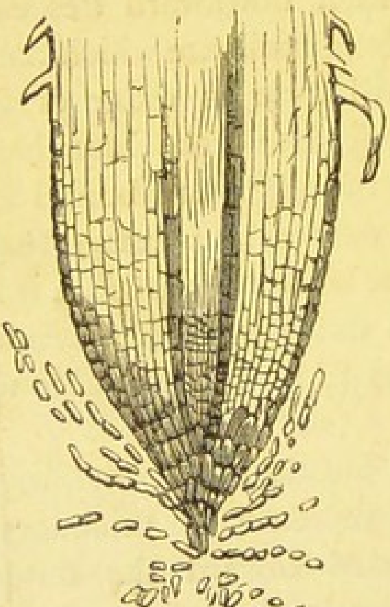
Fig. 33.

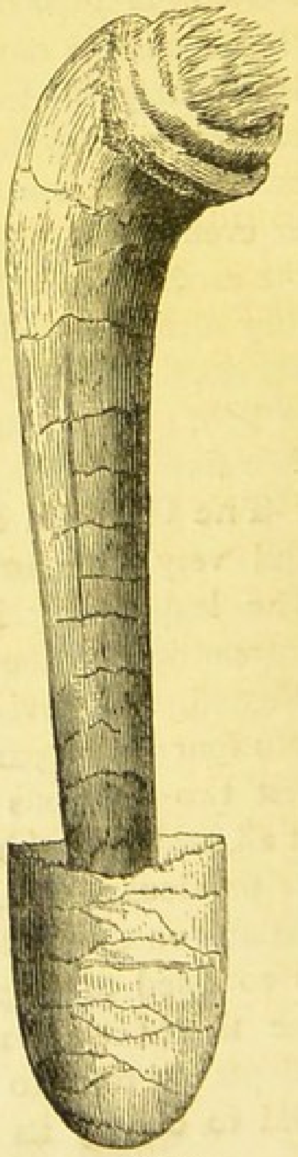
Fig. 34.

A striking illustration of the root-cap is furnished by the air-roots of a Palm—

the Screw Pine (*Pandanus odoratissimus*), exhibited in natural dimensions in Fig. 34. These air-roots issue from the stem above the ground, and, growing downwards, enter the soil, and become roots in the ordinary sense.

When fresh, the diameter of the root is quite uniform, but the parts above the root-cap shrink on drying, while the root-cap itself retains nearly its original dimensions, and thus reveals its different structure.

All subterranean plant structures not necessarily roots.

Distinction between Root and Stem.—All the subterranean parts of the plant are not roots in a proper sense, although commonly spoken of as such. The tubers of the potato and artichoke, and the fleshy horizontal parts of the sweet-flag, or Solomon's seal, are merely underground *stems*, of which many varieties exist.

These and all other stems are easily distinguished from true roots by the *imbricated buds*, of which indications may usually be found on their surfaces, as in the *eyes* of the potato tuber. The side or secondary roots are indeed marked in their earliest stages by a protuberance on the primary root, but these have nothing in common with the structure of true buds. The onion bulb is itself a fleshy bud, as will be noticed subsequently. The true roots of the onion are the fibres which issue from the base of the bulb. The roots of many plants exhibit no buds upon their surface, and are incapable of developing them under any conditions. Other plants may produce them when cut off from the parent plant during the growing season. Such are the plum, apple, poplar, and hawthorn. The roots of the former perish if deprived of connexion with the stem and leaves: the latter may strike out new stems and leaves for themselves. Plants like the plum are, therefore, capable of propagating by *root-cuttings*, i.e. by placing pieces of their roots in warm and moist earth.

Tap-roots direct prolongation of axis.

Tap-Roots.—All plants whose embryos are furnished with two seed leaves, or *cotyledons*, and whose stems increase externally by addition of new rings of growth—the *Dicoty-*

ledonous plants, or *Exogens*—have, at first, a single descending axis, the *tap-root*, which penetrates vertically into the ground. From this central tap-root lateral roots branch out more or less regularly, and these lateral roots subdivide again and again. In many cases, especially at first, the lateral roots issue from the tap-root with great order and regularity, as much as is seen in the branches of the stem of a fir-tree or of a young grape-vine. In older plants this order is lost, because the soil opposes mechanical hindrances to regular development. In many cases the tap-root grows to a great length, and forms the most striking feature of the radication of the plant. In others it enters the ground but a little way, or is surpassed in extent by its side branches. The tap-root is conspicuous in the dock (*Rumex*) and in seedling fruit-trees. The upper portion of the tap-root of the beet, turnip, carrot, and radish, expands under cultivation, and becomes a fleshy, nutritive mass, in which lies the value of these plants for agriculture. The lateral roots of other plants, as of the dahlia and sweet potato, swell out at their extremities to tubers.

Monocotyledons have no tap-root.

Crown Roots.—In *Monocotyledonous plants*, or *Endogens*, —that is, plants whose embryos have only one seed leaf or *cotyledon*, and whose stems do not increase by external additions, such as the cereals, grasses, lilies, and palms,—the descending axis is not prolonged into a tap-root, but gives off a number of roots at once from its base. This is strikingly seen in the onion and hyacinth, as well as in maize.

Rootlets.—This term we apply to the slender roots but a few inches long, which are formed last in the order of growth, and correspond to the larger roots as twigs correspond to the branches of the stem.

Offices of the Root threefold.

THE OFFICES OF THE ROOT are threefold :

1. To fix the plant in earth and maintain it in an erect position.

2. To absorb nutriment from the soil for the growth of the entire plant ; and,

3. In the case of many plants, especially those whose terms of life extend through several or many years, to serve as a storehouse for the future use of the plant.

Plants fixed in the ground by their roots,

i. The Firmness with which a Plant is fixed in the Ground depends upon the nature of its roots. It is easy to lift an onion from the soil, a carrot requires much more force, while a dock may resist the full strength of a powerful man. A small beech, which has a tap-root, withstands the force of a wind that would prostrate a maize plant, which has only side roots. In the nursery it is the custom to cut off the tap-root of apple, peach, and other trees, when very young, in order that they may be readily and safely transplanted as occasion shall require. The depth and character of the soil, however, to a certain degree influence the extent of the roots and the tenacity of their hold. The roots of maize, which in a rich and tenacious earth extend but two or three feet, have been traced to a length of ten or even fifteen feet in a light sandy soil. The roots of clover, and especially those of lucerne, extend very deeply into the soil, and the latter acquire in some cases a length of thirty feet. The roots of the ash have been known as much as ninety-five feet long (*Jour. Roy. Agr. Soc.* vi. p. 342).

which also absorb food from the soil.

ii. Root-absorption.—The office of absorbing Plant Food from the Soil is one of the utmost importance, and one for which the root is especially adapted by the following particulars, viz. :—

Conditions favouring root-absorption.

Structure.

a. The Delicacy of its Structure, especially that of the newer portions, the cells of which are very soft and absorbent, as may be readily shown by immersing a young seedling bean in solution of indigo, when the roots at once acquire a blue colour from imbibing the liquid, while the stem is for a considerable time unaltered.

It is a common but erroneous idea that absorption from the soil can only take place through the *ends* of the roots—through the so-called spongioles. On the contrary, the extreme tips of the rootlets cannot take up liquids at all (Ohlerts, *loc. cit.;* see p. 225). All other parts of the roots which are still young and delicate in surface texture are constantly engaged in the work of imbibing nutriment from the soil.

In most perennial plants, indeed, the larger branches of the roots become after a time coated with a corky or otherwise nearly impervious cuticle, and the function of absorption is then transferred to the rootlets. This is demonstrated by placing the old brown-coloured roots of a plant in water, but keeping the delicate and unindurated extremities above the liquid. Thus situated, the plant withers nearly as soon as if its root-surface were all exposed to the air.

Extent of surface,

b. Its rapid Extension in Length, and the vast Surface which it puts in contact with the soil, further adapts the root to the work of collecting food. The length of roots in a direct line from the point of their origin is not indeed a criterion by which to judge of the efficiency wherewith the plant to which they belong is nourished; for two plants may be equally flourishing—be equally fed by their roots—when these organs in one case reach but one foot, and in the other extend two feet from the stem to which they are attached. In one case, the roots would be fewer and longer; in the other, shorter and more numerous. Their aggregate length, or, more correctly, the aggregate absorbing surface, would be nearly the same in both.

which, however, varies with nature of soil,

The Medium in which Roots grow has a great influence on their extension. When they are situated in concentrated nutritive solutions, or in a very fertile soil, they are short, and numerously branched. Where their food is sparse, they are attenuated, and bear a comparatively small number of rootlets. Illustrations of the former condition are often seen. Bones and masses of manure are not infrequently found completely covered and penetrated by a fleece of stout roots. On the other hand, the roots which grow in poor, sandy soils, are very long and slender.

as shown by experiments with fertilizers placed in different relations to roots.

Nobbe has described some experiments which completely establish the point under notice (*Vs. St.* iv. p. 212). He allowed maize to grow in a poor clay soil, contained in glass cylinders, each vessel having in it a quantity of a fertilizing mixture disposed in some peculiar manner for the purpose of observing its influence on the roots. When the plants had been nearly four months in growth, the vessels were placed in water until the earth was softened, so that by gentle agitation it could be completely removed from the roots. The latter, on being suspended in a glass vessel of water, assumed nearly the position they had occupied in the soil; and it was observed that where the fertilizer had been thoroughly mixed with the soil, the roots uniformly occupied its entire mass.

Where the fertilizer had been placed in a horizontal layer at the depth of about one inch, the roots at that depth formed a mat of the finest fibres. Where the fertilizer was situated in a horizontal layer at half the depth of the vessel, just there the root-system was spheroidally expanded. In the cylinders where the fertilizer formed a vertical layer on the interior walls, the external roots were developed in numberless ramifications, while the interior roots were comparatively unbranched. In pots, where the fertilizer was disposed as a central vertical core, the inner roots were far more greatly developed than the outer ones. Finally, in a vessel where the fertilizer was placed in a horizontal layer at the bottom, the roots extended through the soil, as attenuated and slightly branched fibres, until they came in contact with the lower stratum, where they greatly increased and ramified. In all cases, the principal development of the roots occurred in the immediate vicinity of the material which could furnish them with nutriment.

It has often been observed that a plant whose aërial branches are symmetrically disposed about its stem, has the larger share of its roots on one side; and again, we find roots which are thick with rootlets on one side, and nearly devoid of them on the other.

Development of roots greatest in directions where they are most nourished.

Apparent Search for Food.—It would almost appear, on superficial consideration, that roots are endowed with a kind of intelligent instinct, for they seem to go in search of nutriment.

The roots of a plant make their first issue independently of the nutritive matters that may exist in their neighbourhood. They are organized and put forth from the plant itself, no matter how fertile or sterile the medium that surrounds them. When they attain a certain development, they are ready to exercise their office of collecting food. If food be at hand, they absorb it, and, together with the entire plant, are nourished by it—they grow in consequence. The more abundant the food, the better they are nourished, and the more they multiply. The plant sends out rootlets in all directions; those which come in contact with food, live, enlarge, and ramify; those which find no nourishment, remain undeveloped, or perish.

The actual quantity of roots belonging to a plant cannot be roughly estimated.

The Quantity of Roots actually attached to any Plant is usually far greater than can be estimated by roughly lifting them from the soil. To extricate the roots of wheat or clover, for example, from the earth, completely, is a matter of no little difficulty. Schubart has made the most satisfactory observations we possess on the roots of several important crops, growing in the field. He separated them from the soil by the following expedient:—An excavation was made in the field to the depth of six feet, and a stream of water was directed against the vertical wall of soil until it was washed away, so that the roots of the plants growing in it were laid bare. The roots thus exposed in a field of rye, in one of beans, and in a bed of garden peas, presented the appearance of a mat or felt of white fibres, to a depth of about four feet from the surface of the ground. The roots of winter wheat he observed as deep as seven feet, in a light subsoil, forty-

Proportion of roots to entire plant at different periods.

seven days after sowing. The depth of the roots of winter wheat, winter rye, and winter colza, as well as of clover, was three to four feet. The roots of clover, one year old, were three and a half feet long, those of two-years old clover but four inches longer. The quantity of roots per cent. of the entire plant in the dry state was found :—

Winter Wheat—examined last day of April . . .	40 per cent.
,, ,, ,, ,, May . . .	22 ,,
,, Rye ,, ,, April . . .	34 ,,
Peas examined four weeks after sowing	44 ,,
,, ,, at the time of blossom	24 ,,

Hellriegel has likewise studied the radication of barley and oats (*Hoff. Jahresbericht*, 1864, p. 106). He raised plants in large glass pots, and separated their roots from the soil by careful washing with water. He observed that directly from the base of the stem twenty to thirty roots branch off sideways and downward. These roots, at their point of issue, have a diameter of $\frac{1}{25}$ of an inch, but a little lower the diameter diminishes to about $\frac{1}{100}$ of an inch. Retaining this diameter, they pass downward, dividing and branching to a certain depth. From these main roots branch out innumerable side roots, which branch again, and so on, filling every crevice and pore of the soil.

Absolute length of roots in cereals.

To ascertain the total length of root, Hellriegel weighed and ascertained the length of selected average portions. Weighing then the entire root system, he calculated the entire length. He estimated the length of the roots of a vigorous barley plant at 128 feet, that of an oat plant at 150 feet.* He found that a small bulk of good fine soil sufficed for this development: $\frac{1}{40}$ cubic foot answered for a barley plant, $\frac{1}{32}$ cubic foot for an oat plant, in these experiments.

Hellriegel observed also that the quality of the soil

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* Rhenish, 34 = 35 English feet.

influenced the development. In rich, porous, garden soil, a barley plant produced 128 feet of roots; but in a coarse-grained, compacter soil, a similar plant had but 80 feet of roots.

Absorbent surface enormously increased by root-hairs,

c. Root-Hairs.—The real absorbent surface of roots is, in most cases, not to be appreciated without microscopic aid. The roots of the onion and of many other bulbs, *i.e.* the fibres which issue from the base of the bulbs, are perfectly smooth and unbranched throughout their entire length. Other agricultural plants have roots which are not only visibly branched, but whose finest fibres are more or less thickly covered with minute *hairs*, scarcely perceptible to the unassisted eye. These root-hairs consist always of tubular elongations of the external root-cells, and through them the actual root-surface exposed to the soil becomes something almost incalculable. The accompanying figures illustrate the appearance of root-hairs.

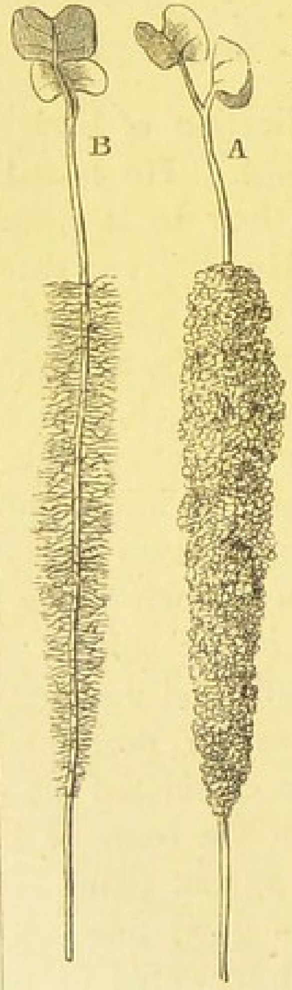

Fig. 35

Fig. 35 represents a young, seedling, mustard plant. A is the plant, as carefully lifted from the sand in which it grew, and B the same plant freed from adhering soil by agitating in water. The entire root, save the tip, is thickly beset with hairs. In Fig. 36 a minute portion of a barley root is shown highly magnified. The hairs are seen to be slender tubes that proceed from, and form part of, the outer cells of the root.

which are not found on older roots.

The older roots lose their hairs, and suffer a thickening of the outermost layer of cells. These dense-walled and nearly impervious cells cohere together and constitute a rind, which is not found in the young and active roots.

Root-hairs most abundant in poor soils and on roots with dense surfaces,

As to the development of the root-hairs, they are more abundant in poor than in good soils, and appear to be most numerously produced from roots which have otherwise a dense and unabsorbent surface. The roots of those plants which are destitute of hairs are commonly of considerable thickness, and remain white and of delicate texture, preserving their absorbent power throughout the whole time that the plant feeds from the soil, as is the case with the onion.

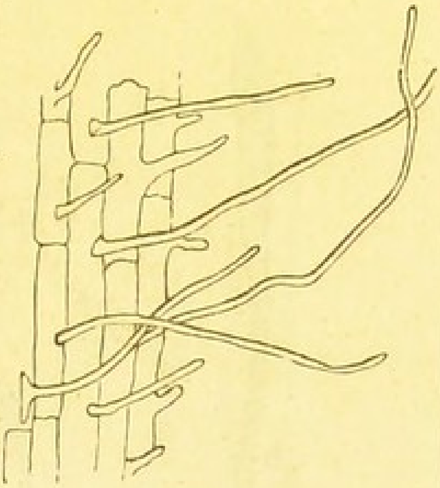

Fig. 36.

The Silver Fir (*Abies Picea*) has no root-hairs, but its rootlets are covered with a very delicate cuticle, highly favourable to absorption. The want of root-hairs is further compensated by the great number of rootlets which are formed, and which, perishing mostly before they become superficially indurated, are continually replaced by new ones during the growing season (Schacht, *Der Baum*, p. 165).

bring soil into intimate contact with roots.

The root-hairs, as they extend into the soil, are naturally brought into close contact with its particles. This contact is much more intimate than has been usually supposed. If we carefully lift a young wheat plant from dry earth, we notice that each rootlet is coated with an envelope of soil. This adheres with considerable tenacity, so that gentle shaking fails to displace it; and if it be mostly removed by vigorous agitation or washing, the root-hairs are found either to be broken, or in many places inseparably attached to the particles of earth.

Fig. 37 exhibits the appearance of a young wheat plant as lifted from the soil and pretty strongly shaken. *S*, the seed; *b*, the blade; *c*, roots covered with hairs and enveloped in soil. Only the growing tips of the roots, *w*,

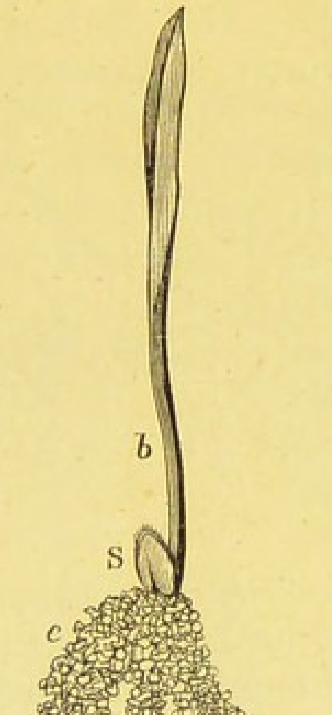

Fig. 37.

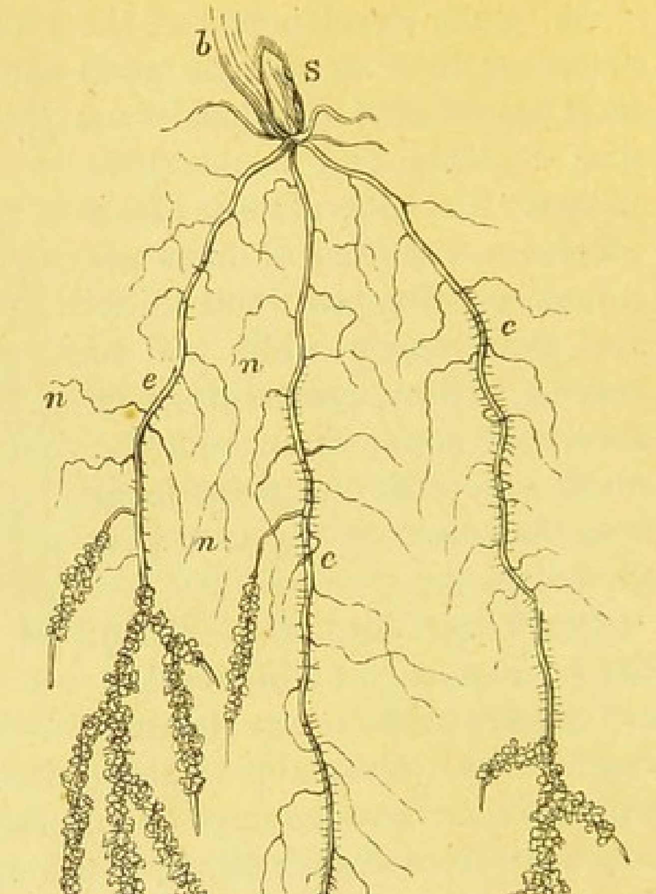

Fig. 38.

which have not put forth hairs, come out clean of soil. Fig. 38 represents the roots of a wheat plant one month older than those of the previous figure. In this instance not only the root-tips are naked as before, but the older parts of the primary roots, *c*, and of the secondary roots, *n*, no longer retain the particles of soil; the hairs upon them being, in fact, dead and decomposed. The newer parts of the root alone are clothed with active hairs, and to these the soil is firmly attached as before. The next illustration,

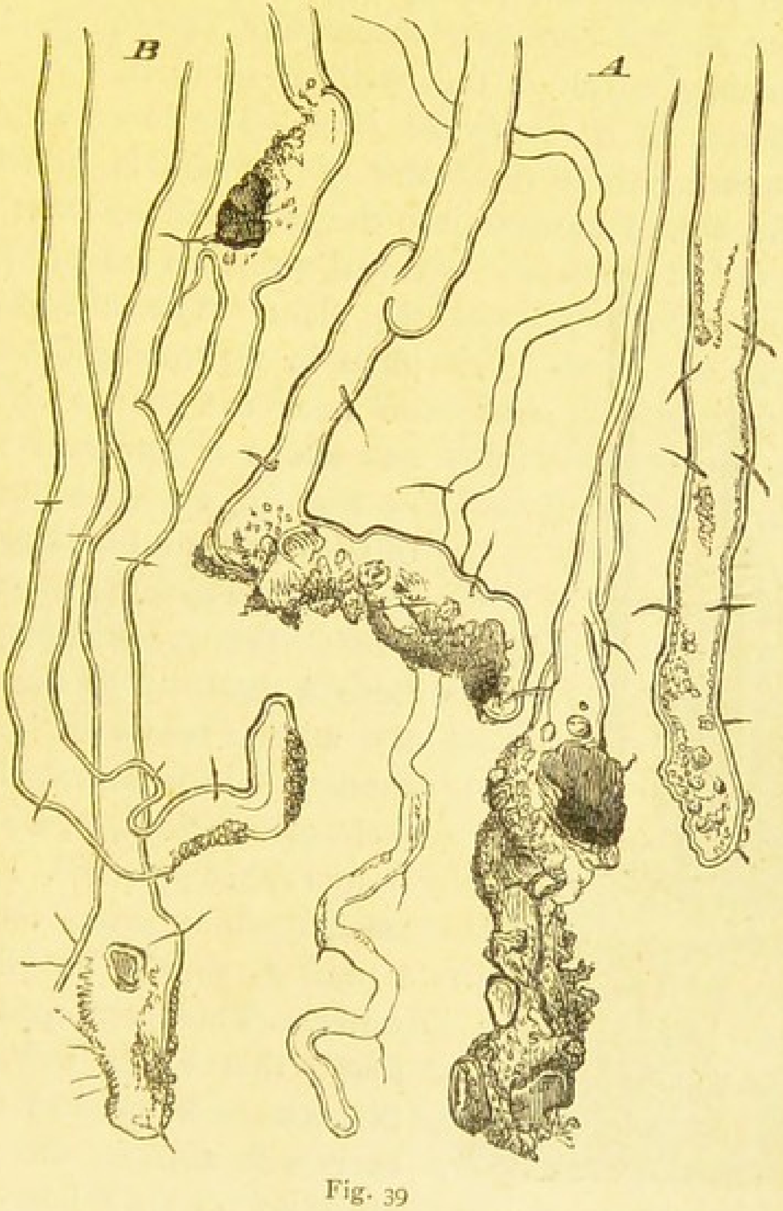

Fig. 39

Fig. 39, exhibits the appearance of root-hairs with adhering particles of earth when magnified 800 diameters—*A*, root-hairs of wheat seedling like Fig. 37; *B*, of oat plant, both from loamy soil. Here the intimate attachment of the soil and root-hairs is plainly seen. The latter, in forcing their way against considerable pressure, often expand round and partially envelope the particles of earth.

Water imbibed by the roots exerts a continual pressure on all parts of the plant.

Imbibition of Water by the Root.—The force with which active roots imbibe the water of the soil is sufficient to force the liquid upward into the stem and to exert a continual pressure on all parts of the plant. When the stem of a plant in vigorous growth is cut off near the root, and a pressure-gauge is attached to it, as in Fig. 40, we have the means of observing and measuring the force with which the roots absorb water. The pressure-gauge contains a quantity of mercury in the middle reservoir, *b*, and the tube, *c*. It is attached to the stem of the plant, *p*, by a stout india-rubber pipe, *q*.* For accurate measurements, the space, *a* and *b*, should be filled with water. Thus arranged, it is found that water will enter *a* through the stem, and the mercury will rise in the tube, *c*, until its pressure becomes sufficient to balance the absorptive power of the roots. Hales, who first experimented in this manner 140 years ago, found, in one instance, that the pressure exerted on a gauge

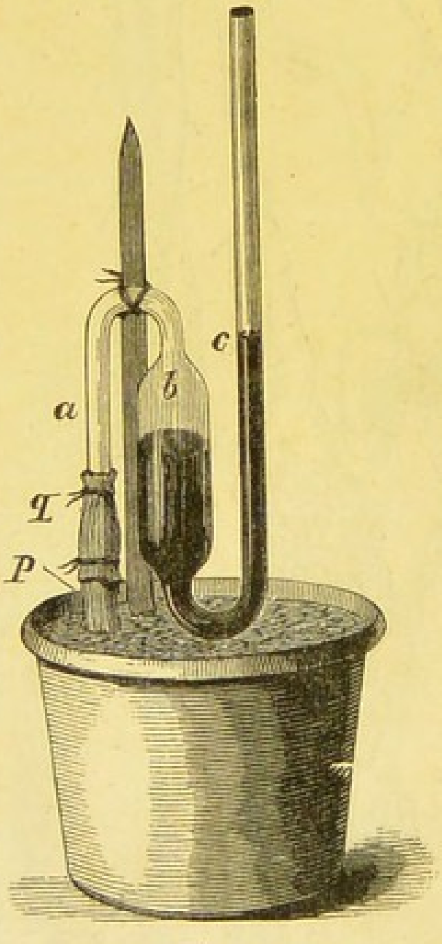

Fig. 40.

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* For experimenting on small plants, a simple tube of glass may be adjusted to the stump vertically by help of a rubber connector.

attached in spring-time to the stump of a grape-vine supported a column of mercury 32½ inches high, which is equal to a column of water of 36½ feet. Hofmeister obtained on other plants, rooted in pots, the following results :—

Bean (*Phaseolus multiflorus*)	6	inches of mercury.
Nettle	14	” ”
Vine	29	” ”

The young and active roots the seat of absorption.

Dutrochet demonstrated that the seat of absorption is the surface of the young and active roots. At least, he found that absorption was exerted with as much force when the gauge was applied near the lower extremity of a root as when attached in the vicinity of the stem. In fact, when other conditions are alike, the column of liquid sustained by the roots of a plant is greater the less the length of stem that remains attached to them. The stem thus resists the rise of liquid in the plant.

While the seat of absorptive power in the root lies near the extremities, it appears from the experiments of Ohlerts that the extremities themselves are incapable of imbibing water. In trials with the young pea, flax, lupine, and horseradish, plants with unbranched roots, he found that they withered speedily when the tips of the roots were immersed for about one-fourth of an inch in water, the remaining parts being in moist air. Ohlerts likewise proved that these plants flourish when only the middle part of their roots is immersed in water. Keeping the root-tips, the so-called spongioles, in the air, or cutting them away altogether, was without apparent effect on the freshness and vigour of the plants. The absorbing surface would thus appear to be confined to those portions of the root upon which the development of root-hairs is noticed.

The absorbent force is manifested by the active rootlets, and most vigorously when these are in the state of most rapid development. For this reason we find, in the vine for example, that during the autumn, when the plant is entering upon a period of repose from growth, the absorbent power is trifling. The effect of this forcible entrance of water into the plant is oftentimes to cause the exudation of it in drops upon the foliage. This may be noticed upon newly sprouted maize, or other cereal plants, where the water escapes from the leaves at their extreme tips, especially when the germination has proceeded under the most favourable conditions for rapid development.

Bleeding in spring illustrates imbibition by roots.

The bleeding of the vine in the spring, and the abundant flow of sap from the sugar-maple, are striking illustrations of this imbibition of water from the soil by the roots. These examples are, indeed, exceptional in degree, but not in kind. Hofmeister has shown that the bleeding of a severed stump is a general fact, and occurs with all plants when the roots are active, when the soil can supply them abundantly with water, and when the tissues above the absorbent parts are full of this liquid. When it is otherwise, water may be absorbed from the gauge into the stem and large roots, until the conditions of activity are renewed.

Temperature influences absorption.

Among the *external circumstances* that influence the absorptive power of the root, may be noticed temperature. By observing a gauge attached to the stump of a plant during a clear summer day, it will be usually noticed that the mercury begins to rise in the morning as the sun warms the soil, and continues to ascend for a number of hours, but falls again as the sun declines. Sachs found in some of his experiments that at a temperature of 41° F., absorption, in the case of tobacco and squash plants, was nearly or entirely suppressed, but was at once renewed by plunging the pot into warm water.

The external supplies of water—if a plant is stationed in the soil, the degree of moisture contained in this medium —obviously must influence, not perhaps the imbibing force, but its manifestation.

The Rate of Absorption is subject to changes dependent on other causes not well understood. Sachs observed that the amount of liquid which issued from potato stalks cut off just above the ground underwent great and continual variation from hour to hour (during rainy weather), at the same temperature and when the soil was saturated with water. Hofmeister states that the formation of roots and buds on the stump is accompanied by a sinking of the water in the gauge.

Conditions influencing rate of absorption ill understood.

Absorption of Nutriment from the Soil.—The food of the plant, so far as it is derived from the soil, enters it in a state of solution, and is absorbed with the water taken up by the rootlets. The absorption of the matters dissolved in water is in some degree independent of the absorption of the water itself, the plant having, to a certain extent, a selective power, which, however, probably admits of a physical explanation, a similar selective action taking place in ordinary osmose.

Nutriment derived from soils taken up in solution.

iii. The Root as a Magazine.—In fleshy roots, like those of the carrot, beet, and turnip, the absorption of nutriment from the soil takes place principally, if not entirely, by means of the slender rootlets which proceed abundantly from all parts of the main or tap-root, and especially from its lower extremity; while the fleshy portion serves as a magazine in which large quantities of pectose, sugar, &c., are stored up during the first year's growth of these *biennial* plants, to supply the wants of the flowers and seed which are developed the second year. When one of these roots is put in the ground for a second year and produces seed, it is found to be quite exhausted of the nutritive matters which it previously contained in so large quantity.

The root often a magazine of nutriment destined to support flowering.

In cultivation, the farmer not only greatly increases the size of these roots and the stores of organic nutritive materials they contain, but, by removing them from the ground in autumn, he employs for food the substances which would otherwise nourish the growth of flowers and seeds during another summer.

Soil-Roots: Water-Roots: Air-Roots.—We may

Roots distinguished according to medium in which they grow.

distinguish, according to the medium in which they are formed and grow, three kinds of roots, viz. *soil-roots*, *water-roots*, and *air-roots*.

Most agricultural plants, and indeed by far the greater number of all plants found in temperate climates, have roots adapted exclusively to the soil, which perish by drying if long exposed to air, or rot if immersed for a time in water. Many aquatic plants, on the other hand, die if their roots be removed from water, or from earth saturated with water.

Air-roots are not common except among tropical plants. Indian corn, however, often throws out roots from the lower joints of the stem, which extend through the air several inches before they reach the soil. The banyan of India (*Ficus indica*) sends out roots from its branches, which penetrate the earth in like manner. Many tropical plants, especially Orchids, emit roots which hang free in the air. The aërial roots of ivy and other climbers serve merely for mechanical support.

A Cycad (*Zamia spiralis*) not only throws out air-roots (*c c*, Fig. 41) from the crown of the main soil-root, but the side rootlets, *b*, after extending some distance horizontally in the soil, send from the same point roots downward and upward, the latter of which, *d*, pass into and remain permanently in the air; *a* is the stem of the plant (Schacht, *Anatomie der Gewächse*, Bd. ii., p. 151).

The roots of some plants can exist either in soil or water.

Some plants have roots which are equally able to exist and perform their functions, whether in the soil or submerged in water. Many forms of vegetation found in our swamps and marshes are of this kind. Of agricultural plants, rice is an example. Rice will grow in a soil of ordinary character in respect of moisture, as the upland cotton soils, or even the pine-barrens of the Carolinas. It flourishes admirably in the tide swamps of the coast, where the land is laid under water for weeks at a time during its growth, and it succeeds equally well in fields which are flooded from the time of planting to that of harvesting (Russell, *North America, its Agriculture and Climate*, p. 176). The willow and alder, trees which grow on the margins of streams, send a part of their roots into soil that is constantly saturated with water, or into the water itself; while others occupy the merely moist or even dry earth. Plants that customarily confine their growth to the soil, occasionally throw out roots as if in search of water, and sometimes choke up drain-pipes, or even wells, by the profusion of water-roots which they emit. At Welbeck, a drain was completely stopped by roots of horseradish plants at a depth of seven feet. At Thornsby Park, a drain sixteen feet deep was stopped entirely by the roots of gorse, growing at a distance of six feet from the drain (*Jour. Roy. Agr.*

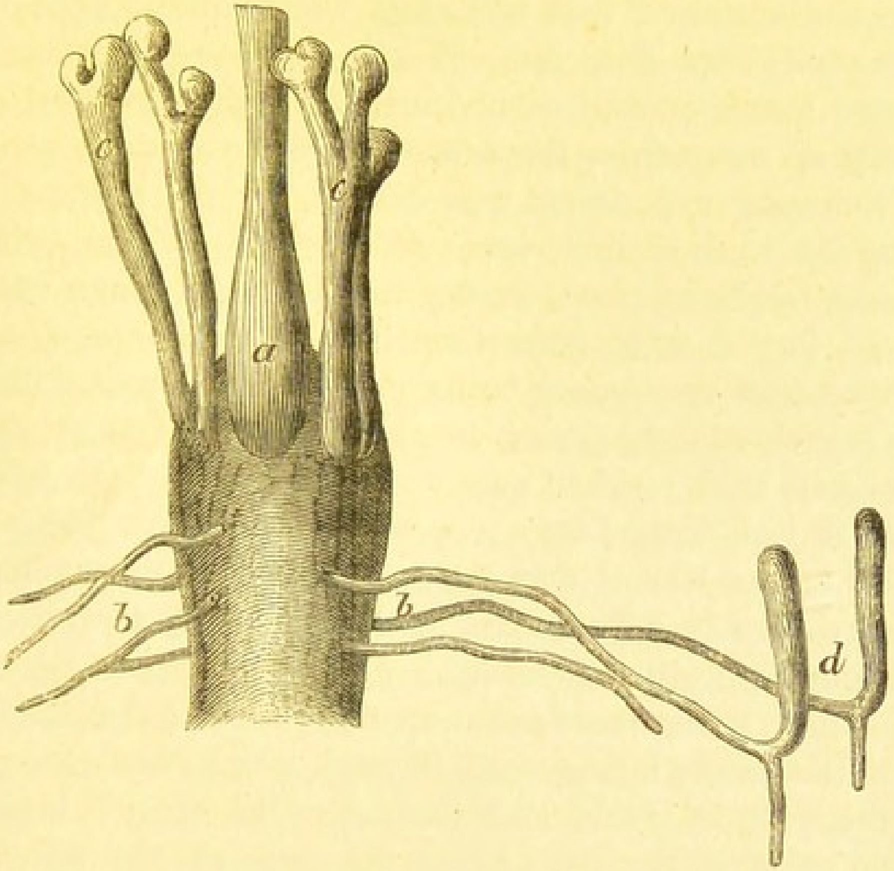

Fig. 41.

The water-roots of land plants sometimes obstruct wells and drains.

Soc. i. 364). In New Haven, Connecticut, some wells are so obstructed by the roots of elm-trees, as to require cleaning out every two or three years. This aquatic tendency has been repeatedly observed in the poplar, cypress, laurel, turnip, mangel-wurzel, and grasses.

Plants may send roots into subsoil to obtain supplies of water.

Henrici surmised that the roots which most cultivated plants send down deep into the soil, even when the latter is by no means porous or inviting, are designed especially to bring up water from the subsoil for the use of the plant. The following experiment was devised for the purpose of testing the truth of this view. On the 13th of May, 1862, a young raspberry plant, having but two leaves, was transplanted into a large glass funnel filled with garden soil, the throat of the funnel being closed with a paper filter. The funnel was supported in the mouth of a large glass jar, and its neck reached nearly to the bottom of the latter, where it just dipped into a quantity of water. The soil in the funnel was at first kept moderately moist by occasional waterings. The plant remained fresh, and slowly grew, putting forth new leaves. After the lapse of several weeks, four strong roots penetrated the filter and extended down the empty funnel-neck, through which they emerged on the 21st of June, and thenceforward spread rapidly in the water of the jar. From this time on, the soil was not watered any more, but care was taken to maintain the supply in the jar. The plant continued to develop slowly; its leaves, however, did not acquire a vivid green colour, but remained pale and yellowish; they did not wither until the usual time, late in autumn. The roots continued to grow, and filled the water more and more. Near the end of December the plant had seven or eight leaves, and a height of eight inches. The water-roots were vigorous, very long, and beset with numerous fibrils and buds. In the funnel tube the roots made a perfect tissue of fibres. In the dry earth of the funnel they were less extensively developed, yet exhibited some buds. The stem and the young axillary leaf buds were also full of sap. The water-roots being cut away, the plant was put into garden soil and placed in a conservatory, where it grew vigorously, and in May bore two offshoots.

The experiment would indicate that plants may extend a portion of their roots into the subsoil chiefly for the purpose of gathering supplies of water (*Henneberg's Jour. für Landwirthschaft*, 1863, p. 280). This growth towards water must be accounted for on the principles asserted in the paragraph—Apparent Search for Food, p. 232.

Land-plants may be grown with their roots in water,

The seeds of many ordinary land-plants—of plants, indeed, that customarily grow in a dry soil, such as the bean, squash, maize, &c.—will readily germinate in moist cotton or saw-dust; and if, when fairly sprouted, the young plants have their roots suspended in water, taking care that the seed and stem are kept above the liquid, they will continue to grow, and if duly supplied with nutriment will run through all the customary stages of development, producing abundant foliage, flowering, and perfecting seeds, without a moment's contact of their roots with any soil (see Water Culture, p. 154).

but afterwards bear transplanting to soil with difficulty.

If plants thus growing with their roots in a liquid medium, after they have formed several large leaves, be carefully transplanted to the soil, they wither and perish, unless frequently watered; whereas similar plants *started in the soil* may be transplanted without suffering in the slightest degree, though the soil be of the usual dryness and receive no water.

The water-bred seedlings, if abundantly watered as often as the foliage withers, recover themselves after a time, and thenceforward continue to grow without the need of watering.

It might appear that the first-formed water-roots are incapable of feeding the plant from a dry soil, and hence the soil must be at first profusely watered; after a time, however, new roots are thrown out, which are adapted to the altered situation of the plant, and then the growth proceeds in the usual manner.

The soil-roots perish when a land-plant is transferred to water.

The reverse experiment would seem to confirm this view. If a seedling that has grown for a short time only in the soil, so that its roots are but twice or thrice branched, have these immersed in water, the roots already formed mostly or entirely perish in a short time. They indeed absorb water, and the plant is sustained by them, but immediately new roots grow from the crown with great rapidity, and take the place of the original roots, which become disorganized and useless. It is, however, only the young and active rootlets, and those covered with hairs, which thus refuse to live in water. The older parts of the roots, which are destitute of fibrils, and which have nearly ceased to be active in the work of absorption, are not affected by the change of circumstance. These facts, which are due to the researches of Dr. Sachs (*Vs. St.* ii. p. 13), would naturally lead to the conclusion that the absorbent surface of the root undergoes some structural change, or produces new roots with modified characters, in order to adapt itself to the medium in which it is placed. It would appear that, when this adaptation proceeds rapidly, the plant is not permanently retarded in its growth by a gradual change in the character of the medium which surrounds its roots, as may happen in the case of rice and marsh plants, when the saturated soil in which they may be situated at one time is slowly dried. Sudden changes of medium about the roots of plants slow to adapt themselves to such alterations would be fatal to their existence.

Nobbe has, however, carefully compared the roots of buckwheat, as developed in the soil, with those emitted in water, without being able to observe any structural differences. The facts detailed above admit of partial, if not complete explanation, without recourse to the supposition that soil and water-roots are essentially diverse in nature.

These results may be due to injuries inflicted during experiments.

When a plant which is rooted in the soil is taken up so that the fibrils are not broken or injured, and set into water, it does not suffer any hindrance in growth, as Sachs has found by late experiments (*Experimental Physiologie*, p. 177). Ordinarily, the suspension of growth and decay of fibrils and rootlets is due, doubtless, to the mechanical injury they suffer in removing from the soil. Again, when a plant that has been reared in water is planted in earth, similar injury occurs in packing the soil about the roots; and moreover, the fibrils cannot be brought into that close contact with the soil which is necessary for them to supply the foliage with water: hence the plant withers, and may easily perish unless profusely watered or shielded from evaporation.

Conditions favourable to development of air-roots.

The issue of either water or soil roots, or both, from the same plant, according to the circumstances in which it is placed, finds something analogous in reference to air-roots. As before stated, these chiefly occur on tropical plants, or in shaded, warm, and very moist situations. Schacht informs us that, in the dark and humid forest ravines of Madeira and Teneriffe, *Laurus canariensis*, a large tree, sends out from its stem during the autumn rains a profusion of fleshy air-roots, which cover the trunk with their interlacing branches, and grow to an inch in thickness. The following summer they dry away and fall to the ground, to be replaced by new ones in the ensuing autumn (*Der Baum*, p. 172).

The formation of air-roots may be very easily observed by filling a tall vial with water to the depth of half an inch, inserting therein a branch of a common house-plant, the *Tradescantia zebrina*, so that the cut end of the stem shall stand in the water, and finally corking the vial air-tight. The plant, which is very tenacious of life, and usually grows well in spite of all neglect, is not checked in its vegetative development by the treatment just described, but immediately begins to adapt itself to its new circumstances. In a few days, if the temperature be 70° or thereabout, air-roots will be seen to issue from the joints of the stem. These are fringed with a profusion of delicate hairs, and rapidly extend to a length of from one to two inches. The lower ones, if they chance to penetrate the water, become discoloured and decay; the others, however, remain for a long time fresh, and of a white colour.

Functions of air-roots.

As already mentioned, Indian corn frequently produces air-roots. The same is true of the oat, of buckwheat, of the grape-vine, and of other plants of temperate regions when they are placed for some time in tropical conditions, *i.e.* when they grow in a rich soil and are surrounded by a very warm and moist atmosphere. It has been conjectured that these air-roots serve to absorb moisture from the air, and thus aid to maintain the growth of the plant. This subject has been studied by Unger, Chatin, and Duchartre. The observers first named were led to conclude that these organs do absorb water from the air. Duchartre, however, denies their absorptive power. They may not perhaps usually condense enough to make good the loss that takes place in other parts of the plant by evaporation. Hence the results of Duchartre, which were obtained on the entire plant, and not on the air-roots alone (*Eléments de Botanique*, p. 216). The aërial roots of epiphytes must also absorb the moisture which trickles down the bark on which they grow, and which would be charged with inorganic and decaying organic matter. De Luca has detected in epiphytes all the usual inorganic constituents of plants. Chatin has also ascertained that absorption is much facilitated in orchids by the spongy absorptive envelope of the aërial roots, which collects water to yield it up gradually to the other root-tissues (*Comptes rendus*, 1856).

Supposed excretion of effete matter from roots.

Root-Excretions.—It has been supposed that the roots of plants perform a function of excretion, the reverse of absorption—that plants, like animals, reject matters which are no longer of use in their organism, and that the rejected matters are poisonous to the kind of vegetation from which they originated. De Candolle, an eminent French botanist, who first advanced this doctrine, founded it upon the observation that certain plants exude drops of liquid from their roots when these are placed in dry sand, and that odours exhale from the roots of other plants. Numerous experiments have been instituted at various times for the purpose of testing this question. The most extensive inquiries we are aware of are those of Dr. Alfred Gyde (*Trans. Highland and Agr. Soc.* 1845-47, pp. 273–92). This experimenter planted a variety of agricultural plants, viz. wheat, barley, oats, rye, beans, peas, vetches, cabbage, mustard, and turnips, in pots filled either with garden soil, sand, moss, or charcoal, and, after they had attained considerable growth, removed the earth, &c. from their roots by washing with water, using care not to injure or wound them, and then immersed the roots in vessels of pure water. The plants were allowed to remain in these circumstances, their roots being kept in darkness, but their foliage exposed to light, from three to seventeen days. In most cases they continued apparently in a good state of health. At the expiration of the time of experiment, the water which had been in contact with the roots was evaporated, and was found to leave a very minute amount of yellowish or brown matter, a portion of which was of organic and the remainder of mineral origin. Dr. Gyde concluded, from his numerous trials, that plants do throw off organic and inorganic excretions similar in composition to their sap; but that the quantity is exceedingly small, and is not injurious to the plants which furnish them. Other experiments, however, have given a purely negative result (Schleiden, *Principles of Bot.* p. 497); and in the light of newer investigations touching the structure of roots, and their adaptation to the medium which happens to invest them, we may well doubt whether agricultural plants in the healthy state excrete any solid or liquid matters whatever from their roots. The familiar excretion of gum, resin, and sugar,* from the stems of trees, appears to result from wounds or disease; and the matters which,

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* From the wounded bark of the Sugar Pine (*Pinus Lambertiana*) of California.

in the experiments of Gyde and others, were observed to be communicated by the roots of plants to pure water, probably came either from the continual pushing off of the tips of the rootlets, by the interior growing point—a process always naturally accompanying the growth of roots—or from the disorganization of the absorbent root-hairs.

Under certain circumstances, small quantities of mineral salts may indeed *diffuse* out of the root-cells into the water of the soil. This is, however, no physiological action, but a purely physical process.

Roots cannot usually survive destruction of leaves.

Vitality of Roots.—It appears that, in the case of most plants, the roots cannot long continue their vitality if their connexion with the leaves be interrupted, unless, indeed, they be kept at a winter temperature. Hence weeds may be effectually destroyed by cutting down their tops; although, in many cases, the process must be several times repeated before the result is attained.

The roots of our root-crops, properly so called—viz. beets, turnips, carrots, and parsnips,—when harvested in autumn, contain the elements of a second year's growth of stem, &c., in the form of a bud at the crown of the root. If the crown be cut away from the root, the latter cannot vegetate, while the growth of the crown itself is not thereby prevented.

As regards *internal structure*, the root closely resembles the stem, and what is stated of the latter on subsequent pages applies in all essential points to the former.

§ 2. The Stem.

The growth of the stem usually upwards.

Shortly after the protrusion of the rootlet from a germinating seed, the Stem makes its appearance. It has, in general, an upward direction, which in many plants is permanent, while in others it shortly falls to the ground and grows thereafter horizontally.

All plants of the higher orders have stems, though in many instances they do not appear above the ground, but extend beneath the surface of the soil, and are popularly considered to be roots.

Functions of the stem.

While the root, save in exceptional cases, does not develop other organs, it is the special function of the stem to bear the leaves, flowers, and seed of the plant, and even in certain tribes of vegetation, like the cacti, which have no leaves to perform the offices of these organs. In general, the functions of the stem are subordinate to those of the organs which it bears—the leaves and flowers. It only extends in length or thickness with the purpose of supporting them mechanically or sustaining them nutritively.

Buds precede stems;

Buds.—In the seed the stem exists in a rudimentary state, associated with undeveloped leaves, forming a *bud.* The stem always proceeds at first from a bud, during all its growth is terminated by a bud at every growing point, and only ceases to be thus tipped when it fully accomplishes its growth by the production of seed, or dies from injury or disease.

their structure.

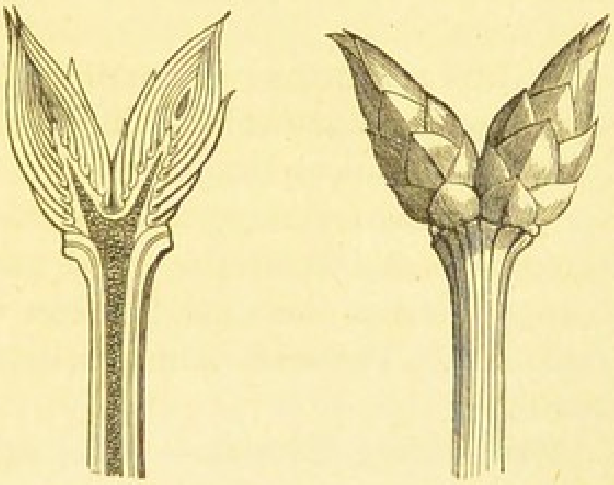

Fig. 42.

In the *leaf-bud* we find a number of embryo leaves and leaf-like scales, in close contact and within each other, but all attached at the base to a central conical axis (Fig. 42). The opening of the bud consists in the lengthening of this axis, which is the stem, and the consequent separation of the leaves from each other. If the rudimentary leaves of a bud be represented by a nest of flower-pots, the smaller placed within the larger, the stem may be represented by a rope of india-rubber passed through the holes in the bottom of the pots. The growth of the stem may now be shown by stretching the rope, whereby the pots are brought away from each other, and the whole combination is made to assume the character of a fully-developed stem, bearing its leaves at regular intervals; with these important differences, that the portions of stem nearest the root extend more rapidly than those above them, and the stem has within it the material and the mechanism for the continual formation of new buds, which unfold in successive order.

In Fig. 42, which represents the two terminal buds of a lilac twig, is shown, not only the external appearance of the buds, which are covered with leaf-like scales, *imbricated* like shingles on a roof; but in the section are seen the edges of the undeveloped leaves attached to the conical axis. All the leaves and the whole stem of a twig of one summer's growth thus exist in the bud, in plan and in miniature. Subsequent growth is but the development of the plan.

In the *flower-bud* the same structure is manifest, save that the rudimentary flowers and fruit are enclosed within the leaves, and may often be seen plainly on cutting the bud open.

Stems interrupted by nodes, which are separated by internodes.

Culms: Nodes: Internodes.—The grasses and the common cereal grains have single, unbranched stems, termed *culms* in botanical language. The leaves of these plants clasp the stem entirely at their base, and at this point is formed a well-defined, thickened knot, or *node*, in the stem. The portions of the stem between these nodes are termed *internodes*. The same terms are also used of all leaf-bearing stems.

Branching Stems.—Other agricultural plants besides those just mentioned, and all the trees of temperate climates, have *branching stems*. As the principal or main stem elongates, so that the leaves arranged upon it separate from each other, we find one or more side or axillary buds at the point where the base of the leaf or of the leaf-stalk unites with the stem. From these buds, in case their growth is not checked, side-stems or branches issue, which again subdivide in the same manner into branchlets.

The nodes of young shoots gradually obliterated.

In perennial plants, when young, or in their young shoots, it is easy to trace the nodes and internodes for some time after the leaves, which only endure for one year, are fallen away. The nodes are manifest by the enlargement of the stem, or by the scar covered with corky matter, which marks the spot where the leaf-stalk was attached. As the stem grows older these indications of its early development are gradually obliterated.

In a forest where the trees are thickly crowded the lower branches die away from want of light; the scars resulting from their removal are covered with a new growth of wood, so that the trunk finally appears as if it had always been destitute of branches to a great height.

When all the buds develop normally and in due proportion, the plant, thus regularly built up, has a symmetrical appearance, as frequently happens with many herbs, and with some cone-bearing trees.

Buds may remain more or less undeveloped.

Latent Buds.—Often, however, many of the buds remain undeveloped either permanently or for a time. Many of the side buds of most of our forest and fruit trees fail entirely to grow, while others make no progress until the summer succeeding their first appearance. When the active buds are destroyed, either by frosts or by pinching, other buds that would else remain latent are pushed into growth. In this way, trees whose young leaves are destroyed by spring frosts, cover themselves again after a time with foliage. In this way, too, the gardener moulds a straggling, ill-shaped shrub or plant into almost any form he chooses: for, by removing branches and buds where they have grown in undue proportion, he not only checks excess, but also calls forth development in the parts before suppressed.

Adventitious buds do not originate from nodes.

Adventitious or **irregular Buds** are produced from the stems as well as older roots of many plants, when they are mechanically injured during the growing season. The soft or red maple and the chestnut, when cut down, habitually throw out buds and new stems from the stump, and the basket-willow is annually polled, or *pollarded*, to induce the growth of slender shoots from an old trunk.

The growth of stems takes place through whole length.

Elongation of Stems.—While roots extend chiefly at their extremities, we find the stem elongates equally, or nearly so, in all its contiguous parts, as is manifest from what has already been stated in illustration of its development from the bud.

Besides the upright stem, there are a variety of prostrate and in part subterranean stems, which may be briefly noticed.

Varieties of prostrate stems.

Runners and **Layers** are stems which branch out horizontally just above the soil, and, coming in contact with the earth, take root, forming new plants, which may thenceforward grow independently. The gardener takes advantage of these stems to propagate certain plants. The strawberry furnishes the most familiar example of runners, while many of the young shoots of the currant fall to the ground and, taking root, become layers. The runner usually bears but few leaves. The layer does not differ from an ordinary stem, except by the circumstance, often accidental, of becoming prostrate. Many plants which usually send out no layers are nevertheless artificially *layered* by bending their stems or branches to the ground, or by attaching them to a ball or pot of earth. The striking of roots from the layer is in many cases facilitated by cutting half through, twisting, or otherwise wounding the stem at the node where it is buried in the soil.

The *tillering* of wheat and other cereals, and of many grasses, is the spreading of the plant by layers. The first stems that appear from these plants ascend vertically, but subsequently other stems issue, whose growth is, for a time, nearly horizontal. They thus come in contact with the soil, and emit roots from their lower joints. From these again grow new stems and new roots in rapid succession, so that a *stool* produced from a single kernel of winter wheat, having perfect freedom of growth, has been known to carry fifty or sixty grain-bearing culms (Hallet, *Jour. Roy. Soc. of Eng.* xxii. p. 372).

Suckers.—When branches arise from the stem below the surface of the soil, so that their course is partly subterranean and partly aërial, as in the Rose and Raspberry, they are termed *Suckers*. These leafy shoots put out roots from their buried nodes, and may be separated artificially and used for propagating the plant, an operation called by gardeners "parting the roots."

Varieties of subterranean stems.

Subterranean Stems.—Of these there are three forms. They are usually thought to be roots, from the fact of existing below the surface of the soil. This circumstance is, however, quite accidental. The pods of the ground-nut (*Arachis hypogæa*) ripen beneath the ground—the flower-stems lengthening and penetrating the earth as soon as the blossom falls; but ground-nuts are not by any means to be confounded with roots.

Root-stock a subterranean stem with leaf-scales and roots at the nodes.

Rhizome or Root-stock.—True roots are destitute of leaves. This distinguishes them from the *rhizome* or *root-stock*, which is a subterranean root-like stem, more or less clothed with leaf-scales, and with the internodes usually little developed. The flower-de-luce, Solomon's seal, and water-lily afford good examples. The inflorescence is produced from the aërial development of the terminal bud, while the onward extension of the root-stock is effected by axillary buds. Certain widely-spreading plants afford examples of rhizomes with developed internodes, as the Sand Sedge, various Mints, and Couch-grass (*Triticum repens*, represented in Fig. 43), which infests so many farms. Each node of the root-stock being usually supplied with roots, and having latent buds, is ready to become an independent growth the moment it is detached from its parent plant. In this way couch-grass becomes especially troublesome to the farmer, for, within certain limits, the more he harrows the fields where it has obtained a footing, the more does it spread and multiply.

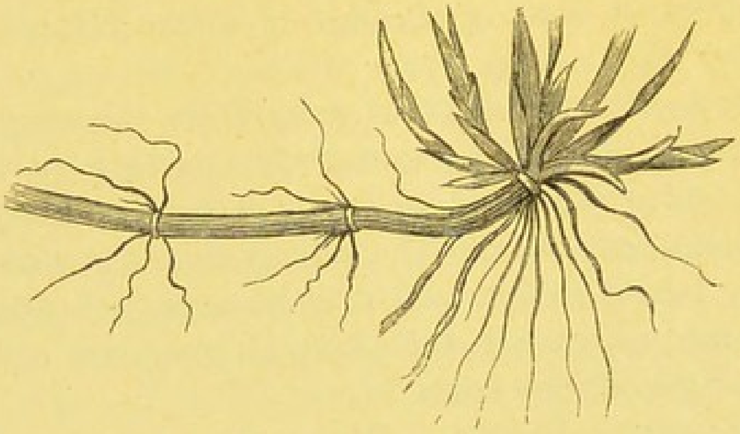

Fig. 43.

Corms consist of enlarged base of the stem.

Corms externally more or less resemble bulbs, but consist principally of the short, solid, enlarged base of the stem, in some herbaceous plants, as the Crocus and Cuckoo-pint (*Arum maculatum*). They bear leaf-buds either at the summit or side, and may be regarded as much shortened rhizomes, consisting of only a few undeveloped internodes.

Tubers enlarged extremities of stems.

The Tubers of most agricultural plants are fleshy enlargements of the extremities of subterranean stems. Their *eyes* are the points where the buds exist, sometimes three together, and where minute scales—rudimentary leaves—may be observed. The common potato and Jerusalem artichoke are instances of tubers. Tubers serve excellently for propagation. Each eye, or bud, may become a new plant. From the quantity of starchy matter accumulated in them, they are of great importance as food. The number of tubers produced by a potato plant appears to be increased by planting originally at a considerable depth, or by piling earth round the base of the aërial stems during the early stages of its growth.

Bulbs are permanent buds.

Bulbs differ from *Corms* in consisting of concentric layers of thickened and persistent scales, which are attached to a flattened disk, the depressed axis, the internodes of which always remain undeveloped. The bulb is, in fact, a fleshy permanent bud, usually in part or entirely subterranean. From its apex, the proper stem, the foliage, &c. proceed; while from its base, roots are sent out. The structural identity of the bulb with a bud is shown by the fact that the onion, which furnishes the commonest example of the bulb, often bears bulblets at the top of its stem, in place of flowers. In like manner, the axillary buds of the tiger-lily are thickened and fleshy, and fall off as bulblets to the ground, where they produce new plants.

Structure of the stem described;

STRUCTURE OF THE STEM.—The stem is so complicated in its structural composition that to discuss it fully would occupy a volume. For our immediate purposes it is, however, only necessary to notice it very concisely.

consists at first of cellular,

The rudimentary stem, as found in the seed, or the new-formed part of the maturer stem at the growing points just below the terminal buds, consists of *cellular tissue*, i.e. of an aggregate of rounded and cohering cells, which rapidly multiply during the vigorous growth of the plant.

which is afterwards penetrated by vascular tissue.

In some of the lower orders of vegetation, as in mushrooms and lichens, the stem, if any exist, always preserves a purely cellular character; but in all flowering plants the original cellular tissue of the stem, as well as of the root, is shortly penetrated by *vascular tissue*, consisting of ducts or tubes, which result from the obliteration of the horizontal partitions of cell-tissue, and by wood-cells, which are many times longer than wide, and the walls of which are much thickened by internal deposition.

These ducts and wood-cells, together with some other forms of cells, are usually found in close connexion, and are arranged in bundles. They are always disposed lengthwise in the stem and branches. They are found to some extent in the softest herbaceous stems, while they constitute a large share of the trunks of most shrubs and trees. From the toughness which they possess, and the manner in which they are woven through the original cellular tissue, they give to the stem its solidity and strength.

Important distinctions in the structure of the stems in endogens and exogens.

Flowering plants may be divided into two great classes, in consequence of important and obvious differences in the structure of their stems and seeds. 1. *Monocotyledons*, or *Endogens*; 2. *Dicotyledons*, or *Exogens*.

Naked eye anatomy of endogenous stems.

Endogenous Plants are those whose stems enlarge by the formation of new woody bundles dispersed amongst the older ones, and not arranged in concentric layers. The embryos of endogenous plants have only a single seed-leaf,—or, in botanical language, have but one *cotyledon*; hence are called monocotyledonous. Indian corn, sugar-cane, sorghum, wheat, oat, rye, barley, the onion, asparagus, and all the grasses, belong to this class of plants.

If a stalk of maize, asparagus, or bamboo, be cut across, the bundles of ducts are seen disposed somewhat uniformly throughout the section, though less abundantly towards the centre. On splitting the fresh stalk lengthwise, the vascular bundles may be torn out like strings. At the nodes, where the stem branches, or where leaf-stalks are attached, the vascular bundles likewise divide and form a *network*. In a ripe maize stalk which is exposed to circumstances favouring decay, the soft cell-tissue first suffers change and often quite disappears, leaving the firmer vascular bundles unaltered in form. A portion of the base of such a stalk, cut lengthwise, is represented in Fig. 44, where the vascular bundles are seen arranged parallel to each other in the internodes, and curiously interwoven and branched at the nodes, both at

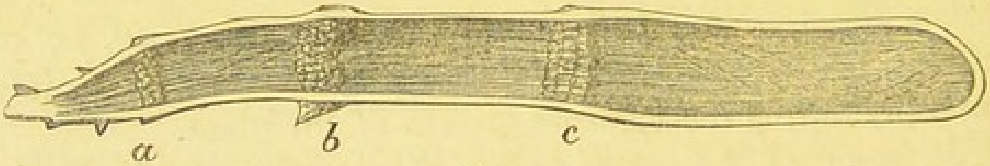

Fig. 44.

those (*a* and *b*) from which roots issue, or at that (*c*) which was clasped by the base of a leaf.

The endogenous stem, as represented in the maize-stalk, has no well-defined *bark* that admits of being stripped off externally, and no separate central *pith* of soft cell-tissue free from vascular bundles. It, like the aërial portions of all flowering plants, is covered with a skin, or *epidermis*, composed usually of one or several layers of flattened cells, whose walls are thick, and far less penetrable to fluid than the delicate texture of the interior cell-tissue. The stem is denser and harder at the circumference than towards the centre. This is due to the fact that the bundles are more numerous and older towards the outside of the stem. The newer bundles, as they continually form at the base of the growing terminal bud, pass to the inside of the stem, and afterwards outwards and downwards, and hence the designation endogenous, which in plain English means *inside-grower*.

In consequence of this growth of the bundles, the stems of most woody endogens, as the palms, after a time become so indurated externally, that all lateral expansion ceases, and the stem increases only in height. In some cases, the tree dies because its interior is so closely packed with bundles that the descent of new ones, and the accompanying vital processes, become impossible.

In herbaceous endogens the soft stem admits the indefinite growth of new vascular tissue.

The stems of the *grasses* are hollow, except at the nodes. Those of the *rushes* have a central pith free from vascular tissue.

Minute anatomy of endogenous stems,

The Minute Structure of the Endogenous Stem is exhibited in the accompanying cuts, which represent highly-magnified sections of a *Vascular Bundle* from the maize-stalk. As before remarked, the stem is composed of a groundwork of delicate cell-tissue, in which bundles of vascular tissue are distributed. Fig. 45 represents a as seen in a transverse,

cross section of one of these bundles (*c*, *g*, *h*), as well as of a portion of the surrounding cellular tissue (*a*, *a*). The latter consists of quite large cells, which, being but loosely packed together, have between them considerable intercellular spaces, *i*. The vascular bundle itself is composed

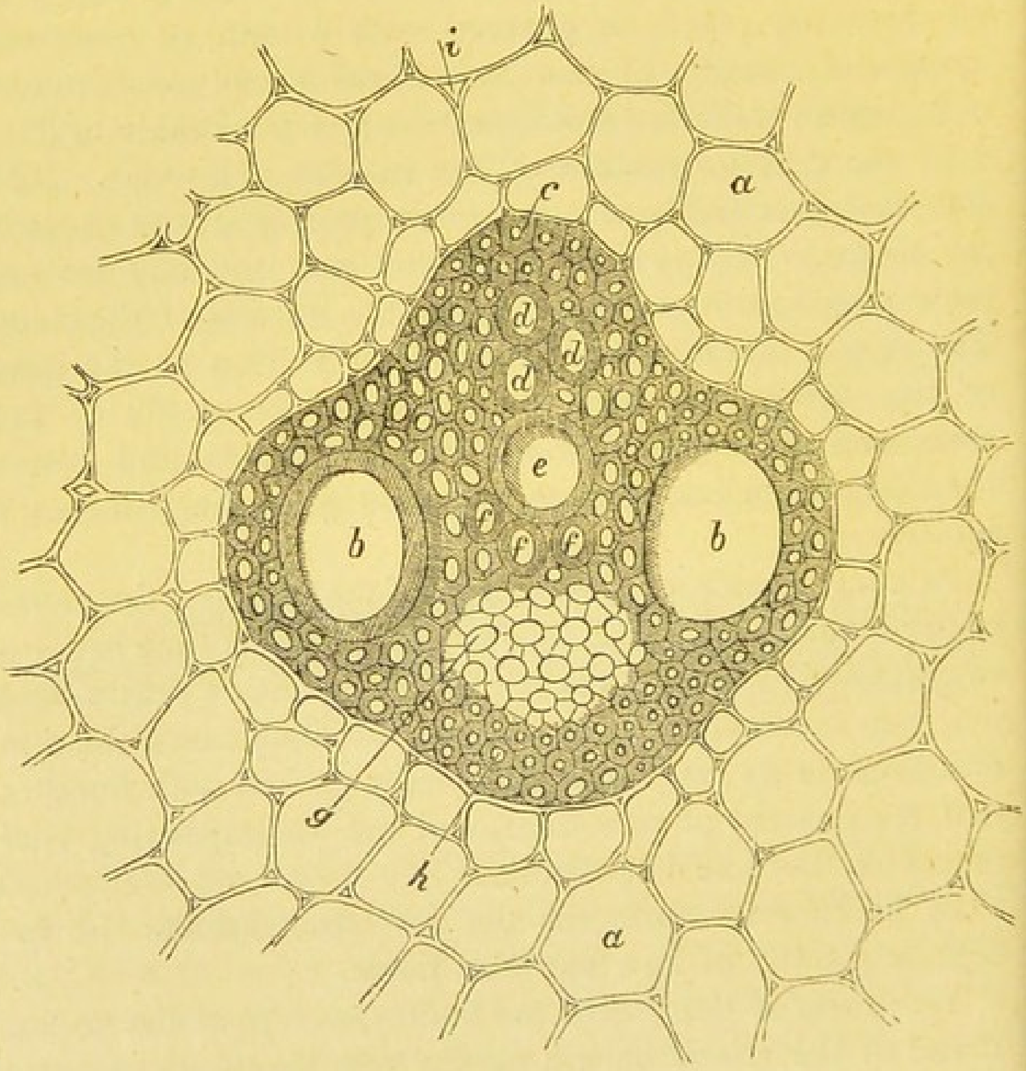

Fig. 45.

externally of narrow thick-walled cells, of which those nearest the exterior of the stem, *h*, are termed *bast-cells*, as they correspond in character and position to the cells of the bast or inner bark of our common trees; those nearest the centre of the stem, *c*, are *wood-cells*. In the maize stem, bast and wood cells are quite alike, and are distinguished only by their position. In other plants, they are often unlike as regards length, thickness, and pliability, though still for the most part similar in form. Among the wood-cells we observe a number of *ducts* (*d*, *e*, *f*), and between these and the bast-cells is a delicate and transparent tissue, *g*, which is the *cambium*, in which all the *growth* of the bundle goes on until it is complete. On either hand is seen a remarkably large duct, *b*, *b*, while the residue of the bundle is composed of long and rather thick-walled wood-cells.

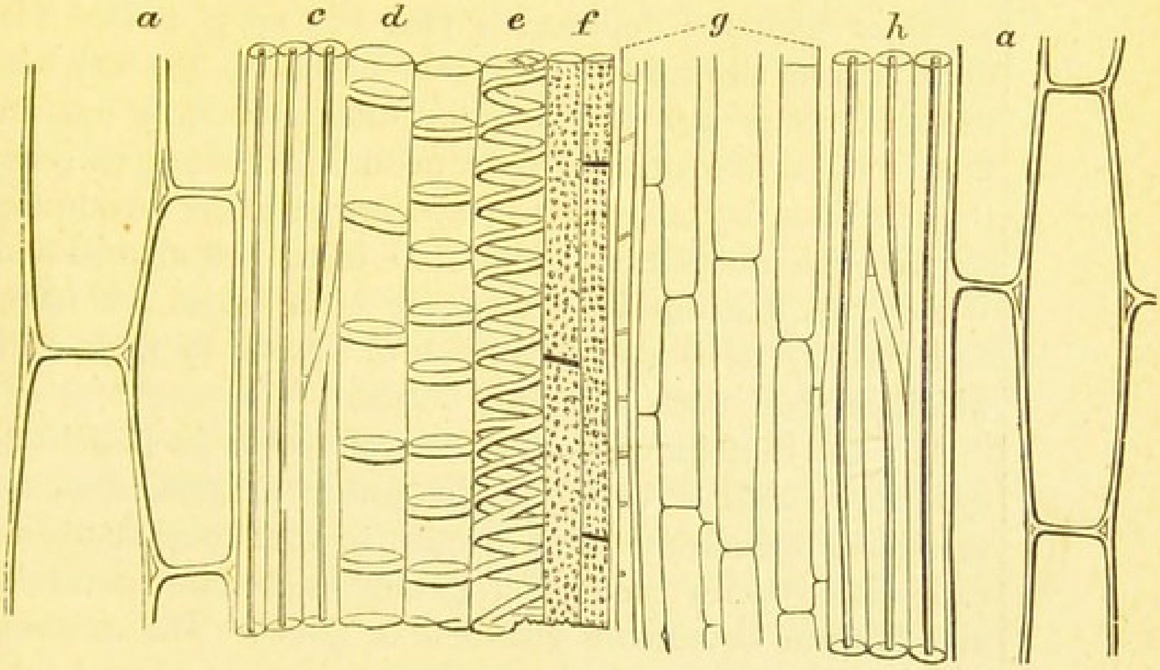

Fig. 46.

and in a vertical section.

Fig. 46 represents a section made vertically through the bundle from *c* to *h*. In this the letters refer to the same parts as in the former cut: *a*, *a*, is the cell-tissue, enveloping the vascular bundle; the cells are observed to be much longer than wide, but are separated from each other at the ends as well as sides by an imperforate membrane. The wood and bast cells, *c*, *h*, are seen to be long, narrow, thick-walled cells, running obliquely to a point at either end. The wood-cells of oak and the toughest woods, as well as the bast-cells of flax and hemp, are quite similar in form and appearance. The ducts are next in the order of our section. Of these there are several varieties, as *ring-ducts*, *d*; *spiral ducts*, *e*; *dotted ducts*, *f*. These are continuous tubes, of more or less considerable length, produced by the absorption of the transverse membranes that once divided them into such cells as *a*, *a*, and they are thickened internally by ring-like, spiral, or punctate depositions (see Fig. 29, p. 218). The dots or pits are simply very thin points in the cell-wall through which sap may soak or diffuse laterally but not flow. When the cells become mature and cease to grow, the pits often become pores by absorption of the membrane, so that the ducts thus enter into direct communication. Wood-cells that consist exclusively of cellulose are pliant and elastic. It is the deposition of lignine in their walls which renders them stiff and brittle.

At *g*, the cambium tissue is observed to consist of delicate cylindrical cells. Among these, partial absorption of the separating membrane often occurs, so that they communicate directly with each other through sieve-like partitions, and become continuous channels or ducts. The *cambium* is the seat of growth by cell formation. Accordingly, when a vascular bundle has attained maturity, it no longer possesses a cambium; such bundles are called *Definite bundles.*

Naked eye anatomy of exogenous stems.

Exogenous Plants are those whose stems continually enlarge in diameter by the formation of new tissue near the outside of the stem. They are *outside-growers.* Their embryos possess two cotyledons, whence they are designated dicotyledonous. All the forest trees of temperate climates, and among agricultural plants the bean, pea, clover, potato, beet, turnip, flax, &c., are exogens.

In the exogenous stem the bundles of ducts and fibres that appear in the cell-tissue are always formed just within the rind. They occur at first separately, as in endogens, The fibres arranged in circular zones

but, instead of being scattered throughout the cellular tissue, are disposed in a circle. As they grow, they usually close up into a ring or zone of wood, which encloses unaltered cell-tissue—the pith.

As the stem enlarges, new rings of fibres may be formed, but always *outside* the older ones. In hard stems of slow growth the rings are close together, and chiefly consist of very firm wood-cells. In the soft stems of herbaceous plants the cellular tissue preponderates, and the ducts and cells of the vascular zones are delicate. The hardening of herbaceous stems which takes place as they become mature is due to the increase and induration of the wood-cells and ducts.

The circular disposition of the fibres in the exogenous stem may be readily seen in a multitude of common plants.

The potato tuber is a form of stem always accessible for observation. If a potato be cut across near the stem end with a sharp knife, it is usually easy to identify upon the section a ring of vascular tissue, the general course of which is parallel to the circumference of the tuber, except where it runs out to the surface in the eyes or buds and in the narrow stem at whose extremity it grows. If a slice across a potato be soaked in a solution of iodine for a few minutes, the vascular rings become strikingly apparent. In its active cambial cells albuminoids are abundant, which assume a yellow tinge with iodine. The starch of the cell-tissue, on the other hand, becomes intensely blue, making the vascular tissue all the more evident.

Since the structure of the root is quite similar to that of the stem, a section of the common beet, as well as one of a branch from any tree of temperate latitudes, may serve to illustrate the concentric arrangement of the vascular zones when they are multipled in number.

round the pith.

Pith is the cellular tissue of the centre of the stem. In young stems it is charged with juices; in older ones it often becomes dead and sapless. In many cases, especially when growth is active, it becomes broken and nearly obliterated, leaving a hollow stem, as in a rank pea-vine, or clover stalk, or in a hollow potato. In the potato tuber the pith cells are occupied throughout with starch, although, as the coloration by iodine makes evident, the quantity of starch diminishes from the vascular zone towards the centre of the tuber.

The rind consists at first of epidermis alone;

The *Rind*, which at first consists of mere *epidermis*, or short thick-walled cells, overlying soft cellular tissue, becomes penetrated with cells of unusual length and tenacity, which, from their position in the plant, are termed bast-cells.

bast tissue afterwards formed between it and the wood.

These, together with latex canals, constitute the so-called *bast*, which grows chiefly upon the interior of the rind in successive annual layers in close proximity to the wood. With their abundant development and with age the rind becomes *bark* as it occurs on shrubs and trees. The bast-cells give to the bark its peculiar toughness, and cause it to come off the stem in long and pliant strips.

All the textile materials employed in making cloth and cordage, with the exception of cotton, as flax, hemp, New Zealand flax, &c., are bast fibres (see p. 218).

In some plants the annual layers of bast are separated by cellular tissue, so that in old stems they may be split from one another. Russia matting is made by weaving strips of the bast layers of the Lime (*Tilia Europæa*). The lace of the Lace-bark tree of Jamaica (*Lagetta lintearia*) is the bast. Cuba bast, used for tying up cigars and introduced during the Russian war for gardeners, is the inner bark of *Paritium elatum* (Mallow order). The bast of the vine separates in long shreds a year or two after its formation.

Corky layer replaces epidermis.

The epidermis of young stems is replaced after a certain age by the *corky layer*. This differs much in its condition in different trees. In the Birch it is formed of alternate layers of large and small celled tissue, and splits and rolls up. In the Plane it is thrown off in large plates periodically by the expansion of the cellular tissue underneath.

In the Maple, Elm, and Oak, especially in the Cork Oak (*Quercus suber*), it receives regular additions on its inner side, and does not separate; after a time it consequently acquires considerable thickness, the growth of the stem furrows it with deep longitudinal rifts, and it gradually decays, or drops away exteriorly, as the newer bark forms within.

Pith-rays connect cellular tissue of bark and pith.

Pith Rays.—Those portions of the first-formed cell-tissue which were interposed between the young and originally ununited wood fibres remain, and connect the pith with the cellular tissue of the bark. They interrupt the straight course of the bast-cells, producing the netted appearance often seen in bast layers, as in the Lace-bark. In hard stems they become flattened by the pressure of the fibres; they are especially conspicuous in the Oak and Maple, and form what is commonly known as the *silver grain.* The botanist terms them pith-rays, or *medullary rays.* Fig. 47 exhibits a section of the wood of the Spruce magnified 200 diameters. The section is made in the direction of the wood-cells, *h*, across the pith-rays, *m*, *n*. Besides the pith-rays, the wood is also traversed by the tissues of lateral branches, which are connected with the centre of the stem, and may be traced to the pith and its sheath of spiral ducts.

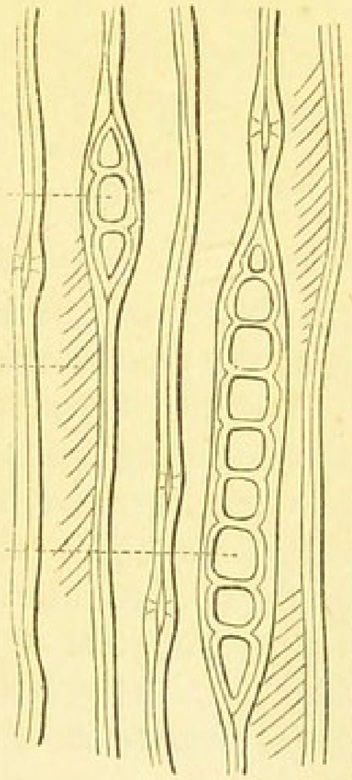

Fig. 47.

Growing part of stem or cambium.

Cambium of Exogens.—The growing part of the exogenous stem is between the fully-formed wood and the mature bark. There is, in fact, no definite limit where wood ceases and bark begins, for they are connected by the cambial or formative tissue, from which, on the one hand, wood fibres, and on the other, bast fibres, rapidly develop. In the cambium, likewise, the pith-rays which connect the inner and outer parts of the stem continue their outward growth.

In spring-time the new cells that form in the cambial region are very delicate and easily broken. For this reason the rind or bark may be stripped from the wood without difficulty. In autumn these cells become thickened and indurated; become, in fact, full-grown bast and wood cells, so that to peel the bark off smoothly is impossible.

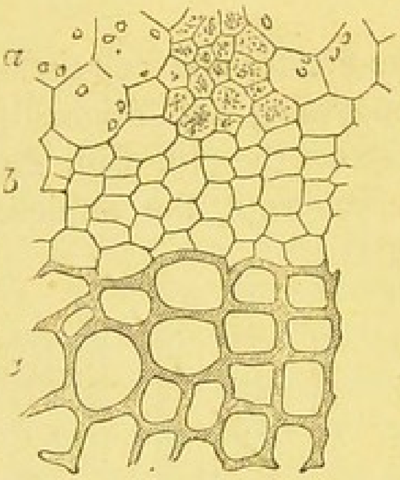

Fig. 48.

Fig. 48 is the exterior part towards the rind of a vascular bundle from potato haulm. *c* consists of wood-cells with ducts, *b* is the cambium tissue, *a* are cells containing a fluid turbid with minute granules; the dotted walls of these cells indicate that they have undergone the process of thickening.

Minute structure of exogenous stem.

Minute Structure of Exogenous Stems.—The accompanying figure (49) will serve to convey an idea of the minute structure of the elements of the exogenous stem. It exhibits a highly-magnified section *lengthwise*, through a young potato tuber. *a*, *b*, is the rind; *e* is the vascular ring; *f*, the pith. The outer cells of the rind are converted into *cork*. They have become empty of sap, and are nearly impervious to air and moisture. This corky layer, *a*, constitutes the thin coat or skin that may be so readily peeled off from a boiled potato. Whenever a potato is superficially wounded, even in winter time, the exposed part heals over by the formation of cork-cells. The cell-tissue of the rind consists at its centre, *b*, of full-formed cells with delicate membranes, which contain numerous and large starch grains. On either hand, as the rind approaches the corky layer or the vascular ring, the cells are smaller, and contain smaller starch grains; on either side of these are noticed cells, containing no starch, but having *nuclei* (*c*, *y*). These nucleated cells are capable of multiplication, and they are situated where the growth of the tuber takes place. The rind, which makes a large part of the flesh of the potato, increases in thickness by the formation of new cells within and without. Without, where it joins the corky skin, the latter likewise grows. Within, contiguous to the vascular zone, new ducts are formed. In a similar manner, the pith expands by formation of new cells where it joins the vascular tissue. The latter consists, in our figure, of ring, spiral, and dotted ducts, like those already described as occurring in the maize-stalk. The delicate cambial cells, *c*, are in the region of most active growth. At this point new cells rapidly develop, those to the right, in the figure, remaining simple cells and becoming loosely filled with starch; those to the left developing new ducts.

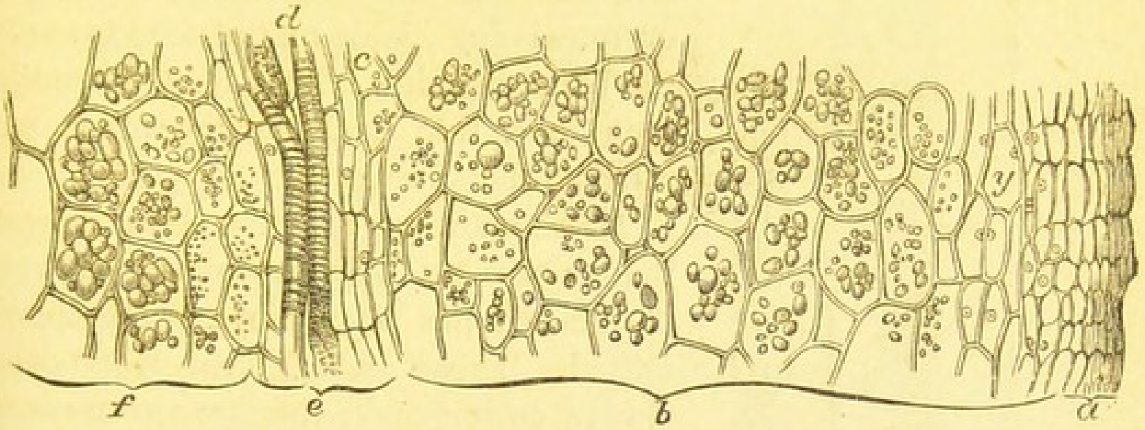

Fig. 49.

In the slender overground potato stem, as in all the stems of most agricultural plants, the same relation of parts is to be observed, although the vascular and woody tissues often preponderate. Wood-cells are especially abundant in those stems that need strength for the fulfilment of their offices, and in them, especially in those of our trees, the structure is commonly more complicated.

Coniferous trees have no ducts, but wood-cells

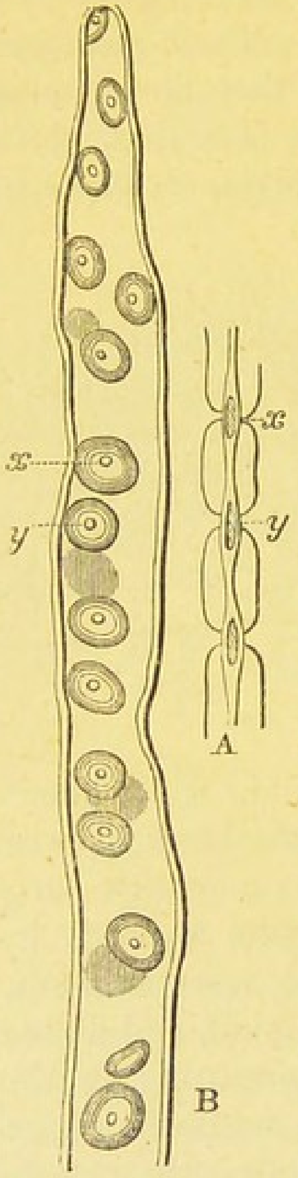

Fig. 50.

Circular markings of Coniferous Wood.—In the wood of cone-bearing trees there are no proper ducts, such as have been described. The wood-cells, which are of unusual size, have disk-like markings on their lateral walls, few or none being visible on the sides towards the bark and pith. They may be readily seen in a thin deal shaving made parallel to the silver grain.

These markings are thin places, where the thickening deposit lining the rest of the cell has been more or less intermitted. Those of adjacent wood-cells always correspond; the two membranes at the same time separating, and each bulging inwards, leave a lenticular space like that between two watch-glasses placed edge to edge.

marked with circular disks.

Fig. 50, *A*, represents a portion of an isolated wood-cell of the Scotch Fir (*Pinus sylvestris*), magnified 200 diameters. Upon it are seen nearly circular disks, *x*, *y*, the structure of which, while the cell is young, is shown by a section through them lengthwise. *B* exhibits such a section through the thickened walls of two contiguous and adhering cells. *x*, in both *A* and *B*, shows the lenticular space between the two primary cell-walls; *y* is the narrow part of the channel that remains while the membrane thickens around it. This is seen in *A*, *y*, as a pit or disk within the large ring caused by the lenticular interspace.

In the next figure (51), representing a transverse section of the spring wood of the same tree magnified 300 diameters, the structure and the gradual formation of these disks is made evident. *R* are the young cells of the rind; *C* is the cambium, where cell multiplication goes on; *W* is the wood, whose cells are more developed the older they are, *i.e.* the more distant from the cambium, as is seen from their figure and in the thickness of their walls. At *a* is shown the disk in its earliest stage; *b* and *c* exhibit it in a more advanced growth. At *d*, the disk has become a pore, the primary membrane has been absorbed, and a free channel made between the two cells. The dotted lines at *d* lead out laterally to two concentric circles, which represent the disk-pore seen flatwise, as in Fig. 50. At *e*, the section passes through the new annual ring into the autumn wood of the preceding year.

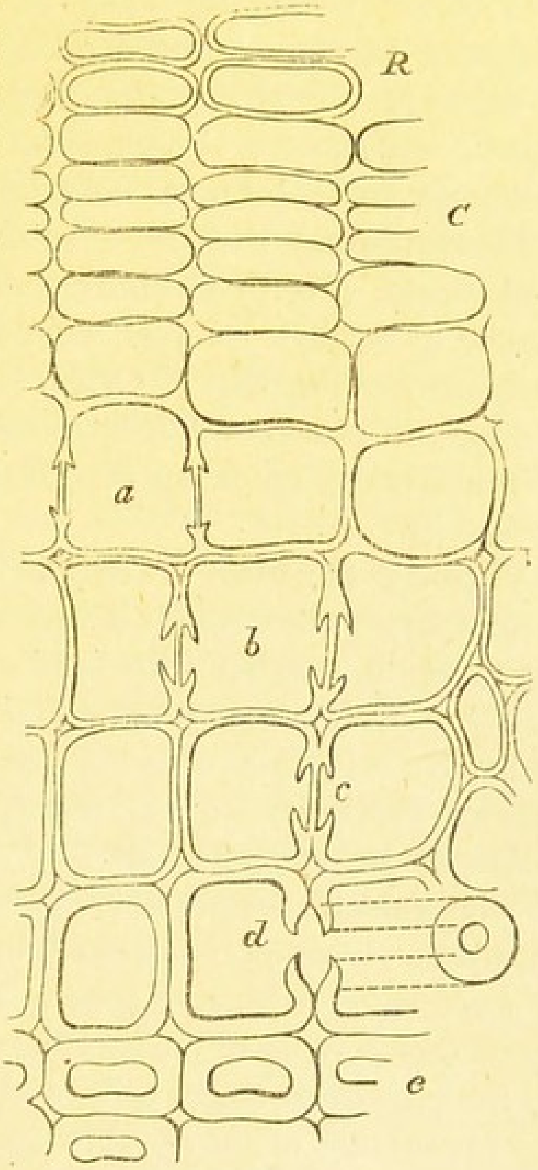

Fig. 51.

Ducts which carry milky juice described.

Milk Ducts.—Besides the ducts already described, there is, in many plants, a system of irregularly branched channels containing a milky juice, as in the sweet potato and dandelion. Milk ducts do not appear to be formed like true vessels by the fusion of cells into tubes, but are intercellular spaces lined by a false membrane from alteration of the walls of the cells which bound them. They occur most abundantly in the pith and inner bark of stems, and in the cellular tissue of roots. These canals contain a granular fluid (*latex*), becoming milky on exposure to the air, and gradually hardening into a resinous substance. The latex of different plants supplies some of the most important organic substances—gum-resins, like gutta-percha or caoutchouc, and substances containing alkaloids, like opium.

Stems of annual

Herbaceous Stems.—Annual stems of the exogenous kind, whose growth is entirely arrested by winter, consist usually of a single ring of woody tissue with interior pith and surrounding bark. Often, however, the zone of wood is thin, and possesses but little solidity, while the chief part of the stem is made up of cell-tissue, so that the stem is *herbaceous*.

and perennial exogens contrasted.

Woody Stems.—Perennial exogenous stems consist, in temperate climates, of a series of rings or zones, corresponding in number with that of the years during which their growth has been progressing. The stems of our shrubs and trees, especially after the first few years of growth, consist, for the most part, of woody tissue, the proportion of cell-tissue being very small.

The annual cessation of growth which occurs at the approach of winter is marked by the formation of smaller or finer wood-cells, as shown in Fig. 51, while the vigorous renewal of activity in the cambium at spring-time is exhibited by the growth of larger cells, and in many kinds of wood in the production of ducts, which, as in the Oak, are visible to the eye at the interior of the annual layers.

Distinction between sap and heart wood.

Sap-wood and Heart-wood.—The living processes in perennial stems, while proceeding with most force in the cambium, are not confined to that locality, but go on to a considerable depth in the wood. Except at the cambial layer, however, these processes consist not in the formation of new cells, nor the enlargement of those once formed—not properly in growth—but in the transmission of sap and the deposition of organized matter on the interior of the wood-cells. In consequence of this deposition the inner or heart-wood of many of our forest trees becomes much denser in texture and more durable for industrial purposes. It then acquires a colour different from the outer or sap-wood, becomes brown in most cases, though it is yellow in the barberry and red in the red cedar.

The final result of the filling up of the cells of the heart-wood is to make this part of the stem almost or quite impassable to sap, so that the interior wood may be removed by decay without disturbing the vigour of the tree.

Stem places different organs in communication with root.

Passage of Sap through the Stem.—The stem, besides supporting the foliage, flowers, and fruit, has also a most important office in admitting the passage upward to these organs, of the water and mineral matters which enter the plants by the roots. Similarly, it allows the downward transfer to the roots of substances gathered by the foliage from the atmosphere. To this and other topics connected with the ascent and descent of the sap we shall hereafter recur.

The stem constitutes the chief part by weight of many plants, especially of forest-trees, and serves the most important uses in agriculture, as well as in a thousand other industries.

§ 3. LEAVES.

Leaves are lateral appendages of stem.

These most important organs issue from the stem, are at first folded together in the bud, and afterwards expand so as to present a great amount of surface to the air and light.

The leaf consists of a thin membrane of cell-tissue, directly connected with the cellular layer of the bark, arranged upon a skeleton or network of fibres and ducts continuous with those of the inner bark and wood.

In certain plants, as cactuses, there scarcely exist any leaves, or, if any occur, they do not differ, except in external form, from the stems. Many of these plants above ground are, in form, all stem, while in structure and function they are all leaf.

In the grasses, although the stem and leaf are distinguishable in shape, they are but little unlike in other external characters.

In forest-trees, we find the most obvious and striking differences between the stem and leaves.

A green colour due to chlorophyll characteristic of leaves.

Green Colour of Leaves.—A peculiarity most characteristic of the leaf, so long as it is in vigorous discharge of its proper vegetative activities, is the possession of a green colour, owing to the presence of *chlorophyll.* This colour is also proper in most cases to the young bark of the stem, a fact further indicating the connexion between these parts, or rather demonstrating their identity of origin and function; for it is true, not only in the case of the cactuses, but also in that of all other young plants, that the green (young) stems perform, to some extent, the same offices as the leaves. The loss of green colour that occurs in autumn in the foliage of our deciduous trees, or on the maturing of the plant in case of the cereal grains, is connected with the cessation of growth and death of the leaf. The chemical properties of chlorophyll are described on page 96.

There are plants whose foliage has a red, brown, white, or other than a green colour during the period of active growth. Many of these are cultivated by florists for ornamental purposes. The cells of these coloured leaves are by no means destitute of chlorophyll, as is shown by microscopic examination, though this substance is associated with other colouring matters which mask its green tint.

External form of leaves variable, but internal structure simple.

Structure of Leaves.—While in shape, size, modes of arrangement upon and attachment to the stem, we find among leaves endless diversity, there is great simplicity in the matter of their internal structure.

The accompanying figure (52) represents the appearance of a piece of bean-leaf as seen on a section from the upper to the lower surface, and highly magnified.

The whole surface of the leaf, on both sides, is covered with *epidermis*, a coating which, in many cases, may be readily stripped off the leaf, and consists of thick-walled cells, which are for the most part devoid of liquid contents, except when very young (*E*, *E*, Fig. 52).

Below the upper epidermis there often occur one or more layers of oblong cells, whose sides are in close contact, and which are arranged endwise, with reference to the plane of the leaf. Below these, down to the lower epidermis, for one-half to three-quarters of the thickness of the leaf, the cells are commonly spherical or irregular in figure and arrangement, and more loosely disposed, with numerous and large interspaces.

The interspaces among the leaf-cells are occupied with air, which is also in most cases the only content of the epidermal cells. The active cells of the leaf contain some or all of the various proximate principles which have been already noticed, and in addition *chlorophyll*, or leaf-green. Under the microscope this substance is commonly seen in the form of minute grains attached to the walls of the cells, as in Fig. 52, or coating starch granules, or else floating free in the cell sap.

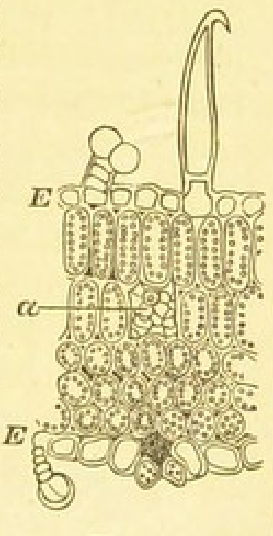

Fig. 52.

The structure of the *veins* or ribs of the leaf is similar to that of the vascular bundles of the stem of which they are branches. At *a*, Fig. 52, is seen the cross section of a vein in the bean-leaf.

The *epidermis*, while often smooth, is frequently beset with hairs or glands, as seen in the figure. These are variously-shaped cells, sometimes empty, sometimes, as in the nettle, filled with an acid liquid.

The epidermis provided with leaf-pores or stomata.

Leaf-Pores.—The epidermis is further provided with a vast number of curious "breathing pores," or *stomata*, by means of which the intercellular spaces in the interior of

Stomata place the interspaces of the leaf in communication with the atmosphere.

the leaf may be brought into direct communication with the outer atmosphere. Each of these stomata consists usually of two curved cells, which are disposed toward each other nearly like the two sides of the letter *O* (Fig. 53). The opening between them is an actual orifice in the skin of the leaf. The size of the orifice is, however, constantly changing, as the atmosphere becomes drier or more moist, and as the sunlight acts more or less intensely on its surface. In moist air they curve outwards, and the aperture is enlarged; in dry air they straighten and shut together, and nearly or entirely close the entrance. The effect of strong light is to enlarge their orifices.

In Fig. 52 is represented a section through the shorter diameter of a pore on the under surface of a bean-leaf. The air-space within it is shaded black. Unlike the other epidermal cells, those of the leaf-pore contain grains of chlorophyll.

Fig. 53 represents a portion of the under surface of a potato leaf, magnified 200 diameters. The outline of the epidermal cells is marked by irregular double lines. The round bodies in the cells of the pores are starch-grains, often present in these cells when not existing in any other part of the leaf.

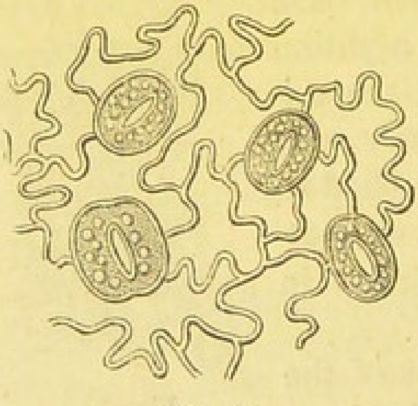

Fig. 53.

Stomata wanting on submerged leaves.

The stomata are with few exceptions altogether wanting on the submerged leaves of aquatic plants. On floating leaves they occur, but only on the upper surface. Thus, as a rule, they are not found in contact with liquid water. On the other hand, they are either absent from, or comparatively few in number upon, the upper surfaces of land plants, which are exposed to the heat of the sun, while they exist in great numbers on the lower sides of all green leaves. In number and size, they vary remarkably. Some leaves possess but 800 to the square inch, while others have as many as 170,000 to that amount of surface. About 100,000 may be counted on an average-sized apple leaf. In general, they are largest and most numerous on plants which belong to damp and shaded situations, and then exist on both sides of the leaf.

Epidermis thick in plants of dry climates.

The epidermis itself is most dense—consists of thick-walled cells and several layers of them—in leaves which belong to the vegetation of sandy soils in hot climates. Often it is impregnated with wax on its upper surface, and is thereby made almost impenetrable to moisture. On the other hand, in rapidly-growing plants adapted to moist situations, the epidermis is thin and delicate.

Water exhaled by leaves of growing plants.

Exhalation of Water Vapour.—A considerable loss of water goes on from the leaves of growing plants when they are freely exposed to the atmosphere. The water thus lost exhales in the form of invisible vapour. The quantity of water exhaled from any plant may be easily ascertained, provided it is growing in a pot of glazed earthen or other impervious material. A metal or glass cover is cemented air-tight to the rim of the vessel and around the stem of the plant. The cover has an opening, with a cork, through which weighed quantities of water are added from time to time, as required. The amount of exhalation during any given interval of time is learned, with a close approach to accuracy, by simply noting the loss of weight which the plant and pot together suffer. Hales, who first experimented in this manner, found that a sunflower, whose foliage had an aggregate surface of 39 square feet, gave off 22 ounces of water in a space of 24 hours. Knop observed a maize plant to exhale, between May 22 and September 4, no less than 36 times its weight of water.

Exhalation varies with humidity and temperature of the air.

Exhalation is not a regular or uniform process, but varies with a number of circumstances and conditions. It depends largely upon the dryness and temperature of the air. When the air is in the state most favourable to evaporation, the loss from the plant is rapid and large. When the air is saturated with moisture, as during dewy nights or rainy weather, then exhalation is nearly or totally checked.

Chap. III.

The temperature of the soil, and even its chemical composition, the condition of the leaf as to its age, texture, and number of stomata, likewise affect the rate of exhalation.

Exhalation is a process the activity of which varies with different plants; and it may be reduced to a minimum, as in a Wardian case or fernery, without evident influence on growth. Neither is it detrimental, unless the loss is greater than the supply. If water escapes from the leaves faster than it enters the roots, the plant withers; and if this disturbance proceeds too far, it dies.

Exhalation ordinarily proceeds to a large extent from the surface of the epidermal cells. Although the cavities of these cells are chiefly occupied with air, their thickened walls transmit outward the water which is supplied to the interior of the leaf. Otherwise the escape of vapour occurs through the stomata. These pores appear to have the function of regulating the exhalation, to a great extent, by their property of closing, when the air, from its dryness, favours rapid evaporation. They are, in fact, self-acting valves which protect the plant from too sudden and rapid loss of water.

Entire plant pervious to air through stomata.

Access of Air to the Interior of the Plant.—Not only does the leaf allow the escape of vapour of water, but it admits of the entrance and exit of gaseous bodies.

The particles of atmospheric air have easy access to the interior of all leaves, however dense and close their epidermis may be, however few or small their stomata. All leaves are actively engaged in absorbing and exhaling certain gaseous ingredients of the atmosphere during the whole of their healthy existence.

The entire plant is, in fact, pervious to air through the stomata of the leaves. These communicate with the intercellular spaces of the leaf, which are in general occupied exclusively with air, and these again connect with the ducts which ramify throughout the veins of the leaf and branch from the vascular bundles of the stem. In the bark or epidermis of woody stems, as Hales long ago discovered, pores or cracks exist, through which the air has communication with the longitudinal ducts.

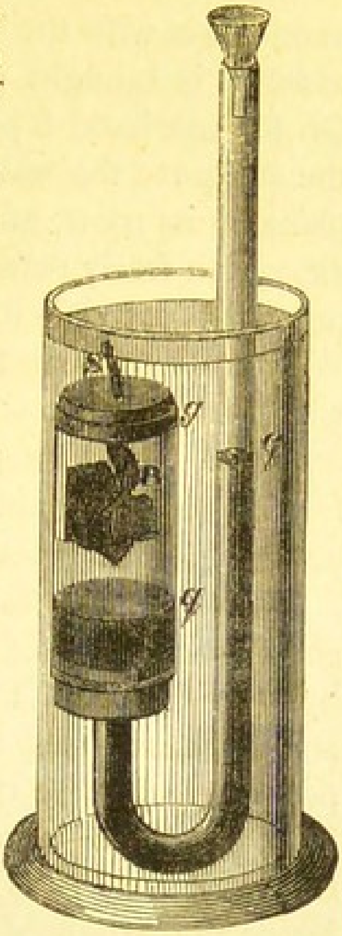

Fig. 54.

These facts admit of demonstration by simple means. Sachs employs for this purpose an apparatus consisting of a short wide tube of glass (*B*, Fig. 54), to which is adapted, below, by a tightly-fitting cork, a bent glass tube. The stem of a leaf is passed through a cork which is then secured air-tight in the other opening of the wide tube, the leaf itself being included in the latter, and the joints are made air-tight by smearing with tallow. The whole is then placed in a glass jar containing enough water to cover the projecting leaf-stem, and mercury is quickly poured into the open end of the bent tube, so as nearly to fill the latter. The pressure of the column of this dense liquid immediately forces air into the stomata of the leaf, and a corresponding quantity is forced on through the intercellular spaces and through the vein-ducts into the ducts of the leaf-stem, whence it issues in fine bubbles at *S*. It is even easy in many cases to demonstrate the permeability of the leaf to air by immersing it in water, and, taking the leaf-stem between the lips, produce a current by blowing. In this case the air escapes from the stomata.

The permeability of the stem to air may be shown by a similar arrangement, or in many instances, as, for example, with a stalk of maize, by simply immersing one end in water and blowing into the other.

On the contrary, roots are destitute of any visible pores, and are not pervious to external air or vapour in the way that leaves and young stems are.

The air-passages in the plant correspond roughly to the mouth, throat, and breathing cavities of the animal. We have, as yet, merely noticed the direct communication of these passages with the external air by means of microscopically visible openings. But the cells which are not visibly porous readily allow the access and egress of water and of gases by osmose. To the mode in which this is effected we shall recur on subsequent pages.

Offices of the foliage.

The Offices of Foliage are to put the plant in communication with the atmosphere, and to afford the means by which it is brought within the influence of the solar forces. On the one hand it permits, and to a certain degree regulates, the escape of the water which is continually pumped into the plant by its roots, and on the other hand it absorbs from the air, which freely penetrates it, certain gases which furnish the principal materials for the organization of vegetable matter. We have seen that the plant consists of elements, some of which are volatile at the heat of ordinary fires, while others are fixed at this temperature. When a plant is burned, the former, to the extent of 90 to 99 per cent. of the plant, are converted into gases, the latter remain as ashes.

The reconstruction of vegetation from the products of its combustion (or decay) is, in its simplest phase, the gathering by a new plant of the ashes from the soil through its roots, and of these gases, from the air by its leaves, and the compounding of these comparatively simple substances into the highly complex ingredients of the vegetable organism. Of this work the leaves have by far the larger share to perform; hence the extent of their surface and their indispensability to the welfare of the plant.

CHAPTER IV.

THE ORGANS OF REPRODUCTION.

§ 1. The Flower.

Chap. IV.

Growth of stems arrested by flowers.

The onward growth of the stem or of its branches is not* necessarily limited, until, from the terminal buds, instead of leaves only flowers unfold. When this happens, as is the case with most annual and biennial plants raised on the farm or in the garden, the vegetative energy has usually attained its fullest development, and the reproductive function begins to prepare for the death of the individual by providing seeds which shall perpetuate the species.

There is often at first no apparent difference between the leaf-buds and flower-buds, but commonly, in the later stages of their growth, the latter are to be readily distinguished from the former by their greater size, and by peculiar shape or colour.

The flower a branch with modified leaves.

The Flower is a short branch, bearing a collection of organs, which, though usually having little resemblance to foliage, may be considered as leaves, more or less modified in form, colour, and office.

The flower commonly presents four different sets of organs, viz. *Calyx*, *Corolla*, *Stamens*, and *Pistils*, and is then said to be *complete*, as in the case of the apple, potato, and many common plants. Figs. 55 and 56 represent sections of the flowers of the Buttercup and Bramble. The calyx and corolla are *envelopes*, which protect the stamens and pistils, or *essential* organs of the flower, Floral envelopes.

The Calyx is the outermost floral envelope. Its colour is red or white in the Fuchsia, though generally it is green. When it consists of several distinct leaves, they are called *sepals*. The calyx is frequently small and inconspicuous. In some cases it falls away as the flower opens.

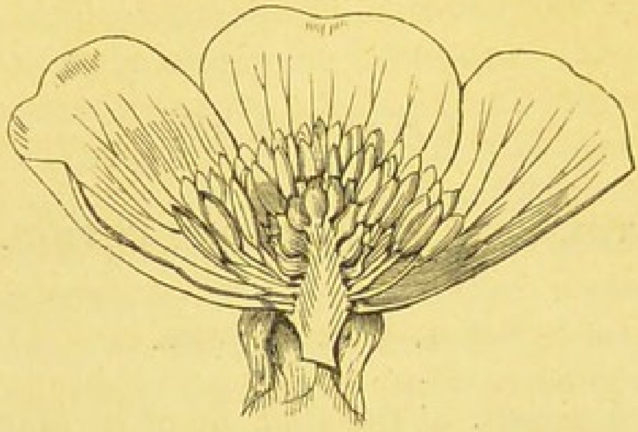

Fig. 55.

The Corolla is one or several series of leaves which are situated within the calyx. It is usually of some other than a green colour (in the Fuchsia, purple, &c.), often has marked peculiarities of form and great delicacy of structure, and thus chiefly gives beauty to the flower. When the corolla is divided into separate leaves, these are termed *petals*.

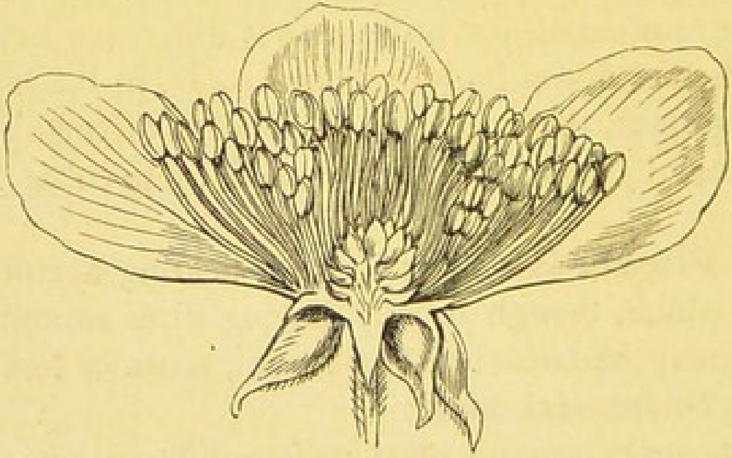

Fig. 56.

Essential organs.

The Stamens are the next series of organs within the corolla. They are generally slender and thread-like, and are terminated by an oblong sack, the *anther*, which, when the flower attains its full growth, discharges a fine yellow or brown dust, the so-called *pollen*.

The forms of anthers, as well as the grains of pollen, vary with nearly every kind of plant. The yellow pollen of Pine and Spruce is not infrequently transported by the wind to a great distance, and when brought down by rain in considerable quantities, has been mistaken for sulphur.

The Pistil, or pistils, occupy the centre of the perfect flower. They are exceedingly various in form, but always have at their base the seed-vessels, or *ovaries*, in which are found the *ovules*, or rudimentary seeds. The summit of the pistil is destitute of the epidermis which covers all other parts of the plant, and is termed the *stigma*.

Arrangement of organs in flowers subject to three kinds of modification.

The structure of flowers is subject to modification from the influence of three conditions—*Cohesion*, *Adhesion*, *Suppression*.

The flower of the Buttercup, Fig. 55, exhibits a type uncomplicated by any of these influences. Each of the four whorls of which the flower consists is composed of a number of organs separately attached to the top of the stem, or *receptacle*, and neither *cohering* with one another nor *adhering* to the members of other whorls. In the flower of the Bramble, Fig. 56, the calyx, corolla, and stamens no longer exhibit a separate, but, on account of *adhesion*, an apparently common attachment, and the bases of the sepals are united by *cohesion* into a tube.

Statement that floral organs are modified leaves supported.

As has been remarked, the floral organs may be considered to be modified leaves; or rather, all the appendages of the stem—the leaves and the parts of the flower together—are different developments of one fundamental type.

The justness of this idea is sustained by the transformations which are often observed.

The Rose in its natural state has a corolla consisting of five petals, but has a multitude of stamens and pistils. In a rich soil, or as the effect of those agencies which are united in "cultivation," nearly all the stamens lose their reproductive function and proper structure, and revert to petals; hence the flower becomes double. The tulip, poppy, and numerous garden flowers, illustrate this interesting metamorphosis.

On the other hand, the reversion of all the floral organs into ordinary green leaves has been observed not infrequently in the rose, white clover, and other plants.

Incomplete flowers.

Suppression.—While the complete flower consists of the four sets of organs above described, only the stamens and pistils are essential to the production of seed. The latter, accordingly, constitute a *perfect* flower even in the absence of calyx and corolla.

The flower of buckwheat has no corolla, but a white or pinkish calyx.

The grasses have flowers, included in scale-like leaves, which, as the plants mature, become chaff.

Stamens and pistils sometimes separated.

In various plants the stamens and pistils are borne in separate flowers. Such are called *monœcious* plants, of which the birch and oak, maize, cucumber, and often the strawberry, are examples.

In maize, the staminate flowers are the "tassels" at the summit of the stalk; the pistillate flowers are the young ears, the pistils themselves being the "silk," each fibre of which has an ovary at its base.

Diœcious plants are those which bear the staminate (male, or sterile) flowers and the pistillate (female, or fertile) flowers on different individuals; the willow, hop, and hemp are of this kind.

Fertilization by the pollen necessary to fructification.

Fertilization and Fructification.—The grand function of the flower is *fructification*. For this purpose the pollen must fall upon or be carried by wind, insects, or other agencies, to the naked tip of the pistil. Thus situated, each pollen grain sends out a slender tube of microscopic dimensions, which penetrates the interior of the pistil until it enters the ovary and comes in contact with the ovule or rudimentary seed. This contact being established, the ovule is *fertilized* and begins to grow. Thenceforward the corolla and stamens usually wither, while the base of the pistil and the included ovules rapidly increase in size until the seeds are ripe, when the seed-vessel falls to the ground, or else opens and releases its contents.

Fig. 57 exhibits the process of fertilization as observed in a plant allied to buckwheat, viz. the *Polygonum convolvulus.* The cut represents a magnified section lengthwise through the short pistil: *a* is the stigma or summit of the pistil; *b* are grains of pollen; *c* are pollen tubes that have penetrated into the seed-vessel which forms the base of the pistil—one has entered the mouth of the rudimentary seed, *g*, and reached the embryo sack, *e*, within which it causes the development of a germ; *d* represents the interior wall of the seed-vessel; *h*, the base of the seed and its attachment to the seed-vessel.

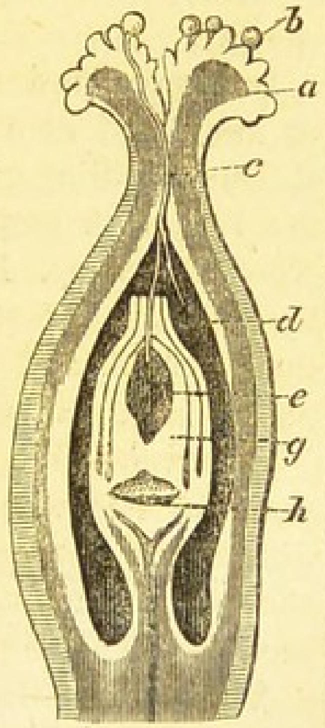

Fig. 57.

Some hermaphrodite plants capable of self-fertilization.

Darwin has shown that certain plants which have pistils and stamens in the same flower, are incapable of self-fertilization, and depend upon insects to carry pollen to their stigmas. Such are many Orchids.

Artificial Fecundation has been proposed by Hooibrenk, in Belgium, as a means of increasing the yield of certain crops. Hooibrenk's plan of agitating the heads of grain at the time when the pollen is ripe, in order to ensure its distribution—which is done by two men traversing the field carrying a rope between them so as to lightly brush over the head—appears to have been found very useful in some cases, though in many trials no good effects have followed its application.

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We must therefore conclude that agitation by the winds and the good offices of insects commonly render artificial assistance in the fecundating process entirely superfluous.

Hybrids produced by union of different species.

Hybridizing.—As the union of different kinds of animals sometimes results in a hybrid, so among plants the ovules of one kind may be fertilized by the pollen of another, and produce a hybrid plant. In both the animal and vegetable kingdoms the limits within which hybridization is possible appear to be narrow. A plant of one family cannot be fertilized by a plant of another. Within the same genus, however, there is every gradation. Varieties sometimes cannot be crossed, while some plants are more readily fertilized by the pollen of other species than by their own. Hybrids also vary from complete fertility to absolute sterility.

In flower and fruit culture, hybridization is practised or attempted as a means of producing new kinds. Thus Rogers' Seedling grapes are believed to be hybrids between the European grape, *Vitis vinifera*, and *Vitis Labrusca* of North America. Hybridization between plants is effected by removing the stamens from the flower before they shed their pollen, and dusting the summit of the pistil with pollen from another kind.

Systematic terms defined.

Species.—We refer a number of individuals to the same species when we are unable to distinguish greater differences between them than experience shows us we should find among a number of plants raised from the seed of the same parent.

Varieties.—Individuals of the same species differ. In fact, no two individuals are quite alike. Circumstances of temperature, food, and habits of life increase these differences, and *varieties* originate when such differences assume a *comparative permanence* and fixity. But as external conditions cause variation away from any particular representative of a species, so their removal may cause variation back again towards the original type.

Among plants, varieties may often be perpetuated by the seed. This is true of our cereal and leguminous plants, which reproduce their kind with striking regularity. Other plants cannot be or are not reproduced unaltered by the seed, but are continued in the possession of their peculiarities by cuttings, layers, and grafts. Here the individual plant is in a sense divided and multiplied. The species is propagated, but not reproduced. The fact that the seeds of a potato, a grape, an apple, or pear, cannot be depended upon to reproduce the variety, may perhaps be more commonly due to unavoidable contact of pollen from other varieties than to inability of the mother-plant to perpetuate its peculiarities. That such inability often exists is, however, well established, and is in general most obvious in varieties that have to the greatest degree departed from the original specific type, and also in hybrids which are sterile.

Varieties often cannot be reproduced by seed.

Darwin's hypothesis is, that new forms of animals and plants may arise by variation, and that all existing species of animals and plants have developed by a process of "natural selection," gradually accumulating variations which are found to be advantageous.

Darwin's theory as to origin of species.

Genus (plural **Genera**).—Species which resemble each other in most important points of structure are associated by botanists in the same group. All the oaks, white, red, &c., taken together, form a group which has a series of characters in common that distinguishes them from all other trees and plants. Such a group of species is called a *genus*.

Genera are groups of species.

Families, or **Orders**, in botanical language, are groups of genera that agree in certain particulars. Thus the several plants well known as mallows, hollyhock, and cotton, are representatives of as many different genera. They all agree in a number of points, especially as regards the structure of their fruit. They are accordingly grouped together into a natural family or order, which differs from all others.

Families are groups of genera.

Classes, Series, and Classification.—*Classes* are groups of orders, and *Series* are groups of classes. In botanical *classification* as now universally employed—classification after the Natural System—all plants are separated into two series, as follow :—

1. *Flowering Plants* (*Phænogams*), which produce flowers and seeds with embryos ; and

2. *Flowerless Plants* (*Cryptogams*), that have no proper flowers, and are reproduced by *spores* which are in most cases single cells. This series includes Ferns, Horse-tails, Mosses, Liverworts, Lichens, Sea-weeds, Mushrooms, and Moulds.

The use of classification is to give precision to our notions and distinctions, and to facilitate the using and acquisition of knowledge. Series, classes, orders, genera, species, and varieties, are as valuable to the naturalist as pigeon-holes are to the accountant, or shelves and drawers to the merchant.

Plants distinguished botanically by two names.

Botanical Nomenclature.—The Latin or Greek names which botanists employ are essential for the discrimination of plants, being equally received in all countries, and belonging to all languages where science has a home. They are made necessary, not only by the confusion of tongues, but by confusions in each vernacular.

Botanical usage requires for each plant two names, one to specify the genus, another to indicate the species. Thus all oaks are designated by the Latin word *Quercus*, while the red oak is *Quercus rubra*, the white oak is *Quercus alba*, the live oak is *Quercus virens*, &c.

The designation of certain important families of plants is derived from a peculiarity in the form or arrangement of the flower. Thus the Pulse family—comprising the bean, pea, and vetch, as well as lucern and clover—are called *Papilionaceous* plants, from the resemblance of their flowers to a butterfly (Latin, *papilio*). Again, the Mustard family—including the radish, turnip, cabbage, watercress,

&c.—are termed *Cruciferous* plants, because their flowers have four petals arranged like the four arms of a cross (Latin, *crux*).

The flowers in a large natural order of plants are arranged side by side, often in great numbers, on the expanded extremity of the flower-stem. Examples are the thistle, dandelion, sunflower, artichoke, China-aster, &c., which, from bearing such compound heads, are called *Composite* plants.

The *Coniferous* (cone-bearing) plants comprise the pines and larches, &c., whose flowers are arranged in conical receptacles.

The flowers of the carrot, parsnip, and caraway, are arranged at the extremities of stalks which radiate from a central stem like the arms of an umbrella; hence they are called *Umbelliferous* plants (from Latin, *umbella*, a sunshade).

§ 2. THE FRUIT.

The fruit consists of seed-vessel and seeds.

THE FRUIT comprises the *seed-vessel* and the *seeds*.

Fruits are either dehiscent—when the seed-vessel opens and sheds the seed; or are indehiscent—when it remains closed.

THE SEED-VESSEL, consisting of the pistil in its matured state and whatever organs may be adherent to it, exhibits a great variety of forms and characters, which serve chiefly to define the different kinds of Fruits. Of these we shall only adduce such as are of common occurrence and belong to the farm.

Common forms of fruits described.

The Nut has a hard, leathery, or bony indehiscent shell, containing a single seed. Examples are the acorn, chestnut, beech-nut, and hazel-nut. The cup of the acorn, and the bur of the others, is a consolidated mass of modified leaves called *bracts*.

The Stone-fruit, or Drupe, is a fruit with a single cavity or cell; the seed-vessel consisting of two parts, the inner hard and strong, the outer fleshy or leathery. Examples are the plum and peach. Raspberries and blackberries are clusters of small drupes.

Pome is a term applied to fruits like the apple and pear, the core of which consists of the true seed-vessels originally belonging to the pistil, while the often edible flesh is the enormously enlarged and thickened calyx, whose withered tip is always to be found at the end opposite the stem.

The Berry is a many-seeded fruit, of which the entire seed-vessel becomes thick and soft; as the grape, currant, tomato.

Gourd-fruits have externally a hard rind, but are fleshy in the interior. The melon, squash, and cucumber are of this kind.

The Achene is a fruit containing a single seed which does not separate from its dry seed-vessel. The so-called seeds of the composite plants (for example, the sunflower, thistle, and dandelion) are *achenes*. On removing the outer husk or seed-vessel, we find within the true seed. Many achenes are furnished with a *pappus*, a downy or hairy appendage, the remains of the calyx, as seen in the thistle, which enables the seed to float and be carried about in the wind.

Grains are properly Fruits. Wheat, rye, and maize consist of the seed and the seed-vessel closely united. When these grains are ground, the bran that comes off is the seed-vessel together with the outer coatings of the seed. Barley and oat grain, in addition to the seed-vessel, have the pale or inner chaff and the flowering glume or outer chaff adhering to the seed.

Pod is the name properly applied to any dry seed-vessel which opens and scatters its seeds when ripe. Several kinds have received special designations; of these we need only notice one.

The Legume is a pod, like that of the bean, which splits into two halves, along whose inner edges seeds are borne. The Pulse family, or papilionaceous plants, are also termed *leguminous*, from the form of their fruit.

Structure of the seed described.

THE SEED, or ripened ovule, is borne on a stalk which connects it with the seed-vessel. Through this stalk it is supplied with nutriment while growing. When matured and detached, a scar commonly indicates the point of former connexion.

The seed has usually two distinct *coats* or integuments. The outer one is often hard, and is generally smooth. In the case of cotton seed it is covered with the valuable cotton fibre. The second coat is commonly thin and delicate.

The Kernel lies within the integuments. In many cases it consists exclusively of the *embryo* or rudimentary plant. In others it contains, besides the embryo, what has received the name of *endosperm*, or *albumen.*

The Endosperm forms the chief bulk of all the grains. If we cut a seed of maize in two lengthwise, we observe extending from the point where it was attached to the cob the soft "chit" (*b*, Fig. 58), which is the embryo, to be presently noticed. The remainder ot the kernel, *a*, is endosperm; the latter, therefore, yields in great part the flour or meal which is so important a part of the food of man and animals.

The endosperm is intended for the support of the young plant as it develops from the embryo, before it is capable of depending on the soil and atmosphere for sustenance. It is not, however, an indispensable part of the seed, and may be entirely removed from it without thereby preventing the growth of a new plant.

Embryo the essential portion of the seed.

The Embryo or **Germ** is the essential and most important portion of the seed. It is, in fact, a ready-formed plant in miniature, and has its root, stem, leaves, and a bud, although these organs are often as undeveloped in form as they are in size.

As above mentioned, the chit of the seeds of maize and

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The embryo of mono-cotyledons.

the other grains is the embryo. Its form is with difficulty distinguishable in the dry seeds; but when they have been soaked for several days in water, it is readily removed from the accompanying endosperm, and plainly exhibits its three parts, viz. the *radicle*, the *plumule*, and the *cotyledon*.

In Fig. 58 is represented the embryo of maize. In A and B it is seen in section imbedded in the endosperm. C exhibits the detached embryo. The *Radicle*, *r*, is the stem of the seed plant; its lower extremity is the point from which downward growth proceeds, and from which the first true roots are produced. The *Plumule*, *c*, is the central bud, out of which the stem with new leaves, flowers, &c., is developed. The *Cotyledon*, *b*, is in structure a ready-formed leaf, which clasps the plumule in the embryo, as the proper leaves clasp the stem in the mature maize plant. The cotyledon of maize does not, however, perform the functions of a leaf; on the contrary, it remains in the soil during the act of sprouting, and its contents, like those of the endosperm, are absorbed by the plumule and radicle. The leaves which appear above-ground, in the case of maize and the other grains (buck-wheat excepted), are those which in the embryo were wrapped together in the plumule, where they can be plainly distinguished by the aid of a magnifier.

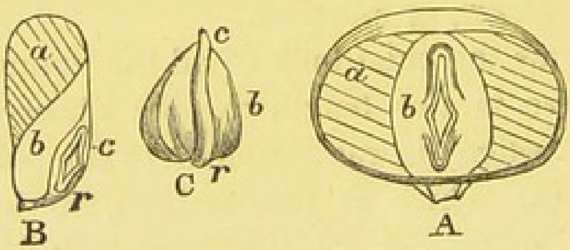

Fig. 58.

It will be noticed that the true grains (which have sheathing leaves and hollow jointed stems) are *monocotyledonous* (one-cotyledoned) in the seed. As has been mentioned, this is characteristic of plants with *endogenous* or inside-growing stems (p. 258).

The embryo of dicoty-ledons.

The seeds of the *Exogens* (outside-growers, p. 262) are *dicotyledonous*, i.e. have two cotyledons. Those of buckwheat, flax, and tobacco, contain an endosperm. The seeds of nearly all other exogenous agricultural plants are destitute of an endosperm, and, exclusive of the coats, consist entirely of embryo. Such are the seeds of the Leguminosæ, viz. the bean, pea, and clover; of the Cruciferæ, viz. turnip, radish, and cabbage; of ordinary fruits, the apple, pear, cherry, plum, and peach; of the Gourd family, viz. the pumpkin, melon, and cucumber; and finally of many hard-wooded trees, viz. the oak, maple, elm, birch, and beech.

We may best observe the structure of the two-cotyledoned embryo in the garden or kidney bean. After a bean has been soaked in warm water for several hours, the coats may be easily removed, and the two fleshy cotyledons (*c*, *c*, in Fig. 59) are found divided from each other save at the point where the radicle, *a*, is seen projecting like a blunt spur. On carefully breaking away one of the cotyledons, we get a side view of the radicle, *a*, and plumule, *b*, the former of which was partially and the latter entirely imbedded between the cotyledons. The plumule plainly exhibits two delicate leaves on which the unaided eye may note the veins. These leaves are folded together along their mid-ribs, and may be opened and spread out with the help of a needle.

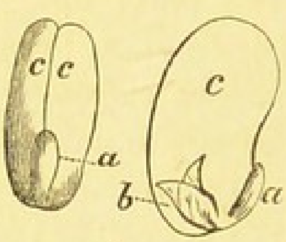

Fig. 59.

When the kidney-bean germinates, the cotyledons are carried up into the air, where they become green, and constitute the first pair of leaves of the new plant. The second pair are the tiny leaves of the plumule just described, between which is the bud, whence all the subsequent aërial organs develop in succession.

In the horse-bean, as in the pea, the cotyledons never assume the office of leaves, but remain in the soil, and gradually yield a large share of their contents to the growing plant, shrivelling and shrinking greatly in bulk, and finally falling away and passing into decay.

§ 3. VITALITY OF SEEDS, AND THEIR INFLUENCE ON THE PLANTS THEY PRODUCE.

The embryo dormant in mature seeds.

Duration of Vitality.—In the mature seed, when kept from excess of moisture, the embryo lies dormant. The duration of its vitality is very various. The seeds of the willow, it is asserted, will not grow after having once become dry, but must be sown when fresh; they lose their germinative power in two weeks after ripening.

The seeds of wheat usually lose their power of growth after having been kept three to seven years. Vilmorin, from his own trials, doubts altogether the authenticity of the "mummy wheat."

Dietrich (*Hoff. Jahr.* 1862–3, p. 77) experimented with seeds of wheat, rye, and a species of Bromus, which were 185 years old. Nearly every means reputed to favour germination was employed, but without success. After proper exposure to moisture, the place of the germ was usually found to be occupied by a slimy, putrefying liquid.

The older the seeds the smaller the number that germinate.

In agriculture it is a general rule that the newer the seed the better the results of its use. Experiments have proved that the older the seed the more numerous the failures to germinate, and the weaker the plants it produces.

Londet made trials in 1856–7 with seed-wheat of the years 1856, 1855, 1854, and 1853.

The following table exhibits the results, which illustrate the statement just made :—

	Per cent. of Seeds sprouted.	Length of Leaves four days after coming up.	Number of Stalks and Ears per hundred Seeds.
Seed of 1853	none	—	—
,, 1854	51	0·4 to 0·8 inches	269
,, 1855	73	1·2 ,,	365
,, 1856	74	1·6 ,,	404

The results of similar experiments made by Haberlandt on various grains are contained in the following table :—

	Per cent. of Seeds that germinated in 1861 from the years						
	1851	1854	1855	1857	1858	1859	1860
Wheat	0	8	4	73	60	84	96
Rye	0	0	0	0	0	48	100
Barley	0	24	0	48	33	92	89
Oats	0	56	48	72	32	80	96
Maize	—	76	56	—	77	100	97

Old seeds yield weak plants.

Results of the Use of long-kept Seeds.—The fact that old seeds yield weak plants is taken advantage of by the florist in producing new varieties. It is said that while the one-year-old seeds of Ten-weeks Stocks yield single flowers, those which have been kept four years give mostly double flowers.

In case of melons, the experience of gardeners goes to show that seeds which have been kept several, even seven years, though less certain to come up, yield plants that give the greatest returns of fruit; while plantings of new seeds run excessively to vines.

Immature seeds may be capable of germination.

Unripe Seeds.—Experiments by Lucanus prove that seeds gathered while still unripe,—when the kernel is soft and milky, or, in case of cereals, even before starch has formed, and when the juice of the kernel is like water in appearance,—are nevertheless capable of germination, especially if they be allowed to dry in connexion with the stem (after ripening). Such immature seeds, however, have less vigorous germinative power than those which are allowed to mature perfectly; when sown, many of them fail to come up, and those which do, yield comparatively weak plants at first, and in poor soil give a poorer harvest than well-ripened seed. In rich soil, however, the plants which do appear from unripe seed may in time become as vigorous as any (Lucanus, *Vs. St.* iv. p. 253).

According to Siegert, the sowing of unripe peas tends to produce earlier varieties. Liebig says: "The gardener is aware that the flat and shining seeds in the pod of the

Stock Gillyflower will give tall plants with single flowers, while the shrivelled seeds will furnish low plants with double flowers throughout."

Light seeds yield weak plants.

Dwarfed or Light Seeds.—Dr. Müller, as well as Hellriegel, found that light grain sprouts quicker but yields weaker plants, and is not so sure of germinating as heavy grain.

Baron Liebig asserts (*Natural Laws of Husbandry*, Eng. ed. 1863, p. 7) that "the strength and number of the roots and leaves formed in the process of germination are (as regards the non-nitrogenous constituents) in direct proportion to *the amount of starch in the seed.*" These conclusions have been since partially confirmed, so far as regards wheat seeds, by subsequent experiments. Further, "Poor and sickly seeds will produce stunted plants, which will again yield seeds bearing in a great measure the same character." But, on the contrary, he states (on page 48 of the same book, foot-note), quoting from another experimenter, that "Boussingault has observed that even seeds weighing two or three milligrammes (1-30th or 1-20th of a grain), sown in an absolutely sterile soil, will produce plants in which all the organs are developed, but their weight after months does not amount to much more than that of the original seed. The plants are reduced in all dimensions; they may, however, grow, flower, and even bear seed, which only requires a fertile soil to *produce again a plant of the natural size.*" These seeds must be diminutive, yet placed in a fertile soil they give a plant of normal dimensions. We must thence conclude that the amount of starch, gluten, &c. —in other words, the weight and composition of a seed—is not altogether an index of the vigour of the plant that may spring from it.

Schubert, whose observations on the roots of agricultural plants are detailed in a former chapter (p. 232), says, as the result of much investigation: "The vigorous development of plants depends far less upon the size and weight of the seed than upon the depth to which it is covered with earth, and upon the stores of nourishment which it finds in its first period of life."

The value of seed-wheat is related to its specific gravity.

Value of Seed as related to its Density.—From a series of experiments made at the Royal Agricultural College at Cirencester in 1863–6, Professor Church concludes that the value of seed-wheat stands in a certain connexion with its *specific gravity* (*Practice with Science*, pp. 107, 342, 345; London, 1867). He found :—

1. That seed-wheat of the greatest density produces the densest seed.

2. The seed-wheat of the greatest density yields the greatest amount of dressed corn.

3. The seed-wheat of medium density generally gives the largest number of ears, but the ears are poorer than those of the densest seed.

4. The seed-wheat of medium density generally produces the largest number of fruiting plants.

5. The seed-wheats which sink in water but float in a liquid having the specific gravity 1·247 are of very low value, yielding, on an average, but 34·4 lbs. of dressed grain for every 100 yielded by the densest seed.

6. The densest seeds are the most translucent or horny, and contain a much higher proportion of nitrogen than the opaque or starchy grains. If this excess of nitrogen be reckoned as existing in the form of albuminoids, it will usually correspond to about 3 per cent.; so that translucent wheat grains may be stated to contain one-fourth more of nitrogenous compounds than the opaque grains from the same kind of wheat, or even from the same individual plant, or even from the same ear.

7. The weight per bushel is dependent upon many circumstances, and bears no constant relation to the density of the seed.

The densest grains are not, according to Church, always the largest. The seeds he experimented with ranged from sp. gr. 1·354 to 1·401.

DIVISION III.

Life of the Plant.

CHAPTER I.

GERMINATION OF PLANTS.

§ 1. INTRODUCTORY.

CHAP. I.

The study of the life of the whole plant follows the study of its different parts.

*HAVING traced the composition of vegetation from its ultimate elements to the proximate organic compounds, and studied its structure in the simple cell as well as in the most highly-developed plant, and, as far as needful, explained the characters and functions of its various organs, we approach the subject of VEGETABLE LIFE and NUTRITION, and are ready to inquire how the plant increases in bulk and weight and produces starch, sugar, oil, albuminoids, &c., which constitute directly or indirectly almost the entire food of animals.

The beginning of the individual plant is in the seed, at the moment of fertilization by the action of a pollen tube on the contents of the embryo sack. Each embryo whose development is thus ensured is a plant in miniature, or rather an organism that is capable, under proper circumstances, of unfolding into a plant.

The first process of development, wherein the young plant commences to manifest its separate life, and in which it is shaped into its proper and peculiar form, is called *germination*.

The general PROCESS and CONDITIONS OF GERMINATION are familiar to all. In agriculture and ordinary gardening we bury the ripe and sound seed a little way in the soil, and in a few days it usually sprouts, provided it finds a certain degree of warmth and moisture.

Let us attend somewhat in detail, first to the phenomena of germination, and afterward to the requirements of the awakening seed.

§ 2. THE PHENOMENA OF GERMINATION.

The different stages of germination traced

The student will do well to watch with care the various stages of the act of germination, as exhibited in several species of plants. For this purpose a dozen or more seeds of each plant are sown—the smaller kinds of seed, half an inch, the larger, one inch deep—in a box of earth or sawdust, kept duly warm and moist, and one or two of each kind are uncovered and dissected at successive intervals of twelve hours until the process is complete. In this way it is easy to trace all the visible changes which occur as the embryo is quickened. The seeds of the kidney-bean, pea, maize, buckwheat, and barley, may be employed.

We thus observe that the seed first absorbs a large amount of moisture, in consequence of which it swells and becomes more soft. We see the germ enlarging beneath the seed coats; shortly the integuments burst and the radicle appears; afterward the plumule becomes manifest.

The endosperm, if the seed have one, and in many plants the cotyledons (as with the horse-bean, pea, maize, and barley), remain in the place where the seed was deposited. In other plants (kidney-bean, buckwheat, squash, radish, &c.) the cotyledons ascend and become the first pair of leaves. In the former case the rudimentary stem or radicle scarcely elongates at all; in the latter it grows through its whole length, and elevates the cotyledons above the soil.

The ascending plumule shortly unfolds new leaves, and, if coming from the seed of a branched plant, lateral buds make their appearance. The roots are formed at the other end of the radicle.

When the plantlet ceases to derive nourishment from the mother seed, the process is finished.

§ 3. The Conditions of Germination.

As to the conditions of germination, we have to consider in detail the following :—

Range of temperature necessary for germination.

a. **Temperature.**—*A certain range of Warmth is essential to the sprouting of a Seed.*—Göppert, who experimented with numerous seeds, observed none to germinate below 4°.

Sachs has ascertained for various agricultural seeds the extreme limits of temperature at which germination is possible. The lowest temperatures range from 5° to 13°; the highest, from 39° to 47°. Below the minimum temperature a seed preserves its vitality; above the maximum it is killed. He finds, likewise, that the point at which the *most rapid* germination occurs is intermediate between these two extremes, and lies between 26° and 34°. Either elevation or reduction of temperature from these degrees retards the act of sprouting.

In the following table are given the special temperatures of germination for six common plants :—

	Lowest Temperature.	Highest Temperature.	Temperature of most rapid Germination.
Wheat	5° C.	40° C.	29° C.
Barley	5	40	29
Pea	7	39	29
Maize	9	46	34
Scarlet-bean	9·5	44	26
Squash	12	46	34

For all agricultural plants cultivated in England, a range of temperature of from 13° to 32° is adapted for healthy and speedy germination.

It will be noticed in the above table that the seeds of plants introduced into northern latitudes from tropical regions, as the squash, bean, and maize, require and endure higher temperatures than those native to temperate latitudes, like wheat and barley. The extremes given above are by no means so wide as would be found were we to experiment with other plants. It is probable that some seeds will germinate nearly at 0°, or the freezing-point of water, while the cocoa-nut is said to yield seedlings with greatest certainty when the heat of the soil is 49°.

Sachs has observed that the temperature at which germination takes place materially influences the relative development of the parts, and thus the form of the seedling. According to this industrious experimenter, very low temperatures retard the production of new rootlets, buds, and leaves. The rootlets formed directly from the embryo become, however, very long. On the other hand, very high temperatures cause the rapid formation of new roots and leaves, even before those existing in the germ are fully unfolded. The medium and most favourable temperatures bring the parts of the embroyo first into development, at the same time the rudiments of new organs are formed which are afterward to unfold.

The vitality of some seeds has been found not to be destroyed by a cold of −18°; nor by a dry heat of 75°.

Moisture indispensable to germination.

b. **Moisture.**—A certain amount of *moisture* is indispensable to all growth. In germination it is needful that the seed should absorb water, so that motion and solution, and in consequence chemical action, can take place in the contents of the germ-cells. Until the seed is more or less imbued with moisture, no signs of sprouting are manifested, and if a half-sprouted seed be allowed to dry the process of growth is effectually checked, and, in many cases, the vitality altogether lost.

The degree of moisture different seeds will endure or require is exceedingly various. The seeds of aquatic plants naturally germinate when immersed in water. The seeds of many land plants, indeed, will quicken under water, but they germinate most healthfully when moist but not wet. Excess of water often causes the seed to rot.

Germination cannot proceed without free oxygen.

c. **Oxygen Gas.**—*Free oxygen,* as contained in the air, is likewise essential. Saussure demonstrated by experiment that proper germination is impossible in its absence, and cannot proceed in a vacuum, or in an atmosphere of other gases. As we shall presently see, the chemical activity of oxygen appears to be the means of exciting the growth of the embryo.

Light probably without influence on germination.

d. **Light.**—It has been stated that *light* is prejudicial to germination, and that therefore seeds must be covered (*Johnston's Lectures on Agr. Chem. and Geology*, 2d. Ed., pp. 226, 227). When, however, we consider that nature does not bury seeds, but scatters them on the surface of the ground of forest and prairie, where they are, at the most, half-covered, and by no means removed from the light, we cannot wholly accept this. The warm and moist forests of tropical regions, which, though shaded, are by no means dark, are covered with sprouting seeds. The gardener knows that the seeds of heaths, calceolarias, and some other ornamental plants, germinate best when uncovered, and the seeds of common agricultural plants will sprout when placed on moist sand or sawdust, with apparently no less readiness than when buried out of sight.

Finally, R. Hoffmann (*Jahresbericht über Agrikultur Chem.* 1864, p. 110) has found in experiments with twenty-four kinds of agricultural seeds that light exercises no appreciable influence of any kind on germination.

The Time required for Germination varies exceedingly, according to the kind of seed. As ordinarily observed, the fresh seeds of the willow begin to sprout within twelve hours after falling to the ground. Those of clover, wheat, and other grains germinate in three to five days. The fruits of the walnut, pine, and larch lie four to six weeks before sprouting, while those of some species of ash, beech, and maple are said not to germinate before the expiration of one and a half or two years.

The time required for germination varies with kind of seed and favourableness of other conditions.

The starchy and thin-skinned seeds quicken most readily. The oily seeds are in general more slow, while such as are situated within thick and horny envelopes require the longest periods to excite growth.

The time necessary for germination depends naturally upon the favourableness of other conditions. Among these conditions we may name the age of the seed and its percentage of moisture, the nature of the soil in which it is sown, and the presence or absence of certain chemical compounds. Many metallic salts arrest or retard germination; on the other hand, very weak chlorine-water accelerates the process. Cold and drought delay germination, when they do not check it altogether. Seeds that are buried deeply in the soil may remain for years, preserving, but not manifesting, their vitality, because they are either too dry, too cold, or have not sufficient access to oxygen to set the germ in motion.

To speak with precision, we should distinguish the time from planting the dry seed to the commencement of germination—which is marked by the rootlet becoming visible, and the period that elapses until the process is complete, *i.e.* until the stores of the mother-seed are exhausted, and the young plant is wholly cast upon its own resources.

At 5° in the experiments of Haberlandt, the rootlet issued after four days in the case of rye, and in five to seven days in that of the other grains and clover. The sugar-beet, however, lay at this temperature twenty-two days before beginning to sprout.

At 11° the time was shortened about one-half in case of the seeds just mentioned. Maize required eleven, kidney-beans eight, and tobacco thirty-one days at this temperature.

The proper depth of sowing varies with other conditions.

Proper Depth of Sowing.—The soil is usually the medium of moisture, warmth, &c., to the seed, and it affects germination only as it influences the supply of these agencies; it is not otherwise essential to the process. The burying of seeds when sown in the field or garden serves to cover them away from birds and keep them from drying up. In the forest, at spring-time, we may see innumerable seeds sprouting upon the surface, or but half covered with decayed leaves.

While it is the almost universal result of experience in temperate regions that agricultural seeds germinate most surely when sown at a depth not exceeding 1 to 3 inches, there are circumstances under which a widely different practice is admissible, or even essential. In the light and porous soil of the gardens of New Haven peas may be sown 6 to 8 inches deep without detriment, and are thereby better secured from the ravages of the domestic pigeon. The Moqui Indians, dwelling upon the tablelands of the higher Colorado, deposit the seeds of maize 12 or 14 inches below the surface. Thus sown, the plant thrives, while, if treated according to the plan usual in the United States and Europe, it might never appear above ground.

The reasons for such a procedure are the following:—The country is without rain, and almost without dew. In summer the sandy soil is continuously parched by the sun at a temperature often exceeding 38° in the shade. It is only at the depth of a foot or more that the seed finds the moisture needful for its growth,—moisture furnished by the melting of the winter's snow.*

R. Hoffmann, experimenting in a light loamy sand upon

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* For these interesting facts the author is indebted to Professor J. S. Newberry.

twenty-four kinds of agricultural and market-garden seeds, found that all perished when buried 12 inches. When planted 10 inches deep, peas, vetches, beans, and maize alone came up; at 8 inches there appeared, besides the above, wheat, millet, oats, barley and colza; at 6 inches those already mentioned, together with winter colza, buckwheat, and sugar-beets; at 4 inches of depth the above and mustard, red and white clover, flax, horseradish, hemp, and turnips; finally, at 3 inches, lucerne also appeared. Hoffmann states that the deep-planted seeds generally sprouted most quickly, and all early differences in development disappeared before the plants blossomed.

On the other hand, Grouven, in trials with sugar-beet seed, made, most probably, in a well-manured and rather heavy soil, found that sowing at a depth of ⅜ to 1¼ inches gave the earliest and strongest plants; seeds deposited at a depth of 2½ inches required five days longer to come up than those planted at ⅜ in. It was further shown that seeds sown shallow in a fine wet clay required four to five days longer to come up than those placed at the same depth in the ordinary soil.

Not only the character of the soil, which influences the supply of air, and warmth, but the kind of weather which determines both temperature and degree of moisture, have their effect upon the time of germination; and since these conditions are so variable, the rules of practice are laid down and must be received with a certain latitude.

§ 4. The Chemical Physiology of Germination.

The seed at first nourishes the seedling.

The Nutrition of the Seedling.—The young plant grows at first exclusively at the expense of the seed. It may be aptly compared to the suckling animal, which, when new-born, is incapable of providing its own nourishment, but depends upon the milk of its mother.

Chap. I.

The Nutrition of the Seedling falls into three processes, which, though distinct in character, proceed simultaneously. These are, 1, *Solution of the Nutritive Matters of the Cotyledons or Endosperm;* 2, *their Transfer;* and 3, *their Assimilation.*

The nutritive matter stored in the seed passes into solution.

1. Solution is effected without difficulty in the case of dextrine, gum, the sugars, albumen and caseine. The water which the seed imbibes to the extent of one-fourth to three times its weight, at once dissolves them. It is otherwise with the fats or oils, with starch and with gluten, which, as such, are nearly or altogether insoluble in water. In the act of germination provision is made for transforming these bodies into the soluble ones above mentioned. So far as these changes have been traced, they are as follow :—

Solution of Fats.—Sachs has recently found that squash seeds, which, when ripe, contain no starch, sugar, or dextrine, but are very rich in oil and albuminoids, suffer by germination such chemical change that nine-tenths of the oil disappears, while at the same time *starch, and in some cases sugar, is formed.* Fleury has also found that in the oily seeds of the castor-oil plant, colza and sweet almond, the fatty matter is converted into dextrine and sugar by the fixation of oxygen (*Adansonia*, iv. pp. 220–247).

Solution of Starch.—The starch thus organized from oily seeds, or which exists ready-formed in the farinaceous (floury) seeds, undergoes further changes, previously alluded to (p. 63), by which it is converted into substances that are soluble in water, viz. dextrine, and grape or cane sugar.

Solution of Albuminoids.—Finally, the insoluble albuminoids are gradually transformed into soluble modifications.

Preparation of malt illustrates chemical changes taking place in germination.

Chemistry of Malt.—The preparation and properties of *malt* may serve to give an insight into the nature of the chemical metamorphoses which have just been indicated.

The grain, most commonly barley, is soaked in water until the grains are soft to the fingers; they are then drained and thrown up in heaps. The masses of soaked grain

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shortly dry, become heated, and in a few days the embryos send forth their radicles. The heaps are shovelled over and spread out, so as to avoid too great a rise of temperature, and when the sprouts are about half an inch in length the germination is checked by drying the grain in the malt-kiln. Here the germinated seeds are exposed first of all to a heat of from 32° to 38°; and finally to a heat of from 63° to 74°, according to the colour desired. The dry grains, after removing the sprouts (radicles), constitute malt, such as is used in the manufacture of beer.

Malt consists of partially germinated seed.

Malt thus consists of starchy seeds whose germination has been checked while in its early stage. The only product of the beginning growth—the sprouts—being removed, it exhibits in the residual seed the first results of the process of solution.

The following figures, derived from the researches of Stein, in Dresden (*Wilda's Centralblatt*, 1860, ii. pp. 8–23), exhibit the composition of 100 parts of Barley, and of the 92 parts of Malt and the 2½ of Sprouts which 100 parts of barley yielded in his experiments :—

The analyses refer to the materials in the dry state. Ordinarily they contain from 5 to 15 per cent. of water. It must not be omitted to state that the proportions of malt and sprouts, as well as their composition, vary somewhat according to circumstances; and furthermore, the best analyses which it is possible to make are but approximate.

Composition of	100 pts. of Barley.	=	92 pts. of Malt.	+	2½ of Sprouts.
Ash	2·42		2·11		0·29
Starch	54·48		47·43		—
Fat	3·56		2·09		0·08
Insoluble Albuminoids	11·02		9·02		0·37
Soluble „	1·26		1·96		0·40
Dextrine	6·50		6·95		0·47
Extractive matters (soluble in water and destitute of nitrogen)	0·90		3·68		
Cellulose	19·86		18·76		0·89
	100·00		92·00		2·50

Insoluble constituents of grain diminished, soluble increased, by malting.

It is seen from the above statement that starch, fat, and insoluble albuminoids, have diminished in the malting process; while soluble albuminoids, dextrine, and other soluble non-nitrogenous matters, have somewhat increased in quantity. With the exception of the disappearance of 3 per cent. of soluble "extractive," the diversities between barley and malt as shown by these analyses are not striking.

In other experiments the loss which barley sustains during malting amounts to 19 per cent.; of this loss 6 per cent. is water, ·48 per cent. saline matter, and 12·52 per cent. carbonaceous matter. It has been further shown that the chief alterations effected in the chemical composition of barley by malting are the diminution of its starch, the increase of its sugar, and the production of a ferment called diastase.

The properties of malt and barley are, in fact, strikingly different. If malt be pulverized and stirred in warm water (68° C.) for an hour or two, the whole of its starch disappears, while sugar and dextrine take its place. The former is recognised by the sweet taste of the wort, as the solution is called. On heating the wort to boiling, a quantity of albumen is coagulated, and may be separated by filtering. This comes from the transformation of the gluten (insoluble albuminoids) of the barley. On adding to the filtered liquid its own bulk of alcohol, dextrine becomes evident, being precipitated as a white powder.

Furthermore, if we mix two or three parts of starch with one of malt, we find that the whole undergoes the same change. An additional quantity of starch remains unchanged.

Transformation of starch into dextrine and sugar by diastase.

The process of germination thus develops in the seed an agency by which the conversion of starch into soluble carbo-hydrates is accomplished with great rapidity.

Diastase.—Payen and Persoz attribute this action to a nitrogenous substance which they term *Diastase*, and which is found in the germinating seed in the vicinity of the embryo, but not in the radicles. They assert that one part of diastase is capable of transforming 2,000 parts of starch, first into dextrine and finally into sugar, and that malt yields $\frac{1}{500}$th of its weight of this substance.

A short time previous to the investigations of Payen and Persoz (1833) Saussure found that *Mucidine*, the soluble nitrogenous body which may be extracted from gluten (p. 87), transforms starch in the manner above described, and it is now known that any albuminoid may produce the same effect, although the rapidity of the action and the amount of effect are usually far less than that exhibited by the so-called diastase.

The change also effected under proper conditions by any albuminoid.

In order, however, that the albuminoids may transform starch as above described, it is doubtless necessary that they themselves enter into a state of alteration; they are in part decomposed, and disappear in the process. These bodies thus altered become *ferments.*

It must not be forgotten, however, that in most cases in which the conversion of starch into dextrine and sugar is accomplished artificially, an elevated temperature is required, whereas in the natural process, as shown in the germinating seed, the change goes on at ordinary temperatures.

It is generally taught that oxygen acting on the albuminoids in presence of water, and within a certain range of temperature, induces the decomposition which confers on them the power in question. The necessity for oxygen in the act of germination has been thus accounted for as needful to the solution of the starch, &c., of the cotyledons. Oxygen has, however, as we shall presently see, other functions to discharge.

How diastase and other similar substances accomplish the change in question is not certainly known.

Starch may assume a soluble form.

Soluble Starch.—The conversion of starch into sugar and dextrine has been explained. This is not, however, the only change of which starch is susceptible. In the bean (*Phaseolus multiflorus*) Sachs (*Sitzungsberichte der*

Wiener Akad. xxxvii. 57) informs us that the starch of the cotyledons is dissolved, passes into the seedling, and reappears (in part at least) as *soluble starch*, without conversion into dextrine or sugar, as these substances do not appear in the cotyledons during any period of germination, except in small quantity near the joining of the seedling. Compare p. 49, *Unorganized Starch.*

Changes in starch grains in becoming dissolved.

The same authority gives the following account of the microscopic changes observed in the starch grains themselves, as they undergo solution. The starch grains of the bean have a narrow interior cavity. This at first becomes filled with a liquid. Next the cavity appears enlarged, its borders assume a corroded appearance, and frequently channels are seen extending to the surface. Finally, the cavity becomes so large, and the channels so extended, that the starch grain falls to pieces. Solution continues on the fragments until they have completely disappeared. In this process it is most probable that the starch assumes the soluble form without loss of its proper chemical characters, though it ceases to strike a blue colour with iodine.*

In malting, starch first converted into soluble variety.

According to Musculus, the most important of the changes which occur in malting is not the mere and immediate conversion of starch into sugar by the assimilation of water, but its conversion into soluble starch first, then into dextrine and sugar. The successive changes are represented thus :—

$$\underset{\text{Starch.}}{3\,C_6H_{10}O_5} = \underset{\text{Soluble Starch.}}{C_{18}H_{30}O_{15}}.$$

$$C_{18}H_{30}O_{15} + H_2O = \underset{\text{Dextrine.}}{C_{12}H_{20}O_{10}} + \underset{\text{Glucose.}}{C_6H_{12}O_6}.$$

It is only the albuminoids themselves whose solution remains to be further noticed. As we have seen (p. 90), insoluble animal fibrine and caseine, by long keeping with

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* According to Liebig, this blue reaction depends upon the adhesion of the iodine to the starch, and is not the result of a chemical combination.

Conditions determining solution of albuminoids.

imperfect access of air, pass into soluble bodies, and latterly E. Mulder has shown that diastase rapidly accomplishes the same change. It would appear, in fact, that the conversion of a small quantity of any albuminoid into a ferment by oxidation is sufficient to render the whole soluble. The ferment exerts on the bodies from which it is formed an action similar to that manifested by it towards starch and other carbo-hydrates.

The production of small quantities of acetic and lactic acids (the acids of vinegar and of sour milk) has been observed in germination.

Carbonic dioxide disengaged in germination.

Gaseous Products of Germination.—The production of carbonic dioxide during the process of germination has been assigned to various causes. The older view, and the one usually adopted in botanical treatises, is that this disengagement of gas is due to the oxidation of starch by the oxygen absorbed from the air. Six molecules of starch absorbing twelve atoms of oxygen may be supposed to give rise to the production of five molecules of glucose on the sugar of malt, together with six molecules of carbonic dioxide. The following equation represents such a change:—

$$6\,C_6H_{10}O_5 + 12\,O = 5\,C_6H_{12}O_6 + 6\,CO_2.$$

Whatever may be the grounds of this opinion, it is probable that other explanations of the phenomenon under notice will finally prove correct. The albuminoids of the seed, for example, are very easily changed in moist air, and it is probably their oxidation which gives rise to a disengagement of carbonic dioxide. Part, however, of this gas may be due to a further change which the glucose undergoes, a fermentation, in fact, of which alcohol and carbonic dioxide are the products.

Traces of other gases have been detected among the volatile products of germination. In this connexion we may name carbonic oxide (CO), marsh gas (CH_4), ammonia (NH_3), and nitrogen (N).

Heat evolved during chemical changes in germination.

Heat developed in Germination.—These chemical changes, like all processes of oxidation, are accompanied with the production of heat. The elevation of temperature may be imperceptible in the germination of a single seed, but it nevertheless occurs, and is doubtless of much importance in favouring the life of the young plant. The heaps of sprouting grain seen in the malt-house warm so rapidly, and to such an extent, that much care is requisite to regulate the process, otherwise the malt is damaged by over-heating.

The sources of the heat thus evolved lie in the chemical actions going on in germination. The absorption of water is one of these, the absorption of oxygen another; but the molecular re-arrangements of the proximate principles of the seed probably also contribute to the resultant effect.

Nutriment after solution transferred to growing parts of seedling,

2. **The Transfer of the Nutriment of the Seedling** from the cotyledons or albumen where it has undergone solution, takes place through the medium of the water which the seed absorbs so largely at first. This water fills the cells of the seed, and, dissolving their contents, carries them into the young plant as rapidly as they are required. The path of their transfer lies through the point where the embryo is attached to the cotyledons, thence they are distributed at first chiefly downward into the extending radicles, after a little both downward and upward toward the extremities of the seedling.

Sachs has observed that the carbo-hydrates (sugar and dextrine) occupy the cellular tissue of the rind and pith, which are penetrated by numerous air-passages; while at first the albuminoids chiefly diffuse themselves through the intermediate cambial tissue which is destitute of air-passages, and are present in largest relative quantity at the extreme ends of the rootlets and of the plumule. Herbert Spencer's experiments led him to think that the transference of stored nutriment from the cotyledons to the axis takes place through the vascular tissue (*Principles of Biology*, vol. ii. p. 543).

where it is again converted into insoluble matters forming the new tissues.

3. **Assimilation** is the conversion of the transferred nutriment into the substance of the plant itself. This process involves two stages, the first being a chemical, the second a structural transformation.

The chemical changes in the embryo are, in part, simply the reverse of those which occur in the cotyledons; viz. the soluble and structureless proximate principles are metamorphosed into the insoluble and organized ones of the same chemical composition. Thus, dextrine may pass into cellulose, and the soluble albuminoids may revert in part to the insoluble condition in which they existed in the ripe seed.

But many other and more intricate changes proceed in the act of Assimilation. With regard to a few of these we have some imperfect knowledge.

Dr. Sachs informs us that when the embryo begins to grow, its expansion at first consists in the enlargement of the ready-formed cells. As a part elongates, the starch which it contains (or which is formed in the early stages of this extension) disappears, and sugar is found in its stead, dissolved in the juices of the cells. When the organ has attained its full size, sugar can no longer be detected, while the walls of the cells are found to have grown both in circumference and thickness, thus indicating the accumulation of cellulose.

CHAPTER II.

§ 1. THE FOOD OF THE PLANT WHEN INDEPENDENT OF THE SEED.

CHAP. II.

The constituents of the ash of plants derived from the soil.

THE roots of a plant, which are in intimate contact with the soil, absorb thence much of the water that fills the active cells; they also imbibe such salts as the water of the soil holds in solution: this water contains much carbonic dioxide, and has in consequence a powerful solvent action on the mineral constituents of plant food. The compounds that the plant *must* derive from the soil are those which are found in its ash, since these are not volatile, and cannot therefore exist in the atmosphere. The root, however, commonly takes up some other elements of its nutrition to which it has immediate access. Leaving out of view for the present those matters which, though found in the plant, appear to be of minor importance, viz. silicon, sodium, fluorine, and manganese, the roots absorb the following substances, viz. :—

Potassium,	Sulphates,
Calcium,	Phosphates,
Magnesium, and	Nitrates, and
Iron,	Chlorides.

These salts enter the plant by the absorbent surfaces of the younger rootlets, and pass upwards, through the active portions of the stem to the leaves and to the developing buds. One of the chief functions of the leaves is to gather *carbonic dioxide* from the air in which they unfold. This compound suffers decomposition in the plant—its carbon

Carbon derived from the atmosphere by plants.

being retained, and most of its oxygen being thrown off into the air. Leaves, however, will not decompose pure unmixed carbonic dioxide unless it be rarefied; they are capable of decomposing it when mixed with hydrogen or nitrogen. Carbonic oxide is not decomposed by plants. In darkness, leaves instead of oxygen yield carbonic dioxide, but a healthy leaf decomposes in sunshine far more carbonic dioxide than it forms in darkness.

The nutrition of plants a processes of deoxidation.

The elimination of oxygen from growing plants is a necessary consequence of the fact that a plant lives for the most part on highly oxygenated food; and, pulling this to pieces and re-arranging its constituents, produces substances containing comparatively small quantities of oxygen. If we suppose starch to be formed, by a plant, from carbonic dioxide and water, we could roughly represent this change as necessitating the extrication of twelve atoms of oxygen:

$$6\,CO_2 + 5\,H_2O = C_6H_{10}O_5 + 12\,O.$$

When the act of germination is finished, which occurs as soon as the cotyledons and endosperm are exhausted of all their soluble matters, the plant begins a fully independent life. Previously, however, to being thus thrown upon its own resources, it has developed all the organs needful to collect its food from without; it has unfolded its perfect leaves into the atmosphere and pervaded a portion of soil with its rootlets.

During the latter stages of germination it gathers its nutriment both from the parent seed and from the external sources which afterward serve exclusively for its support.

Being fully provided with the apparatus of nutrition, its development suffers no check from the exhaustion of the mother seed, unless it has germinated in a sterile soil, or under other conditions adverse to vegetative life.

The decomposition of carbonic dioxide takes place only by day, and under the influence of the sun's light.

From the carbon thus acquired and the elements of water,

Chap. II.

How the proximate principles of plants are built up.

with the co-operation of the ash-ingredients, the plant organizes the carbo-hydrates. Glucose, dextrine, or starch, are amongst the first products of this synthesis. The formation of organic matter proceeds in the cells of the leaf.

The albuminoids require for their production the presence of a compound of *nitrogen*. The salts of *nitric acid*, the nitrates, are commonly the chief, and may be the only supply of the element.

The other proximate principles, viz. pectose, the fats, the alkaloids, and the acids, are built up from the same food elements. In most cases the steps in the construction of organic matters are unknown to us, or subjects of uncertain conjecture. The carbo-hydrates, albuminoids, &c., that are organized in the foliage, are not only transformed into the solid tissues of the leaf, but are diffused to every active organ of the plant.

The plant has within certain limits a power of selecting its food. The seaweed, as has been remarked, contains more potash than soda, although the latter is thirty times more abundant than the former in the water of the ocean. Vegetation cannot, however, always and entirely shut out either excess of nutritive matters or bodies that are of no use or even poisonous to it.

The relations of the plant to the atmosphere and soil described.

The functions of the atmosphere are essentially the same towards plants growing under the conditions of water-culture or of agriculture.

The soil, on the other hand, has offices which are peculiar to itself. We have seen that the roots of a plant have the power to decompose salts, *e.g.* potassium nitrate, and ammonium chloride (p. 157), in order to appropriate one of their ingredients, the other being rejected. In water-culture, the experimenter must be careful to remove the substance which would thus accumulate to the detriment of the plant. In agriculture the soil, by virtue of its chemical and physical qualities, renders such rejected matters comparatively insoluble, and therefore innocuous.

The atmosphere is nearly invariable in its composition at all times, and over all parts of the earth's surface. Its power of directly feeding crops has therefore a natural limit which cannot be materially increased by art.

The soil, on the other hand, is very variable in composition and quality, and may be enriched and improved, or deteriorated and exhausted.

From the atmosphere the crop can derive no appreciable quantity of those elements that are found in its ash.

In the soil, however, from the waste of both plants and animals, large supplies of all the elements of the volatile part of plants may accumulate. Carbon, in the form of carbonic dioxide, existing in the soil itself, in the interstitial air and water of the soil, or generated by the oxidation of humus, may thus be put, as food, at the disposition of the plant. According, however, to Corenwinder, the roots have not the power of absorbing much carbonic dioxide. He admits that the roots, in drawing up the water in the soil, absorb also the carbonic dioxide which that water contains; but they probably lose by exosmose or by other causes more carbonic dioxide than they receive. Hence the power which roots have of eroding bones or marble, the components of which are soluble in carbonated water, and are thus prepared for root absorption. Nitrogen is chiefly furnished to crops by the soil. Nitrates are formed in the latter from various sources, such as ammonia salts, together with certain proximate animal principles, viz. urea, guanine, tyrosine, uric acid and hippuric acid, which thus serve to supply nitrogen to vegetation, and are ingredients of the best manures. It is, too, from the soil that the crop gathers the greater part of the water it requires, which not only serves as the fluid medium of its chemical and structural metamorphoses, but likewise must be regarded as the material from which it mostly appropriates the hydrogen and oxygen of its solid components.

§ 2. THE JUICES OF THE PLANT, THEIR NATURE AND MOVEMENTS.

General course of the nutrient fluids in the plant.

The fluid imbibed by the roots, and containing inorganic matter derived from the soil, is carried upwards through the stem, where it is mixed with organic matter, becoming sweet in the maple, or assuming other properties in different plants. This *crude sap* undergoes important changes in the leaves, by which it is converted into *elaborated sap*, which afterwards descends to supply material for the growth of new wood, or accumulations of nutriment such as are found in the potato, and also in the new wood itself.

Flow of sap in the plant not constant.

A maple in early March, without foliage, with its whole stem enveloped in a nearly impervious bark, its buds wrapped up in horny scales, and its roots surrounded by cold or frozen soil, cannot be supposed to have its sap in motion. Its juices must be nearly or absolutely at rest; and when sap runs copiously from an orifice made in the trunk, it is simply because the tissues are charged with liquid under pressure, which escapes at any outlet that may be opened for it.

Sap does move in the plant when evaporation of water goes on from the surface of the foliage. This always happens whenever the air is not saturated with vapour. When a wet cloth, hung out, dries rapidly by giving up its moisture to the air, then the leaves of plants lose their moisture more or less readily, according to the nature of the foliage.

Mr. Lawes found that in the moist climate of England common plants (wheat, barley, beans, peas, and clover) exhaled, during five months of growth, more than 200 times their (dry) weight of water. The water that thus evaporates from the leaves is supplied by the soil, and, entering the roots, rapidly streams upward through the stem as long as a waste is to be supplied, but ceases when evaporation from the foliage is checked.

Bleeding of trees in the spring before the leaves expand.

It is well known, that from a maple-tree "tapped" in spring-time, or from a grape-vine wounded at the same season, a copious flow of sap takes place, which continues for a number of weeks. The escape of liquid from the vine is commonly termed "bleeding," and while this rapid issue of sap is thus strikingly exhibited in comparatively few cases, bleeding appears to be a universal phenomenon, one that may occur, at least to some degree, under certain conditions with every plant.

The conditions under which sap flows are various, according to the character of the plant. Our perennial trees have their annual period of active growth in the warm season, and their vegetative functions are nearly suppressed during cold weather. As spring approaches the tree renews its growth, and the first evidence of change within is furnished by its bleeding when an opening is made through the bark into the young wood. A maple, tapped for making sugar, loses nothing until the spring warmth attains a certain intensity, and then sap begins to flow from the wounds in its trunk. The flow is not constant, but fluctuates with the thermometer, being more copious when the weather is warm, and falling off or suffering check altogether as it is colder.

The stem of the living maple is always charged with water, and never more so than in winter.* But, as the escape of sap goes on for fourteen to twenty days at the rate of several gallons per day from a single tree, new quantities of water must be continually supplied.

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* Experiments made in Tharandt, Saxony, under direction of Stoeckhardt, show that the proportion of water, both in the bark and wood of trees, varies considerably in different seasons of the year, ranging, in case of the beech, from 35 to 49 per cent. of the fresh-felled tree. The greatest proportion of water in the wood was found in the months of December and January; in the bark, in March to May. The minimum of water in the wood occurred in May, June, and July; in the bark much irregularity was observed.

Causes of the rising of the sap in spring.

The flow of sap often begins when the ground is covered with one or two feet of snow, and when we cannot suppose the soil has a higher temperature than it had during the previous winter months. Nevertheless, it must be that the deeper roots are warm enough to be active all the winter through, and that they begin their action as soon as the trunk acquires a temperature sufficiently high.

The rising of the sap in the spring may indirectly result from the transformation of the starch, stored up in the roots of the tree, into sugar (see p. 320). When this occurs absorption of water will take place from the soil, producing a distension which will result in a powerful upward thrust of the liquid contained in roots and stem (H. Spencer, *Principles of Biology*, vol. ii. p. 562).

The issue of sap from the maple-tree in the sugar season is closely connected with the changes of temperature that take place above ground. The sap begins to flow from a cut when the trunk itself is warmed to a certain point, and in general the flow appears to be the more rapid the warmer the trunk. During warm clear days the radiant heat of the sun is most rapidly absorbed by the dark rough surface of the tree; then the temperature of the latter rises most speedily and acquires the greatest elevation—even surpasses that of the atmosphere by several degrees; then, too, the yield of sap is most copious. On clear nights, cooling of the tree takes place with corresponding rapidity; then the snow or surface of the ground is frozen, and the flow of sap is checked altogether. From trees that have a sunny exposure, sap runs earlier and faster than from those having a cold northern aspect. Sap starts sooner from the spiles on the south side of a tree than from those towards the north.

The flow of sap from the tree influenced by temperature;

The mode in which changes of temperature in the trunk influence the flow of sap is very obvious. The wood-cells contain, not only water, but air. Both are expanded by heat, and both contract by cold. Air, especially, undergoes a decided change of bulk in this way. Water expands nearly one-twentieth in being warmed from 0° to 100°, and air increases in volume more than one-third by the same change of temperature. When, therefore, the trunk of a tree is warmed by the sun's heat the air is expanded, exerts a pressure on the sap, and forces it out of any wound made through the bark and wood-cells. It only requires a rise of temperature to the extent of a few degrees to occasion from this cause alone a considerable flow of sap from a large tree (Hartig).

If we admit that water continuously enters the deep-lying roots whose temperature and absorbent power must remain, for the most part, invariable from day to day, we should have a constant slow escape of sap from the trunk were the temperature of the latter uniform and sufficiently high. This really happens at times during every sugar season. When the trunk is cooled down to the freezing-point, or near it, the contraction of air and water in the tree makes a vacuum there, sap ceases to flow, and air is sucked in through the spile; as the trunk becomes heated again, the gaseous and liquid contents of the ducts expand, the flow of sap is renewed and proceeds with increased rapidity until the internal pressure passes its maximum.

ceases when the buds expand.

As the season advances and the temperature of the soil rises, the pressure from below undoubtedly increases, and larger quantities of water are forced into the trunk, but at a certain time the escape of sap from a wound suddenly ceases. At this period a new phenomenon supervenes. The buds which were formed the previous summer begin to expand as the vessels are distended with sap, and finally, when the temperature attains the proper range, they unfold into leaves.

The cessation of flow from a cut results from two circumstances: first, the vigorous cambial growth, whereby incisions in the bark and wood rapidly heal up; and second, the extensive evaporation that goes on from foliage.

That evaporation of water from the leaves often proceeds more rapidly than it can be supplied by the roots is shown by the facts—that the delicate leaves of many plants wither when the soil about their roots becomes dry, that water is often rapidly sucked into wounds on the stems of trees which are covered with foliage, and that the proportion of water in the wood of the trees of temperate latitudes is least in the months of May, June, and July.

Evergreens do not bleed in the spring-time. The oak loses little or no sap, and among other trees great diversity is noticed as to the amount of water that escapes at a wound on the stem. The leaves admit continual evaporation, and furnish an outlet to the water. The coloured heart-wood existing in many trees is impervious to water, as shown by the experiments of Boucherie and Hartig. Sap can only flow through the white, so-called sap-wood. In early June, the new shoots of the vine do not bleed when cut, nor does sap flow from the wounds made by breaking them off close to the older stem, although a gash in the latter bleeds profusely.

Sap consists chiefly of water.

Composition of Sap.—The sap in all cases consists chiefly of water. This liquid, as it is absorbed, brings in from the soil a small proportion of certain saline matters—the phosphates, sulphates, nitrates, &c., of the alkalies and alkaline earths. It finds in the plant itself its organic ingredients. These may be derived from matters stored in reserve during a previous year, as in the crude sap of trees; or may be newly formed, as in the elaborated sap.

Sugar in sap derived from transformation of starch.

The sugar of maple sap, in spring, is undoubtedly produced by the transformation of starch, which is found abundantly in the wood in winter. According to Hartig (*Jour. für Prakt. Ch.* v. p. 217, 1835), all deciduous trees contain starch in their wood and yield a sweet spring sap, while evergreens contain little or no starch. Hartig reports having been able to procure from the root-wood of the horse-chestnut in one instance no less than 26 per cent. of starch. This is deposited in the tissues during summer and autumn to be dissolved for the use of the plant in developing new foliage. In evergreens and annual plants the organic matters of the sap are derived more directly from the foliage itself. The leaves absorb carbonic acid and unite its carbon to the elements of water, with the production of sugar and other carbo-hydrates. In the leaves also, probably, nitrogen, from the nitrates and ammonia salts gathered by the roots, is united to carbon, hydrogen, and oxygen, in the formation of albuminoids.

Besides sugar, malic acid and minute quantities of albumen exist in maple sap. Towards the close of the sugar season the sap appears to contain other organic substances which render the sugar impure, brown in colour, and of different flavour.

The spring sap of many other deciduous trees of temperate climates contains sugar; but while it is cane-sugar in the maple, in other trees it consists mostly or entirely of grape-sugar.

Sugar is the chief organic ingredient in the juice of the sugar-cane, Indian corn, beet, carrot, turnip, and parsnip. The sap that flows from the vine and from many cultivated herbaceous plants contains little or no sugar; in that of the vine, gum or dextrine is found in its stead.

Sap flowing from a plant becomes more and more dilute.

We cannot infer the quantity of sap *in* a plant from what may *run out* of an incision, for the sap that thus issues is for the most part water forced up from the soil. It is equally plain that the sap thus collected has not the normal composition of the juices of the plant; it must be diluted, and must be the more diluted the longer and the more rapidly it flows.

Ulbricht has made partial analyses of the sap obtained from the stumps of potato, tobacco, and sunflower plants. He found that successive portions, collected separately, exhibited a decreasing concentration. In sunflower sap, gathered in five successive portions, the litre contained the following quantities (in grammes) of solid matter :—

Volatile matter . .	1·45	0·60	0·30	0·25	0·21
Ash	1·58	1·56	1·18	0·70	0·60
Total . .	3·03	2·16	1·48	0·95	0·81

The water which streams from a wound dissolves and carries forward with it matters, that in the uninjured plant would probably suffer a much less rapid and extensive translocation. From the stump of a potato stalk would issue, by the mere mechanical effect of the flow of water, substances generated in the leaves whose proper movement in the uninjured plant would be downwards into the tubers.

Fluids contained in cellular and vascular tissue chemically different.

The transverse section of the plant presents two kinds of tissue, the cellular and vascular. These contain different juices, as is shown by their chemical reactions. In the cell-tissues exist chiefly the non-nitrogenous principles, sugar, starch, oil, &c. The liquid in these cells, as Sachs has shown, commonly contains also organic acids and acid salts, and hence gives a red colour to blue litmus. In the vascular tissue albuminoids preponderate, and the sap of the ducts commonly has an alkaline reaction towards test papers. These different kinds of sap are not, however, always strictly confined to either tissue. In the root-tips and buds of many plants (maize, squash, onion) the *young* (new-formed) cell-tissue is alkaline from the preponderance of albuminoids, while the spring sap flowing from the ducts and wood of the maple is faintly acid.

In many plants is found a system of channels (milk-ducts) independent of the vascular bundles, which contain an opaque white or yellow juice. This liquid is seen to exude from the broken stem of the milk-weed (*Asclepias*), of lettuce, or of celandine (*Chelidonium*), and may be noticed to gather in drops upon a fresh-cut slice of the sweet potato. The milky juice often differs not more strikingly in appearance than it does in taste, from the transparent sap of the cell-tissue and vascular bundles. The former is commonly acrid and bitter, while the latter is sweet or simply insipid to the tongue.

Motion of fluids partly along ducts, partly from cell to cell.

The distribution of fluids in plants takes place partly by their direct passage along the ducts in the youngest tissues, partly by a process of gradual transference or exudation from cell to cell. The part which the ducts play has been much disputed. In the older tissues they are usually found full of air. Hence it has been assumed that ducts are never occupied with fluids (*Schleiden's Principles of Botany*, p. 517). In the younger parts of plants the course taken by coloured liquids when absorbed* proves that they ascend much more readily by the vascular than by the cellular tissues. Herbert Spencer found that they move fifty times more rapidly through the former than through the latter (*Principles of Biology*, vol. ii. p. 555). Rainey thought that the intercellular tissue was the only channel of ascent of the crude sap; but he employed mercuric chloride in his experiments, and this is so different to any of the ordinary constituents of the sap that it could hardly be expected to behave in the same way. The vegetable colouring matters which have been used by other observers are not open to the same objection, as they are almost chemically inert; and if a mixture of them be used any risk of error from the selective combination of one of them with particular parts of the tissues is got rid of. In all the lower kinds of plants, which possess no ducts or vascular tissue, the motion of fluids can only take place by transmission from cell to cell.

Causes of motion in the fluids of plants.

Herbert Spencer describes the causes of motion in the fluids of all plants as those actions only which disturb the liquid equilibrium in a plant by permanently abstracting water or sap from some part of it. These actions are the absorption of materials for the formation of new tissues in

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* As in Unger's experiment of placing a hyacinth in the juice of the poke-weed (*Phytolacca*), or in Hallier's observations on cuttings dipped in cherry-juice (*Vs. St.* ix. p. 1).

growing parts; the loss by evaporation mainly through adult leaves; and the loss by extravasation through vessels compressed in the oscillations produced by wind. All the other actions concerned must be classed as aids, facilitating the redistribution of fluid that continually restores the equilibrium continually disturbed. Of these, capillary action may be named as the first, osmose as the second, and the propulsive effect of mechanical strains as the third (*loc. cit.* pp. 553-4).

The rapid supply of water to the foliage of a plant, either from the roots or from a vessel in which the cut stem is immersed, goes on when the cellular tissues of the bark and pith are removed or interrupted, but is at once checked by severing the vascular bundles.

The proper motion of the nutritive matters in the cellular tissues of vascular plants—of the salts dissolved from the soil, and of the organic principles compounded from carbonic acid, water, and nitric acid or ammonia in the leaves—is one of *slow diffusion* mostly through the walls of imperforate cells, and goes on in all directions.

Descent of the elaborated sap.

When a cutting from one of our common trees is girdled at its middle and placed in circumstances favourable for growth, as in moist, warm air, with its lower extremity in water, roots form chiefly at the edge of the bark just above the removed ring. The twisting, or half-breaking, as well as ringing of a layer, promotes the development of roots. Latent buds are often called forth on the stems of fruit trees, and branches grow more vigorously, by making a transverse incision through the bark just below the point of their issue. Girdling a fruit-bearing branch of the vine near its junction with the older wood has the effect of greatly enlarging the grapes. It is well known that a wide wound made on the stem of a tree heals up by the formation of new wood, and commonly the growth is most rapid and abundant above the cut. From these facts it was concluded that sap descends in the bark, and, not being able to pass below a wound, leads to the organization of new roots or wood just above it.

The accompanying illustration, Fig. 60, represents the base of a cutting from an exogenous stem (pear or currant) girdled at B and kept for some days immersed in water to the depth indicated by the line L. The first manifestation of growth is the formation of a protuberance at the lower edge of the bark, which is known to gardeners as a *callus*, C. This is an extension of the cellular tissue. From the callus shortly appear rootlets, R, which originate from the vascular tissue. Rootlets also break from the stem above the callus, and also above the water, if the air be moist. They appear likewise, though in less number, below the girdled place.

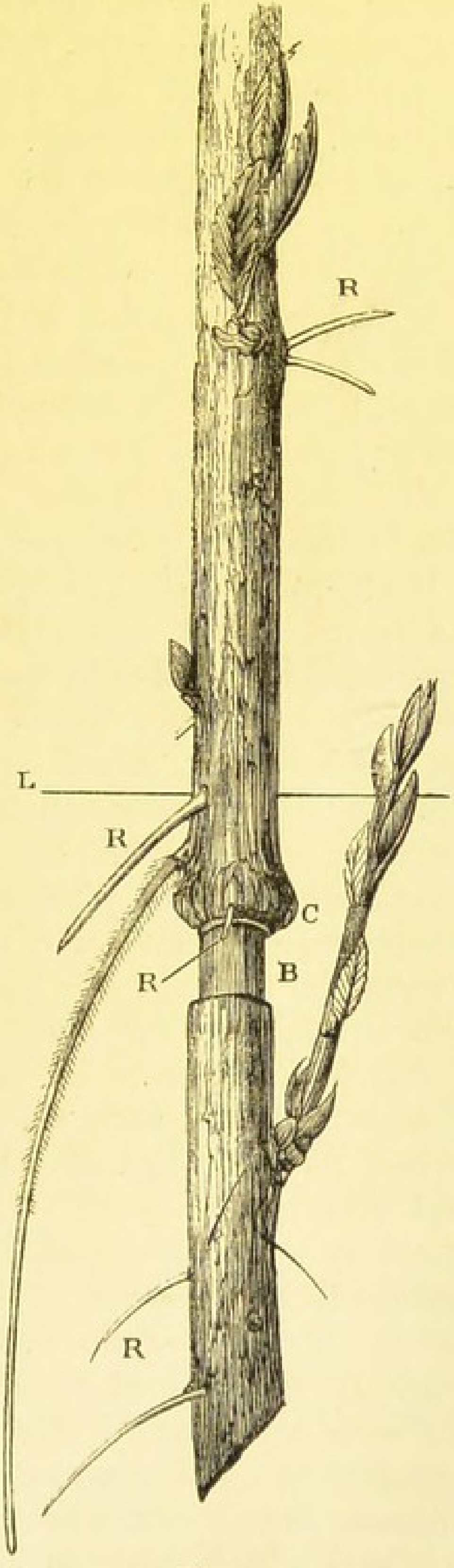

Fig. 60.

Nearly all the organic substances (carbo-hydrates, albuminoids, lignine, &c.) that are formed in a plant are produced in the leaves, and must necessarily find their way down to nourish the stem and roots. Investigation has shown that the most abundant downward movement of the nutrient matters generated in the leaves proceeds in the cambium. The cellular tissues of the leaves communicate directly with, and are a continuation of, the cambium, and hence matters formed by the leaves must move most rapidly in the cambium. According, however, to Herbert Spencer, the descent of the sap takes place, not through the cellular cambium, but by the same channels by which it ascends. He states that these are the outer and latest-formed layer of the sap wood, which is essentially vascular, the vascular systems of new axes taking their rise from it (*loc. cit.* p. 550).

Girdling only injurious when active vascular bundles are confined to the exterior of the stem.

In endogenous plants and in some exogens (*Piper medium*, *Amaranthus sanguineus*) the vascular bundles pass into the pith and are not confined to the exterior of the stem. Girdling such plants does not give the result above described. With them, roots are formed chiefly or entirely at the base of the cutting (Hanstein), and not above the girdled place.

In all cases, without exception, the matters organized in the leaves, though most readily and abundantly moving downwards in the vascular tissues, are not confined to them exclusively. When a ring of bark is removed from a tree, the new *cell-tissues*, as well as the vascular, are interrupted. Notwithstanding, matters are transmitted downwards, through the older wood. When but a *narrow* ring of bark is removed from a cutting, roots often appear below the incision, though in less number, and the new growth at the edges of a wound on the trunk of a tree, though most copious above, goes on all around the gash.

Both the cell-tissue and the vascular thus admit of the transport of the nutritive matters downwards. In the former, the carbo-hydrates—starch, sugar, inuline—the fats, and acids, chiefly occur. Vessels, however, may contain starch in the winter (Rainey, *Experimental Inquiry*, p. 31). Ordinarily the contents of cells must pass into solution before they can exude into the vessels. In the older ducts, air is contained, except when by vigorous root-action the stem is surcharged with water. In the cambium, and probably also in the newest sap-wood, are found the albuminoids, though not unmixed with carbo-hydrates. If a tree have a deep gash cut into its stem (but not reaching to the coloured heart-wood), growth is not suppressed on either side of the cut, but the nutritive matters of all kinds pass out of a vertical direction around the incision, to nourish the new wood above and below. Girdling a tree is not fatal, if done in the spring or early summer when growth is rapid, provided that the young cells, which form externally, are protected from dryness and other destructive influences. An artificial bark, *i.e.* a covering of cloth or clay to keep the exposed wood moist and away from air, saves the tree until the wound heals over.*

Elaborated sap may sometimes ascend.

Evidence that nutrient matters also pass *upwards* in the outer tissues of the stem is furnished, not only by tracing the course of coloured liquids, but also by the fact that undeveloped buds perish in most cases when the stem is girdled between them and active leaves. In the exceptions to this rule, the vascular bundles penetrate the pith.

The substances organized by the plant distributed to the parts where they are needed.

The substances which are organized in the foliage of a plant, as well as those which are imbibed by the roots, move to any point where they can supply a want. Carbohydrates pass from the leaves, not only downwards, to nourish new roots, but upwards, to feed the buds, flowers, and fruit. In cereals, the power of the leaves to gather and organize atmospheric food nearly or altogether ceases as they approach maturity. The seed grows at the expense of matters previously stored in the foliage and stems (p. 208), to such an extent that it may ripen quite perfectly, although the plant be cut when the kernel is in the milk, or even earlier, while the juice of the seeds is still watery and before starch-grains have begun to form.

In Belgium the flax crop is harvested while the capsules are still green. Experience has shown, that while it is then in its best state for the separation of the fibre, the seeds become sufficiently mature in the sheaf for the purpose of vegetation.

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* If the freshly exposed wood be rubbed or wiped with a cloth, whereby the moist cambial layer (of cells containing nuclei and capable of multiplying) is removed, no growth can occur (Ratzeburg).

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In biennials accumulated nutriment expended in flowering.

In biennial root-crops, the root is the focus of motion for the matters organized by growth during the first year; but in the second year the stores of the root are completely exhausted for the support of flowers and seed, so that the direction of the movement of these organized matters is reversed. In both years the motion of *water* is always the same, viz. from the soil upwards to the leaves.*

The summing up of the whole matter is, that the nutrient substances in the plant are not absolutely confined to any path, and may move in any direction. The fact that they chiefly follow certain channels, and move in this or that direction, is plainly dependent upon the structure and arrangement of the tissues, on the sources of nutriment, and on the seat of growth or other action.

§ 3. The Causes of Motion of the Vegetable Juices.

Porosity either massive or molecular.

Porosity of Vegetable Tissues.—Porosity is a universal property of bodies. It is of two kinds, massive and molecular. Massive porosity exists in bodies containing visible pores admitting the passage of minute masses of matter. Molecular porosity exists in all bodies, and is due to the fact that their ultimate molecules are never in contact, and consequently frequently admit of the passage of molecules of other kinds of matter between them. Massive porosity is always visible, though it may require a microscope for its proper display. Molecular porosity could not be absolutely demonstrated unless the ultimate molecules of a body could also be seen. A fibre of linen, to the unassisted eye, has

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* The motion of water is always upwards, because the soil always contains more water than the air. If a plant were so situated that its roots should steadily lack water while its foliage had an excess of this liquid, it cannot be doubted that then the "sap" would pass down in a regular flow. In this case, nevertheless, the nutrient matters would take their normal course.

no pores. Under the microscope we find that it is a tubular cell, the bore being much less than the thickness of the walls. By immersing it in water it swells, becomes more transparent, and increases in weight. If the water be coloured by solution of indigo or cochineal, the fibre is visibly penetrated by the dye. It is therefore porous, not only in the sense of having an interior cavity which becomes visible by a high magnifying power, but likewise in having an apparently imperforate substance through which liquids can freely pass. In like manner, all the vegetable tissues are more or less porous and penetrable to water.

The tissues of plants become turgid by absorbing water.

Imbibition of Liquids by Porous Bodies.—Not only do the tissues of the plant admit of the access of water into their pores, but they forcibly drink in or absorb this liquid, when it is presented to them in excess, until their pores are full.

When the molecules of the porous body have freedom of motion, they separate from each other on imbibing a liquid; the body itself swells. Even powdered glass or fine sand perceptibly increases in bulk by imbibing water. Clay swells much more. Gelatinous silica, pectine, gum tragacanth, and boiled starch, hold a vastly greater amount of water in their pores.

In vegetable and animal membranes, we find a greater or less degree of expansibility from the same cause, but here the structural connexion of the molecules puts a limit to their separation, and the result of saturating them with a liquid is a state of turgidity and tension, which subsides to one of yielding flabbiness when the liquid is partially removed.

The energy with which vegetable matters imbibe water may be gathered from a well-known fact. In granite quarries, long blocks of stone are split out by driving plugs of dry wood into holes drilled along the desired line of fracture and pouring water over the plugs. The liquid penetrates the wood with immense force, and the toughest rock is easily broken apart.

Absorption varies with different substances and different liquids.

The imbibing power of different tissues and vegetable matters is widely diverse. In general, the younger organs or parts take up water most readily and freely. The sap-wood of trees is far more absorbent than the heart-wood and bark. The cuticle of the leaf is often comparatively impervious to water. Of the proximate elements we have cellulose and starch-grains able to retain, even when air-dry, 10 to 15 per cent. of water. Wax and the solid fats, as well as resins, on the contrary, do not greatly attract water, and cannot easily be wetted with it. They render cellulose, which has been impregnated with them, unabsorbent.

Those vegetable substances which ordinarily manifest the greatest absorbent power for water are pectine, pectic and pectosic acids, vegetable mucilage, bassorine, and albumen. In the living plant the protoplasmic membrane exhibits great absorbent power. Of mineral matters, gelatinous silica (Exp. 58, p. 109) is remarkable on account of its attraction for water.

Not only do different substances thus exhibit unlike adhesion to water, but the same substance deports itself variously towards different liquids.

100 parts of dry ox-bladder were found by Liebig to absorb during 24 hours—

268	parts of	pure water.
133	,,	saturated brine.
38	,,	alcohol (84 per cent.).
17	,,	bone oil.

A piece of dry leather will absorb either oil or water, and apparently with equal avidity. If, however, oiled leather be immersed in water, the oil is gradually and perfectly displaced, as the farmer well knows from his experience with greased boots. India-rubber, on the other hand, is impenetrable to water, while oil of turpentine is imbibed by it in large quantity, causing the caoutchouc to swell up to a pasty mass many times its original bulk.

The absorbent power is influenced by the size of the

Absorptive energy varies with the minuteness of the pores.

pores. Other things being equal, the finer these are, the greater the force with which a liquid is imbibed. This is shown by what has been learned from the study of a kind of pores whose effect admits of accurate measurement. A tube of glass, with a narrow, uniform calibre, is such a pore. In a tube of 1 millimetre (about $\frac{1}{25}$ of an inch) in diameter, water rises 30 mm. In a tube of $\frac{1}{10}$ millimetre, the liquid ascends 300 mm. (about 11 inches); and in a tube of $\frac{1}{100}$ mm. a column of 3,000 mm. is sustained. In porous bodies, like chalk, plaster stucco, closely packed ashes or starch, Jamin found that water was absorbed with force enough to overcome the pressure of the atmosphere from three to six times; in other words, to sustain a column of water in a wide tube 100 to 200 ft. high. (*Comptes rendus*, 50, p. 311.)

Absorption influenced by temperature.

Absorbent power is influenced by temperature. Warm water is absorbed by wood more quickly and abundantly than cold. In cold water starch does not swell to any striking or even perceptible degree, although considerable liquid is imbibed. In warm water, however, the case is remarkably altered. The starch-grains are forcibly burst open, and a paste or jelly is formed that holds many times its weight of water (Exp. 27, p. 50). On freezing, the particles of water are mostly withdrawn from their adhesion to the starch. The ascent of liquids in narrow tubes whose walls are unabsorbent is, on the contrary, diminished by a rise of temperature.

Different kinds of absorption are included in the general physical phenomenon of adhesion.

Adhesive or Capillary Attraction.—The absorption of a liquid into cavities of a porous body, as well as its rise in a narrow tube, are but expressions of the general fact that there is an attraction between the molecules of the liquid and the solid. In its simplest manifestation this attraction exhibits itself as *Adhesion*, and this term we shall employ to designate the kind of force under consideration. If a clean plate of glass be dipped in water, the liquid touches, and sticks to, the glass. On withdrawing the glass,

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a film of water comes away with it. If two squares of glass be set up together upon a plate, so that they shall be in contact at their vertical edges on one side, and one-eighth of an inch apart on the other, it will be seen, on pouring a little water upon the plate, that this liquid rises in the space between them several inches or feet where they are in very near proximity, and curves downwards to their base where the interval is large.

Rise of liquids in fine tubes due to adhesion ;

Capillary Attraction—the common designation of the force that causes liquids to rise in fine tubes—is the same adhesion which is manifested in all the cases of absorption which have been alluded to. In many phenomena of absorption, however, chemical affinity appears to supervene with more or less vigour.

Adhesive attraction is not manifested universally between solids and liquids. Glass dipped in mercury is not touched or wetted by it, and when a capillary tube is plunged in this liquid, we see no rise, but a depression, within the bore. A greased glass tube deports itself similarly towards water.

produces continuous motion if liquid is continuously withdrawn after rising.

Adhesion may be a Cause of continual Movement under certain circumstances. When a new cotton wick is dipped into oil, the motion of the oil may be followed by the eye, as it slowly ascends, until the pores are filled. At this moment the adhesive attraction between cotton and oil is satisfied, and motion ceases. Any cause which removes oil from the pores at the apex of the wick will disturb the equilibrium which had been established between the solid and the liquid. A burning match, held to the wick, by its heat destroys the oil, molecule after molecule, and this process becomes permanent when the wick is lighted. As the pores at the base of the flame give up oil to the latter, they fill themselves again from the pores beneath, and the motion thus set up propagates itself to the oil in the vessel below, and continues as long as the flame burns or the oil holds out.

In this process, the pores, if of the same material and of equal size, exert everywhere an equal attraction for the molecules of oil. The wick, above, contains indeed less oil than below; for two reasons. In the first place, gravitation, or the earth's attraction, acts most powerfully on the oil below, and secondly, time is required for the particles of oil to pass upwards, and they cannot reach the summit as rapidly as they might be consumed. We get a further insight into the nature of this motion when we consider what happens after the oil has all been sucked up into the wick. Shortly thereafter the dimensions of the flame are seen to diminish. It does not, however, go out, but burns on for a time with continually decreasing vigour. When the supply of liquid in the porous body is insufficient to saturate the latter, there is still the same tendency to equalization and equilibrium. If at last, when the flame expires because the combustion of the oil fails below that rate which is needful to generate heat sufficient to decompose it, the wick be placed in contact at a single point with another dry wick of equal mass and porosity, the oil remaining in the first will enter again into motion, will pass into the second wick from pore to pore, until equilibrium is again restored and the oil has been shared equally between them.

In the case of water contained in the cavities of a porous body, evaporation from the surface of the latter becomes remotely the cause of a continual upward motion of the liquid.

Evaporation of water from leaves necessitates imbibition by roots.

The exhalation of water as vapour from the foliage of a plant thus necessitates the entrance of water as liquid at the roots, and maintains a flow of it, partly by capillary adhesion in the longer cells, and partly by absorption from cell to cell.

Liquid Diffusion.—The movements that proceed in plants when exhalation is out of the question, viz. such as are manifested in the stump of a vine cemented into a gauge (Fig. 40, p. 238), are not to be accounted for by capillarity or mere absorptive force under the conditions as yet noticed. To approach their elucidation we require to attend to other considerations.

Adhesive attraction amongst liquids ;

The particles of many different kinds of liquids attract each other. Water and alcohol may be mixed together in all proportions in virtue of their adhesive attraction. If we fill a vial with water to the rim and carefully lower it to the bottom of a tall jar of alcohol, we shall find after some hours that alcohol has penetrated the vial, and water has passed out into the jar, notwithstanding the latter liquid is considerably heavier than the former. If the water be coloured by indigo or cherry-juice, its motion may be followed by the eye, and after a certain lapse of time the water and alcohol will be seen to have become uniformly mixed throughout the two vessels. This manifestation of adhesive attraction is termed *Liquid Diffusion.*

What is true of two liquids likewise holds for two solutions, *i.e.* for two solids made liquid by the action of a solvent. A vial filled with coloured brine, or syrup, and placed in a vessel of water, will discharge its contents into the latter, itself receiving water in return ; and this motion of the liquids will not cease until the whole is uniform in composition, *i.e.* until every molecule of salt or sugar is equally attracted by all the molecules of water.

When several or a large number of soluble substances are placed together in water, the diffusion of each one throughout the entire liquid will go on in the same way until the mixture is homogeneous.

may produce continuous movements in liquids.

Liquid Diffusion may be a Cause of continual Movement whenever circumstances produce continual disturbances in the composition of a solution, or in that of a mixture, of liquids.

If into a mixture of two liquids we introduce a solid body which is able to combine chemically with, and solidify one of the liquids, the molecules of this liquid will begin to move towards the solid body from all points, and this motion will cease only when the solid is able to combine with no more of the one liquid, or no more remains for it to unite with. Thus, when quicklime is placed in a mixture of alcohol and water, the water is in time completely condensed in the lime, and the alcohol is rendered anhydrous.

The rate of diffusion varies with the nature of the liquids, and with their temperature.

Rate of Diffusion.—The rate of diffusion varies with the nature of the liquids; if solutions, with their degree of concentration and with the temperature.

Colloids and Crystalloids.—There is a class of bodies whose molecules are singularly inactive in many respects, and have, when dissolved in water or other liquid, a very low capacity for diffusive motion. These bodies are termed *Colloids*,* and are characterised by swelling up or uniting with water to bulky masses (hydrates) of gelatinous consistence, by inability to crystallize, and by feeble and poorly-defined chemical affinities. Starch, dextrine, the gums, the uncrystallized albuminoids, pectine and pectic acid, gelatine, tannin, and gelatinous silica, are colloids. Opposed to these, in the properties just specified, are those bodies which *crystallize*, such as saccharose, glucose, oxalic, citric, and tartaric acids, and the ordinary salts.

Other bodies which have never been seen to crystallize have the same high diffusive rate; hence the class is termed by Graham *Crystalloids*.†

Colloidal bodies, when insoluble, are capable of imbibing liquids, and admit of liquid diffusion through their molecular interspaces. Insoluble crystalloids are, on the other hand, impenetrable to liquids in this sense. The colloids swell up more or less, often to a great bulk, from absorbing a liquid: the volume of a crystalloid remains unchanged.

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[*] From two Greek words which signify glue-like.

[†] We have already employed the word crystalloid to distinguish the amorphous albuminoids from their modifications or combinations which present the aspect of crystals (p. 93). This use of the word was proposed by Nägeli in 1862. Graham had employed it, as opposed to colloid, in 1861. It will perhaps be found that Nägeli's crystalloids are crystalloid in Graham's sense.

In his study of the rates of diffusion of various substances, dissolved in water to the extent of one per cent. of the liquid, Graham found the following

APPROXIMATE TIMES OF EQUAL DIFFUSION.

Hydrochloric acid,	Crystalloid	1
Sodium chloride,	,,	$2\frac{1}{3}$
Cane-sugar,	,,	7
Magnesium sulphate,	,,	7
Albumen,	Colloid	49
Caramel,	,,	98

The table shows that the diffusive activity of hydrochloric acid through water is ninety-eight times as great as that of caramel. In other words, a molecule of the acid will travel ninety-eight times as far in a given time as the molecule of caramel.

Diffusion through an intervening membrane, or osmose.

Osmose,* **or Membrane Diffusion.**—When two miscible liquids or solutions are separated by a porous diaphragm, the phenomena of diffusion (which depend upon the mutual attraction of the molecules of the different liquids or dissolved substances) are complicated with those of imbibition or capillarity, and of chemical affinity. The adhesive or other force which the diaphragm is able to exert upon the liquid molecules is added to the mere diffusive tendency, and the movements may suffer remarkable modifications.

If we should separate pure water and a solution of common salt by a membrane upon whose substance these liquids could exert no action, the diffusion would proceed to the same result as were the membrane absent. Molecules of water would penetrate the membrane on one side and molecules of salt on the other, until the liquid should become alike on both. Should the water move faster than the salt, the volume of the brine would increase, and that of the water would correspondingly diminish. Were the mem-

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* From a Greek word meaning *impulsion*.

brane fixed in its place, a change of level of the liquids would occur. Graham has observed that common salt actually diffuses into water, through a thin membrane of ox-bladder deprived of its outer muscular coating, at very nearly the same rate as when no membrane is interposed.

Dutrochet was the first to study the phenomena of membrane diffusion. He took a glass funnel with a long and slender neck, tied a piece of bladder over the wide opening, inverted it, poured in brine until the funnel was filled to the neck, and immersed the bladder in a vessel of water. He saw the liquid rise in the narrow tube and fall in the outer vessel. He designated the passage of water into the funnel as *endosmose,* or inward propulsion. At the same time he found the water surrounding the funnel to acquire the taste of salt. The outward transfer of salt was his *exosmose.* The more general word, osmose, expresses both phenomena; we may, however, employ Dutrochet's terms to designate the direction of osmose.

Apparatus for measuring osmose.

Osmometer.—When the apparatus employed by Dutrochet is so constructed that the size of the narrow tube has a known relation to it—for example, exactly $\frac{1}{10}$ that of the membrane—and the narrow tube itself is provided with a millimetre scale, we have the Osmometer of Graham, Fig. 61. The ascent or descent of the liquid in the tube gives a measure of the amount of osmose, provided the hydrostatic pressure is counterpoised by making the level of the liquid within and without equal, for which purpose water is poured into or removed from the outer vessel.

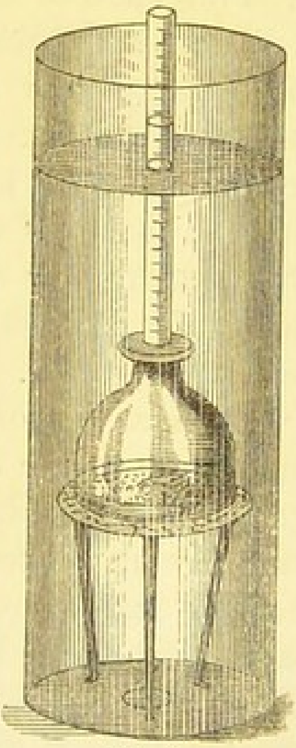
Fig. 61.

Graham designates the increase of volume in the osmometer as *positive osmose*, or simply osmose, and distinguishes the fall of liquid in the narrow tube as *negative osmose.*

In the figure on page 337, the external vessel is intended for the reception of water. The funnel-shaped interior vessel is closed below with membrane, and stands upon a shelf of perforated zinc for support. The graduated tube fits the neck of the funnel by a ground joint.

Action of the intervening membrane in modifying osmose.

Action of the Membrane.—When the membrane itself has an attraction for one or more of the substances between which it is interposed, then the rate, amount, and even direction of diffusion may be greatly changed.

Water is imbibed by the membrane of bladder much more freely than alcohol; on the other hand, a film of collodion (nitro-cellulose left from the evaporation of its solution in ether) is penetrated much more easily by alcohol than by water. If now these liquids be separated by bladder, the apparent flow will be towards the alcohol; but if a membrane of collodion divide them, the more rapid motion will be into the water.

When a vigorous chemical action is exerted upon the membrane by the liquid or the dissolved matters, osmose is greatly heightened. In experiments with a septum of porous earthenware (biscuit porcelain) Graham found that with neutral organic bodies, like sugar and alcohol, or neutral salts, like the alkaline chlorides and nitrates, very little osmose is exhibited, *i.e.* the diffusion is not perceptibly greater than it would be in the absence of the porous diaphragm.

The acids—oxalic, nitric, and hydrochloric—manifest a sensible but still moderate osmose. Sulphuric and phosphoric acids, and salts having a decided alkaline or acid reaction, like potassium hydric oxalate, sodium hydric phosphate, and potassium and sodium carbonates, exhibit a still more vigorous osmose. For example, a solution of one part of potassium carbonate in 1,000 parts of water gains in volume rapidly, and to one part of the salt that passes into the water 500 parts of water enter the solution.

The membrane in modifying osmose undergoes change

In all cases where diffusion is greatly modified by a membrane, the membrane itself is strongly attacked and altered, or dissolved, by the liquids. When animal membrane is used, it constantly undergoes decomposition, and its osmotic action is exhaustible. When earthenware is employed as a diaphragm, lime and alumina are always found in the solutions upon which it exerts osmose.

Graham asserts that to induce osmose in bladder, the chemical action on the membrane must be different on the two sides, and apparently not in degree only, but also in kind, viz. an alkaline action on the albuminoid substance of the membrane on the one side, and an acid action on the other. The water appears always to accumulate on the alkaline or basic side of the membrane. Hence with an alkaline salt, like potassium carbonate, in the osmometer, and water outside, the flow is inwards; but with an acid in the osmometer, there is negative osmose, or the flow is outwards, the liquid then falling in the tube.

Osmotic activity is most highly manifested in such salts as easily admit of decomposition with the setting free of a part of their acid, or alkali.

The osmose of aqueous solutions of different salts may be due to their effect in modifying the hydration of the membrane.

Hydration of the Membrane.—It is remarkable that the rapid osmose of potassium carbonate and other alkaline salts is greatly interfered with by common salt; is, in fact, reduced to almost nothing by an equal quantity of this substance. In this case it is probable that the physical effect of the salt in diminishing the power of the membrane to imbibe water (p. 330), operates in a sense inverse to, and neutralizes the chemical action of, the carbonate. In fact, the osmose of the carbonate, as well as of all other salts, acid or alkaline, may be due to their effect in modifying the *hydration*,* or power of the membrane to imbibe the liquid which is the vehicle of their motion. Graham suggests this view as an explanation of the osmotic influence of colloid membranes, and it is not unlikely that, in the case of earthenware, the chemical action may exert its effect indirectly, viz. by producing hydrated silicates from the burned clay, which are truly colloid, and analogous to animal membranes in respect of imbibition. Graham has shown a connexion between the hydrating effect of acids and alkalies on colloid membranes and their osmotic rate:

"It is well known that fibrine, albumen, and animal membrane swell much more in very dilute acids and alkalies than in pure water. On the other hand, when the proportion of acid or alkali is carried beyond a point peculiar to each substance, contraction of the colloid takes place. The colloids just named acquire the power of combining with an increased proportion of water, and of forming higher gelatinous hydrates, in consequence of contact with dilute acid or alkaline reagents. Even parchment-paper is more elongated in an alkaline solution than in pure water. When thus hydrated and dilated, the colloids present an extreme osmotic sensibility."

An illustration of membrane-diffusion which is highly instructive and easy to produce, is the following:—

Water withdrawn from organized tissues by osmose.

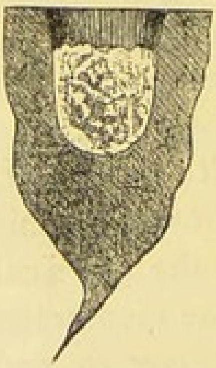
Fig. 62.

A cavity is scooped out in a carrot, as in Fig. 62, so that the sides remain $\frac{1}{4}$ inch or so thick, and a quantity of dry crushed sugar is introduced; after some time, the previously dry sugar will be converted into a syrup by withdrawing water from the flesh of the carrot. At the same time the latter will visibly shrink, from the loss of a portion of its liquid contents. In this case the small portions of juice moistening the cavity form a strong solution with the sugar in contact

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* When *water* is employed as the liquid.

with them, into which water diffuses from the adjoining cells. Doubtless, also, sugar penetrates the parenchyma of the carrot.

In the same manner, sugar, when sprinkled over thin-skinned fruits, shortly forms a syrup with the water which it thus withdraws from them, and salt packed with fresh meat runs to brine by the exosmose of the juices of the flesh. In these cases the fruit and the meat shrink, as a result of the loss of water.

Graham observed gum-tragacanth, which is insoluble in water, to cause a rapid passage of water through a membrane in the same manner from its power of imbibition, although here there could be no exosmose or outward movement.

Osmose aids the motion of the liquids of the plant.

The application of these facts and principles to explaining the movements of the liquids of the plant is obvious. The cells and the tissues composed of cells furnish precisely the conditions for the manifestation of motion by the imbibition of liquids and by simple diffusion, as well as by osmose. The constant disturbances needful to maintain constant motion are to be found in fully adequate degree in the chemical changes that accompany the processes of nutrition. The substances that normally exist in the vegetable cells are numerous, and they suffer remarkable transformations, both in chemical constitution and in physical properties. The rapidly diffusible salts that are presented to the plant by the soil, and the equally diffusible sugar and organic acids that are generated in the leaf-cells, are, in part, converted into the sluggish, soluble colloids, soluble starch, dextrine, albumen, &c., or are deposited as solid matters in the cells or upon their walls. Thus the diffusible contents of the plant not only, but the membranes which occasion and direct osmose, are subject to perpetual alterations in their nature. More than this, the plant grows; new cells, new membranes, new proportions of soluble and diffusible matters, are unceasingly brought into existence.

Imbibition in the cell-membranes and their solid, colloid contents, *Diffusion* in the liquid contents of the individual cells, and *Osmose* between the liquids and dissolved matters and the membranes or colloid contents of the cells, must unavoidably take place.

That we cannot follow the details of these kinds of action in the plant does not invalidate the fact of their operation. The plant is so complicated, and presents such a number and variety of changes in its growth, that we can never expect to understand all its mysteries. From what has been briefly explained, we can comprehend some of the more striking or obvious movements that proceed in the vegetable organism.

Osmose produces absorption of water by the germinating seed.

Absorption and Osmose in Germination.—The absorption of water by the seed is the first step in germination. The coats of the dry seed when put into the moist soil *imbibe* this liquid, which follows the cell-walls from cell to cell, until these membranes are saturated and swollen. At the same time these membranes occasion or permit osmose into the cell cavities, which, dry before, become distended with liquid. The soluble contents of the cells or the soluble results of the transformation of their organized matters diffuse from cell to cell in their passage to the expanding embryo.

The quantity of water imbibed by the air-dry seed commonly amounts to 50 and may exceed 100 per cent. R. Hoffmann has made observations on this subject (*Vs. St.* vii. p. 50). The absorption was usually complete in 48 or 72 hours, and was as follows in case of certain agricultural plants :—

	Per cent.		Per cent.
Mustard	8·0	Oats	59·8
Millet	25·0	Hemp	60·0
Maize	44·0	Kidney bean . . .	96·1
Wheat	45·5	Horse bean . . .	104·0
Buckwheat	46·8	Pea	106·8
Barley	48·2	Clover	117·5
Turnip	51·0	Beet	120·5
Rye	57·7	White clover . . .	126·7

Absorption of water from soil by roots due to osmose.

Root-Action.—Absorption at the roots is unquestionably an osmotic action exercised by the membrane that bounds the young rootlets and root-hairs externally. In principle it does not differ from the absorption of water by the seed. The mode in which it occasions the surprising phenomena of bleeding or rapid flow of sap from a wound on the trunk or larger roots is doubtless essentially as Hofmeister first elucidated by experiment.

This flow proceeds in the ducts and wood-cells. Between these and the soil intervenes loose cell-tissue surrounded by a compacter epidermis. Osmose takes place in the epidermis with such energy as not only to distend to its utmost the cell-tissue, but to cause the water of the cells to filter through their walls, and thus gain access to the ducts. The latter are formed in young cambial tissue, and, when new, are delicate in structure.

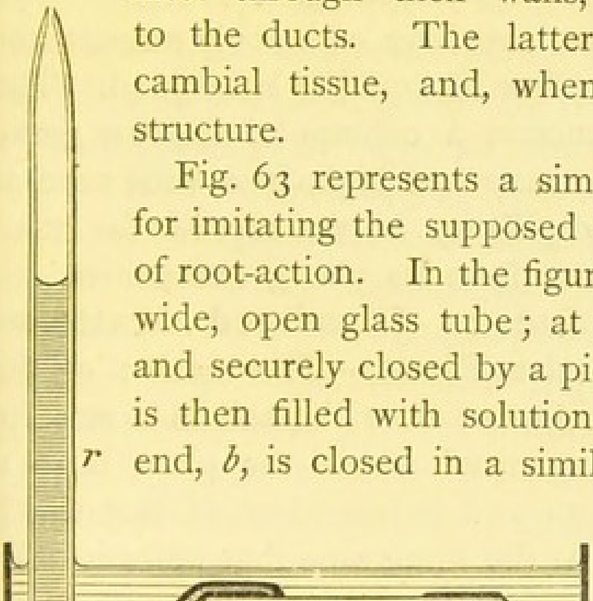

Fig. 63.

Fig. 63 represents a simple apparatus by Sachs for imitating the supposed mechanism and process of root-action. In the figure, *g g* represents a short, wide, open glass tube; at *a*, the tube is tied over and securely closed by a piece of pig's bladder; it is then filled with solution of sugar, and the other end, *b*, is closed in a similar manner by a piece of parchment - paper (p. 44). Finally a cap of india-rubber, K, into whose neck a narrow, bent glass tube, *r*, is fixed, is tied on over *b*. (These joinings must be made very carefully and firmly.) The space within *r* K is left empty of liquid, and the combination is placed in a vessel of water, as in the figure. *C* represents a root-cell whose exterior wall (cuticle), *a*, is less penetrable under pressure than its interior, *b*; *r* corresponds to a duct of vascular tissue, and the surrounding water takes the place of that existing in the pores of the soil. The water shortly penetrates the cell, *C*, distends the previously flabby membranes under the accumulating tension filters through *b* into *r*, and rises in the tube; where in Sachs' experiment it attained a height of 4 or 5 inches in 24 to 48 hours, the tube, *r*, being about 5 millimetres wide, and the area of *b*, 700 sq. mm. When we consider the vast root-surface exposed to the soil in a vine, and that myriads of rootlets and root-hairs unite their action in the comparatively narrow stem, we must admit that the apparatus above figured gives us a very satisfactory glance into the causes of bleeding.

In the stem of the plant we have commonly a resistance to root-action, so far as a flow of liquid is concerned. The root-action which can sustain a column of mercury many inches, or one of water many feet high, in a wide tube, is greatly neutralized by capillarity as we ascend the stem from the root, or the root from its young extremities.

Soluble constituents of the plant distributed through its tissues by osmose.

Motion of Nutritive or Dissolved Matters: Selective Power of the Plant.—The motion of the substances that enter the plant from the soil in a state of solution and of those organized within the plant is to a great degree separate from and independent of that which the water itself takes. At the same time that water is passing upwards through the plant to make good the waste by evaporation from the foliage, sugar or other carbo-hydrates generated in the leaves are diffusing against the water, and finding their way down to the very root-tips. This diffusion takes place mostly in the cell-tissue, and is undoubtedly greatly aided by osmose, *i.e.* by the action of the membranes themselves. The very thickening of the cell-walls by the deposition of cellulose would indicate an attraction for the material from which cellulose is organized. The same transfer goes on simultaneously in all directions, not only into root and stem, but into the new buds, into flowers and fruit. We have considered the tendency to equalization between two masses of liquid separated from each other by penetrable membranes. Demand creates supply. In two contiguous cells, one of which contains solution of sugar, and the other solution of potassium nitrate, these substances must diffuse until they are mingled equally, unless, indeed, the membranes or some other substance present exert an opposing and preponderating attraction.

In the simplest phases of diffusion each substance is to a certain degree independent of every other. Potassium nitrate dissolved in the water of the soil *must* diffuse into the root-cells of a plant if it be absent from the sap of this root-cell and the membrane permit its passage. When the root-cell has acquired a certain proportion of potassium nitrate, a proportion equal to that in the soil-water, the nitrate *cannot* enter it any more. So soon as a molecule of the salt has gone on into another cell, or been removed from the sap by any chemical transformation, then a molecule may and must enter from without.

Osmose affords an explanation of the selective powers of plants.

Silica is much more abundant in grasses and cereals than in leguminous plants. In the former it exists to the extent of about 25 parts in 1,000 of the air-dry foliage, while the leaves and stems of the latter contain but 3 parts. (See Wolff's Table in Appendix.) When these crops grow side by side, their roots are equally bathed by the same soil-water. Silica enters both alike, and, so far as regards itself, brings the cell-contents to the same state of saturation that exists in the soil. The cereals are able to dispose of silica by giving it a place in the cuticular cells; the leguminous crops, on the other hand, cannot remove it from their juices; the latter remain saturated, and thus further diffusion of silica from without becomes impossible except as room is made by new growth. It is in this way that we have a rational and adequate explanation of the selective power of the plant, as manifested in its deportment towards the medium that invests its roots. The same principles govern the transfer of matters from cell to cell, or from organ to organ, within the plant. Wherever there is unlike composition of two miscible juices, diffusion is thereby set up, and proceeds as long as the cause of disturbance lasts, provided impenetrable membranes do not intervene. The rapid movement of water goes on because there is great loss of this liquid; the slow motion of silica is a consequence of the little use that arises for it in the plant.

Osmose may effect chemical change.

Strong chemical affinities may be overcome by osmose. Graham long ago observed the decomposition of alum (aluminium and potassium sulphate) by mere diffusion; its potassium sulphate having a higher diffusive rate than its aluminium sulphate. In the same manner potassium hydric sulphate put in contact with water separates into potassium sulphate and free sulphuric acid.

We have seen (p. 157) that the plant when vegetating in solutions of salts is able to decompose them. It separates the components of potassium nitrate—appropriating the acid and leaving the base to accumulate in the liquid. It resolves ammonium chloride—taking up ammonia and rejecting the chlorine. The action in these cases we cannot definitely explain, but our analogies leave no doubt as to the general nature of the agencies that co-operate to such results.

Albuminoids require the concourse of a carbo-hydrate and a nitrate for their formation.

The albuminoids in their usual form are colloid bodies, and very slow of diffusion through liquids. They pass a membrane of nitro-cellulose to some extent (Schumacher); but can scarcely penetrate parchment-paper (Graham). In the plant they are found chiefly in the cambium. Since for their production they undoubtedly require the concourse of a carbo-hydrate and a nitrate, they are not improbably generated in the cambium and young wood, for here the carbo-hydrates from the foliage come in contract with the nitrates as they rise from the soil. On the other hand, the albuminoids become more diffusible in some of their combinations. Schumacher asserts that alkali carbonates and phosphates considerably increase the osmose of albumen through membranes of nitro-cellulose (*Physik der Pflanze*, p. 128). It is probable that those combinations or modifications of the albuminoids which occur in the soluble crystalloids of aleurone (p. 93) and hæmato-globuline (p. 83) are highly diffusible. The fact of their having the form of crystals is of itself presumptive evidence of this view, which deserves to be tested by experiment.

Gaseous bodies, especially the carbonic dioxide and oxygen of the atmosphere, which have free access to the inter-cellular cavities of the foliage, and which are for the most part the only contents of the larger ducts, may be distributed throughout the plant by osmose after having been dissolved in the sap or otherwise absorbed by the cell-contents.

Soluble constituents of plant tissues often sharply separated.

Influence of the Membranes.—The sharp separation of unlike juices and soluble matters in the plant indicates the existence of a remarkable variety and range of adhesive attractions. In orange-coloured flowers we see upon microscopic examination that this tint is produced by the united effect of yellow and red pigments which are contained in the cells of the petals. One cell is filled with yellow pigment, and the adjoining one with red, but these two colours are never contained in the same cell. In fruits we have colouring matters of great tinctorial power and freely soluble in water, but they never forsake the cells where they appear, never wander into the contiguous parts of the plant. In the stems and leaves of the dandelion, lettuce, and many other plants, a white, milky, and bitter juice is contained, but it is strictly confined to certain special channels, and never visibly passes beyond them. The loosely disposed cells of the interior of leaves contain grains of chlorophyll, but this substance does not appear in the epidermal cells, those of the stomata excepted. Sachs found that solution of indigo quickly entered the roots of a seedling bean, but required a considerable time to penetrate the stem (p. 229). Hallier, in his experiments on the absorption of coloured liquids by plants, noticed in all cases, when leaves or green stems were immersed in solution of indigo or black-cherry juice, that these dyes readily passed into and coloured the epidermis, the vascular and cambial tissue, and the parenchyma of the leaf-veins, keeping strictly to the cell-walls, but in no instance communicated any colour to the cells containing chlorophyll (*Phytopathologie*, Leipzig, 1868, p. 67). We must infer that the colouring matters either cannot penetrate the cells that are occupied with chlorophyll, or else are chemically transformed into colourless substances on entering them.

Sachs has shown in numerous instances that the juices of the cambial tissue are alkaline, while those of the adjoining cellular tissue are acid when examined by test-paper (*Exp. Phys. der Pflanzen*, p. 394).

When young and active cells are moistened with solution of iodine, this substance penetrates the cellulose without producing visible change; but when it acts upon the protoplasm, the latter separates from the outer cell-wall and collapses towards the centre of the cavity, as if its contents passed out, without a corresponding endosmose being possible (p. 215).

Cell-membranes must be capable of effecting and maintaining separation.

We may conclude from these facts that the membranes of the cells are capable of effecting and maintaining the separation of substances which have considerable attractions for each other, and obviously accomplish this result by themselves exerting superior attractive or repulsive force.

The influence of the membrane must vary in character with those alterations in its chemical and structural constitution which result from growth or any other cause. It is thus, in part, that the assimilation of external food by the plant is directed, sometimes to one class of proximate ingredients, as the carbo-hydrates, sometimes to another, as the albuminoids, although the supplies of food presented are uniform both in total and relative quantity.

The influence of cell-membranes affected by changes in their conditions.

If a slice of red-beet be washed and put into water, the pigment which gives it colour does not readily dissolve and diffuse out of the cells, but the water remains colourless for several days. The pigment is, however, soluble in water, as is seen at once by crushing the beet, whereby the cells are forcibly broken open and their contents displaced. The cell-membranes of the uninjured root are thus apparently able to withstand the solvent power of water upon the pigment and to restrain the latter from diffusive motion. Upon subjecting the slice of beet to cold until it is thoroughly frozen, and then placing it in warm water so that it quickly thaws, the latter is immediately and deeply tinged with red. The sudden thawing of the water within the pores of the cell-membrane has in fact so altered them that they can no longer prevent the diffusive tendency of the pigment (Sachs).

Mechanical effects of osmose on the plant.

The osmose of water from without into the cells of the plant, whether occurring on the root-surface, in the buds, or at any intermediate point where chemical changes are going on, cannot fail to exercise a great mechanical influence on the phenomena of growth. Root-action, for example, being, as we have seen, often sufficient to overcome a considerable hydrostatic pressure, might naturally be expected to accelerate the development of buds and young foliage, especially since, as common observation shows, it operates in perennial plants, as the maple and grape-vine, most energetically at the season when the issue of foliage takes place. Experiment demonstrates this to be the fact.

If a twig be cut from a tree in winter, and be placed in a room having a summer temperature, the buds, before dormant, shortly exhibit signs of growth; and if the cut end be immersed in water, the buds will enlarge quite after the normal manner, as long as the nutrient matters of the twig last, or until the tissues at the cut begin to decay. It is

Increased hydrostatic pressure on the fluids of plants produces increased activity.

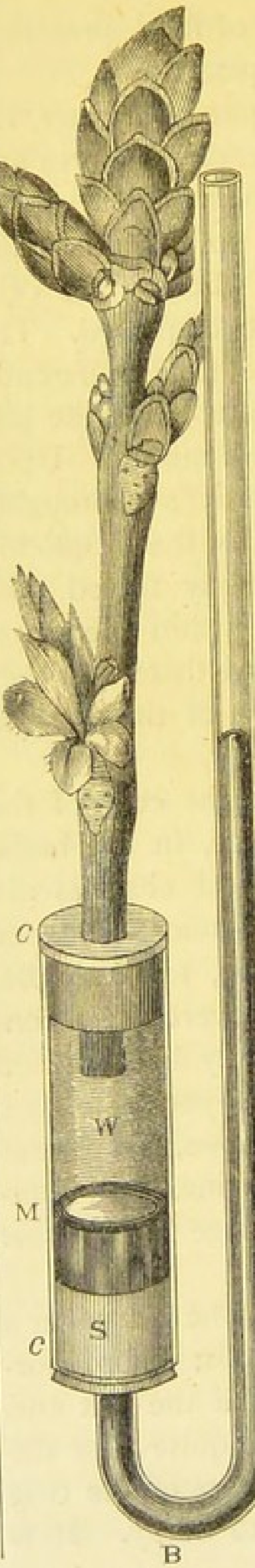

Fig. 64

the summer temperature which excites the chemical changes that result in growth. Water is needful to occupy the expanding and new-forming cells, and to be the vehicle for the transference of nutrient matters from the wood to the buds. Water enters the cut stem by imbibition or capillarity, not merely to replace loss by exhalation, but by osmose acting in the growing cells. Under the same conditions as to temperature, the twigs which are connected with active roots expand earlier and more rapidly than cuttings. Artificial pressure on the water which is presented to the latter acts with an effect similar to that which the natural stress caused by the root-power exerts. This fact was demonstrated by Boehm (*Sitzungsberichte der Wiener Akad.*, 1863) in an experiment which may be made as illustrated by the cut, Fig. 64. A twig with buds is secured by means of a perforated cork, S, into one end of a short wide glass tube, *C C*, which is closed below by another cork through which passes a narrow syphon tube, B. The cut end of the twig is immersed in water, W, which is put under pressure by pouring mercury into the upper extremity of the syphon tube. Horse-chestnut and grape-twigs cut in February and March, and thus treated,—the pressure of mercury being equal to 6 or 8 inches above the level, M,—after 4 to 6 weeks unfolded their buds with normal vigour, while twigs similarly circumstanced but without pressure opened 4 to 8 days later and with less appearance of strength.

Fr. Schulze (*Karsten's Bot. Unters.*, Berlin, ii. 143) found that cuttings of twigs in the leaf, from the horse-chestnut, locust,* willow and rose, subjected to hydrostatic pressure in the same way, remained longer turgescent and advanced much farther in development of leaves and flowers than twigs simply immersed in water.

Amount of water in plant dependent on amount in soil.

The amount of water in the soil influences both the absolute and relative quantity of this ingredient in the plant. It is a common observation that rainy spring weather causes a rank growth of grass and straw, while the yield of hay and grain is not correspondingly increased. The root-action must operate with greater effect, other things being equal, in a nearly saturated soil than in one which is less moist, and the young cells of a plant situated in the former must be subjected to greater internal stress than those of one growing in the latter—must, as a consequence, attain greater dimensions. It is not uncommon to find fleshy roots, especially radishes which have grown in hot-beds, split apart lengthwise; and Hallier mentions the fact of a sound root of Petersilia splitting open after immersion in water for two or three days (*Phytopatholgie*, p. 87). This mechanical effect is indeed commonly conjoined with others resulting from abundant nutrition, but increased bulk of a plant without corresponding increase of dry matter is doubtless in great part the consequence of large supplies of water to the roots and its vigorous osmose into the expanding plant.

Movements of plants produced by wind affect motion of sap.

Effect of Mechanical Strains produced by Wind.—The researches of Knight (*Phil. Trans.* 1803), and more recently of Herbert Spencer, have shown that the movements of plants by the wind must be included

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* Common or False Acacia or North American Locust (*Robinia pseud-Acacia*).

amongst the agencies which assist in maintaining equilibrium in the fluids of plants (see p. 324). Knight made the following experiment. Several young standard apple-trees were, by means of stakes and bandages, prevented from yielding to the impulse of the wind up to about the middle of their stems, the upper parts of the stems and the branches being left in their free natural state. In the course of one summer it was found that much new wood had accumulated in the parts which were kept in motion by the wind, whereas the lower parts of the stem and roots had increased very little in size. One of these trees was afterwards confined in such a manner that it could only move in one direction, viz. north and south. Thus circumstanced, the diameter of the tree from north to south, in that part of the stem which was most exercised by the wind, exceeded that in the opposite direction in the following autumn in the proportion of 13:11 (*Abstract of Phil. Trans.* vol. i. p. 120). The investigations of Herbert Spencer lead also to the result that the exposure of the plant to intermittent mechanical strains, such as are caused by the wind, produce a deposit of resistant substance (wood) at places where it is needed to meet the strains (*Principles of Biology*, vol. ii. p. 544). The oscillations produced by the wind exert transverse strains on the longitudinal ducts, compressing them and driving their contained fluids in the direction of least resistance. A portion will escape through the walls of the tubes, and the quantity so escaping will become greater as the walls become more and more permeable. When the compression, however, is relaxed, the sap lost by exudation will be replaced more readily by a flow of sap along the duct than by its return from the surrounding tissues. There is thus sent up a draught of sap to the place where these intermittent strains are going on, an exudation proportionate to the frequency and intensity of the strains, and a proportionate nutrition or thickening of the wood-cells fitting them to resist the strains (*loc. cit.* p. 545). When a warm

Formation of wood deficient in plants restrained from motion.

Oscillations produce a pumping action in the ducts of stems

Upward or downward movement of sap due to oscillations determined by evaporation from leaves.

sunshine, causing rapid evaporation, is emptying the vessels of the leaves, the osmotic and capillary actions that refill them will be continually aided by the pumping action of the swaying petioles, twigs, and branches. Under these conditions the current of sap will move towards the leaves. During the night, as also at other times when evaporation is not going on, the sap will flow from the leaves, because less force will be required to overcome the inertia of the short columns of liquid between the smaller branches and the leaves than to overcome the inertia of the long columns between them and the roots. It must be borne in mind that the mechanical strains and the pumping process which they keep up, as well as the distention caused by osmose, do not in themselves produce a current either upwards or downwards; they simply help to move the sap towards that place where there is the most rapid abstraction of it—the place to which its motion is least resisted (*loc. cit.* p. 557).

Mechanical strains aid but do not cause sap distribution.

§ 4. Direction of Vegetable Growth.

The roots and stems of plants grow in different directions.

One of the most obvious peculiarities of vegetation is that the roots and stems of plants manifest more or less regular, and often opposite, directions of growth. Roots, in general, grow downwards; stems, in general, upwards, though this is by no means a universal rule, both roots and stems oftentimes manifesting either tendency in different points or at different times of their growth.

Sachs describes the following mode of observing the directive tendency of root and stem.

E, Fig. 65, is a glass flask containing some water; it is closed above by a cork, from which a young seedling is suspended by means of a wire. The flask stands upon a plate of sand, and it is shielded from the light by a pasteboard cover, *R*, the lower edge of which is forced down into the sand. The water in the flask keeps the enclosed air in a moist state. In the experiment, a sprouted nasturtium seed (*Tropæolum majus*) having straight descending roots, *b*, was placed at night in the apparatus with the roots pointing upwards and the plumule, *a*, downwards. The next morning the seedling had the appearance of the figure. During the night the tips of the roots curved over, and the plumule sensibly raised itself. By continuing a similar experiment for a week or more, the rootlets will grow down into the water and the stem will reach the cork. As often as the position of the seedling is reversed, so often the root and stem will reverse the direction of their growth. This experiment being carried on in total darkness, save during the short intervals necessary for observation, the directive tendency is shown to be independent of the action of light.

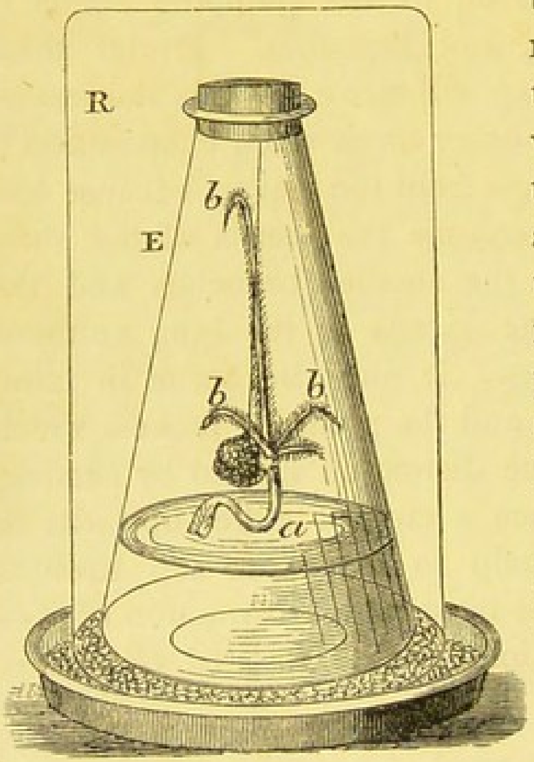

Fig. 65.

Causes of directive power partly external, partly internal.

Causes of Directive Power.—The direction of growth in plants is the resultant effect of unequally acting influences. These are the action of *gravitation*, as in parts which extend directly downwards, or of *internal tension* overcoming gravitation, as in parts which grow vertically upwards.

Influence of gravitation on yielding tissues.

Gravitation.—A root made to grow on a horizontal plate of glass is pushed along by the expansion of its young cells and the formation of new ones until it reaches the edge, when the tip inclines downward, as a wet string would do. If, however, as often happens, the yielding tissue of new cells is partially or entirely enveloped by the more rigid root-cap, the downward tendency may be overcome to a corresponding degree. In this case the tip keeps more or less closely the direction already given to the root, resembling in its growth a half-melted substance protruded from a tube and stiffening as it issues. The passive section of the root is pushed forward as the root itself extends; the cells that at first yield to the gravitating force, afterwards become so rigid and firmly grown to each other as to resist the tendency of this force to coerce them to a vertical position, while new cells are developed beyond, which yield to the gravitating tendency. While, however, gravitation will thus influence the direction of the growth of roots in air or water, it can have but little effect on roots growing in soil. The end of the root, being the only growing part, is the only part which can be bent from its course by gravitation, and the resistance of the soil to a lateral deviation must necessarily be greater than the resistance to direct onward progress.

Internal Tension.—In the upward-growing stem the different parallel and concentric tissues, viz. the cuticle, the cell-tissue of the rind, the wood-cells and ducts, and the pith, exist in a state of unequal tension.

Unequal tension in the different tissues of the stem.

This is shown by well-known facts. If a hollow, succulent stem, like that supporting a dandelion blossom, be cut lengthwise, the parts curve away from each other, thus,) (, and may by a little assistance be rolled together in flat coils. The same separation of the halves may be observed in any succulent stem, provided it be fresh and turgid. It is plain then that the pith-cells of the growing stem are compressed by the cuticle; in other words, the pith-cells are in a state of tension, while the cuticular cells are passively stretched by this interior strain. Closer investigation indicates that the matter is somewhat complicated.

If we strip off the "skin" from a stalk of garden rhubarb, we shall notice that it curves to a coil or spiral.

This skin consists of the true cuticle with a coating of cellular tissue adhering. The tension of the latter and the passivity of the former occasion the curvature. Further dissection demonstrates that in general the cuticle, the wood-cells, and the vascular bundles are passive; while the cellular tissues of the rind and pith, and the corresponding cellular tissues of the leaves, are tense.

It follows from these considerations that the length of a fresh-growing stem must be different from the length of its parts when separate from each other. If we divide a succulent stem lengthwise, into the pith, the wood and the rind, or the corresponding parts, and accurately measure them, we shall find in fact that they differ as to length from each other, and from the stem as a whole. The pith, when the wood is cut away, elongates, the wood shortens, the rind shortens still more. In the original stem the cellular tissue, being united to the vascular, stretches the latter and is at the same time restrained by it. On their being cut apart, the one is free to extend, and the other to shorten. Sachs gives the following comparative measurements of the stem of a tobacco plant and of its parts after separation—the length of the stem being assumed as 100:

Entire stem	100
Rind	94·1
Wood	98·5
Pith	102·9

Unequal tension the result of unequal nutrition.

Causes of Tension.—This tense condition of the considerably developed stem depends partly upon the unequal nutrition of the different tissues. Those parts, in fact, exert tension in which rapid growth—cell multiplication—is taking place. In the simple cell similar tension may exist, caused by the tendency of the formative layer to expand beyond the limits of the cell-wall. Another cause of tension is the different imbibing and osmotic power of the tissues for sap. When a fresh stem or leaf loses a small percentage of water, it becomes flabby, and, except so far as supported by indurated woody tissue, has no self-sustaining power, and droops from an upright direction. On dissecting the flabby stem lengthwise, the halves no longer curve apart, and the tension noticed in the fresh stem does not exist. The water being restored through the root, the normal turgidity and original position are both recovered. This state of internal tension being the result of growth is necessarily dependent on the same conditions. Hence the direction taken by any growing part of the plant is influenced by the amount to which these conditions, such as food, light, and heat, are supplied to it.

Upward Growth.—If a stem whose terminal parts are in a state of highly unequal tension be brought into a horizontal position, it will be found, that, as it makes new growth, the tip curves upward until it becomes vertical. This is due to the fact that while the whole growing part elongates, the under side extends most rapidly.

The upward growth of stems distributes the pressure of the juices equally round the axis.

The question now arises, why do the passive parts of the under side of the stem that is out of the vertical admit of greater expansion by the stress of the rapidly-growing tissues, than those of the upper? The only cause hitherto assigned is the action of gravitation on the juices of the tissues. In a stem inclined from the vertical, the cells of the lower side experience not only the general pressure of the water which renders the whole turgid, but, in addition, they sustain a portion of the weight of the liquid in the cells above them. In other words they are not only subject to the increased hydrostatic pressure originating in the roots, but also to additional pressure from the overlying cells. As the stem becomes more and more vertical this becomes less and less, and is wholly evanescent when the stem is absolutely upright.

Unequal influence of light on the plant produces unequal growth.

Effect of Light.—Solar light, by powerfully influencing the changes which produce growth in the parts of a plant exposed to it, complicates and modifies the direction of growth which would be assumed if the light were equally diffused. Plants so influenced are commonly said to be "drawn." When trees have been planted together too closely the straightness of their tall bare stems is due to the whole energy of the plant being directed to the part most exposed to solar influences. The bareness of the stems is produced by the premature death of the lower branches growing in shade. Herbert Spencer attributes the unsymmetrical shape of the leaves of the lime and other trees to unequal exposure to light. The following passage explains how this arises: "On examining their attitudes and their relations to one another, it will be found that each leaf is so inclined that the half of it next the shoot grows over the shoot and gets plenty of light, while the other half so hangs down that it comes a good deal into the shade of the preceding leaf. The result is, that having leaves which fall into these positions, the species profits by a large development of the exposed halves; and by survival of the fittest, acting along with the direct effect of extra exposure, this modification becomes established."—*Principles of Biology*, vol. ii. p. 143.

Development of roots modified by distribution of food and moisture in soil.

The Development of Roots is also modified, as shown in an earlier part of this work, by the distribution of food and moisture in the soil. This exerts a kind of selection, those roots being most largely developed in the direction where they find most nourishment. By taking advantage of this principle Colonel Greenwood succeeded in leading the root of a horse-chestnut up one side, over the top, and down the other side of a wall of considerable height (see p. 232).

Irritable movements of plants on application of stimulus.

Sensitive Plants.—Many plants exhibit irregular and irritable movements on the application of a stimulus. The leaves of different species of Mimosa and the stamens in Barberries are good samples. These effects are produced by the elasticity which alterations in the turgescence of the cells give rise to. Why, however, such alterations should be produced by the application of a stimulus cannot be satisfactorily accounted for. The resilience of the stamens in Kalmia is owing to their mechanical retraction by the expanding flower.

Sleep of Plants.—Ordinarily leaves expand in the daylight and close towards evening. The habit of flowers is, however, much more various, so that Linnæus drew up a list which he called a floral clock. The stimulus of light seems to have a different effect on plants of different constitutional habit. The weeds called Poor-man's-weather-glass (*Anagallis*) and Go-to-bed-at-noon (*Tragopogon*) show that this peculiarity has not escaped popular observation.

Climbing habit of plants assumed to obtain necessary exposure to light.

Climbing Plants.—The motions of climbing plants have been recently elaborately investigated by Darwin. The object attained by climbing is doubtless the exposure of a large surface of leaves to the action of light and air. Climbing may be effected by modifications of almost every organ.

The majority of stem climbers ascend their supports from left to right. Darwin found that the tip of a young unsupported climbing stem revolved steadily from right to left in about two hours. The motion was slightly accelerated on the side exposed to most light. The revolving motion is produced by the passage of a wave of contraction or turgescence round the stem in the same direction. When the revolving stem meets a support, the motion is arrested in the successive portions which the revolutions bring in contact with it, and the stem remains wound spirally upon it.

There is some limit to the diameter of the support upon which a plant will climb. If the curve of the support is small and that of the plant considerable, it is unable to get sufficient hold. Darwin shows, therefore, that climbing is the mechanical result of the independent revolutions of the growing internodes, and is not, as thought by Mohl, caused by a general dull irritability of the whole stem.

Tendril bearers also exhibit in many cases revolutions of the growing shoots, but climb principally by tendrils, which are "filamentary organs sensitive to contact and used exclusively for climbing."

Tendrils revolve, and immediately curl round any suitable object with which they find themselves in contact. About a day after they have begun to take hold they begin to contract spirally. This has the effect of pulling upwards the attached shoot. In many cases no such spiral contraction takes place unless the tendrils have become attached. Darwin found that slight continued pressure induced the first contraction, but that blows from rain-drops or other tendrils produced no effect (*Journal of Linnæan Society*, vol. ix.).

CHAPTER III.

REPRODUCTION.

§ 1. Flowering.

Chap. III.

Flowering an exhaustive process.

Every addition to the organs of nutrition, besides adding to the bulk of a plant, increases its powers of obtaining food. Apart from accidents, therefore, there would seem to be no limit to the growth and increase of plants but the failure of an adequate supply of nutriment. The reproductive organs, however, on the other hand, stop any further growth in the part of the axis which they terminate; and making large demands on the resources and accumulated nourishment of a plant, supply little or nothing in return. Reproduction is, therefore, an essentially exhaustive process, and does not commence till the plant is provided with a store of accumulated food sufficient to sustain it. It is these stores of food which we especially appropriate in utilizing vegetable produce. In the turnip, for example, the first year of growth is occupied chiefly in accumulating nutritious matter in the enlarged root. The aërial part of the plant is simply a tuft of leaves attached to an axis, with undeveloped internodes. In the following year the growth is all diverted from the root to the ascending axis, which grows rapidly, drawing its supplies from the root, which wastes, becomes hollow, and contains finally little except insoluble fibre. So complete is usually, in the case of biennials, the drain of nutritive matter in the flowering and subsequent maturation of the seed, the plant has neither strength nor material remaining to enable it to put out fresh organs of nutrition, and it consequently dies.

The period of flowering depends on the habit of the plant, and on external conditions.

The Period of Flowering varies greatly in different plants. It depends partly on constitutional habit; and this may depend on external conditions. The perennial plants of warm countries may become annuals in colder ones, as is the case with the Castor-oil plant and the Marvel of Peru with us. It may also depend on the amount of accumulation of food which flowering requires in each case. An annual blooms a few weeks after its germination, and the nourishment it possesses being completely exhausted, it is destroyed by the process. Yet its existence may be sometimes prolonged over more than one season, if the flower-buds be regularly removed, as in the Tree Mignonette of gardeners.

The flowers of woody plants which bear large and fleshy fruits are not produced from terminal, but from lateral buds, which rest upon the "seasoned" wood of the previous year, in which nutritive matter is accumulated.

Fruit trees also exhibit the effects of exhaustion when, after an extensive crop, especially of the late kinds of fruit, the trees fail more or less the succeeding year, though they will bear more abundantly in the year following their rest. The period of accumulation in some plants is very long, and the subsequent exhaustion correspondingly fatal.

The American Aloe, which flowers in its native climate when only five or six years old, only does so with us after the lapse of a period longer in proportion to the retarding influence, and sometimes as much as from fifty to seventy years. The Talipot Palm, which lives to a great age, and bears leaves thirty feet in diameter, flowers only once, and then perishes.

Growth of inflorescence rapid.

The Rate of Growth of the Inflorescence is usually much more rapid than that of other organs. The flower-stem of the American Aloe, even in our conservatories, grows at the rate of a foot a day, and the plant's store of food is proportionately rapidly used up.

Nutriment accumulated to sustain process of flowering.

The Accumulation of Nutriment usually takes place in some part of the axis. In the turnip, beet, radish, carrot, and many other cultivated plants, it is contained in the enlarged root, and the tendency to enlarge seems to be one which may be pretty readily induced, and afterwards increased by cultivation. In other cases the stem becomes loaded with amylaceous or saccharine matter, as with the Sago Palm and Sugar Cane; or the succulence of the whole plant may become sufficient to supply the inflorescence, as with the American Aloe, the sweet juice of which is made by the Mexicans into an intoxicating drink.

The store, wherever situated, will obviously attain its maximum just before or at the time of the first appearance of the flower-buds. It rapidly diminishes as they open. The stalks of the Sugar Cane are cut just before the flowers expand, and the Sago Palm is fit for cutting down at the first appearance of the flower spike.

Chemical changes during flowering and germination similar.

The Chemical Changes which accompany flowering are apparently similar to those which accompany germination. The circumstances of the two processes are indeed in many points identical. In both there is rapid vegetable growth, drawing its supplies from previously accumulated stores. These usually at first contain some form of starch, which in each case first passes into the soluble form, and afterwards into dextrine and sugar. The latter stages, which take place probably more immediately in the neighbourhood of the flower, are accompanied by the absorption of oxygen, the formation of carbonic dioxide, and the evolution of heat.

In ordinary plant growth, the food of the plant is highly oxidized, and its assimilation is consequently attended with the evolution of oxygen. In germination and flowering the food supply of the developing parts contains comparatively little oxygen, and its assimilation is at any rate

Oxidation takes place in development of flowers,

accompanied by the separation of part of its carbon as carbonic dioxide, while oxygen is absorbed. An experiment devised by Persoz illustrates the oxidation which exists during flowering. If the roots of a translucent plant, like Balsam, are watered with a solution of logwood, the colouring matter is reduced when absorbed into the roots, and loses its colour. When, however, it reaches the petals it is again oxidized, and its colour again appears.

The fragrant odour of the Meadow-sweet, which is attributed to the presence of salicyl hydride, is stated by Büchner to be furnished by the oxidation during the expansion of the flower-buds of the salicine which they at first contain. This conversion is artificially imitated when salicine is oxidized by means of potassium dichromate, and salicyl hydride is formed.

with evolution of heat.

The Evolution of Heat in blossoming was first observed by Lamarck in 1777, in the spadix of *Arum Italicum*, where an immense number of blossoms are crowded together. It was afterwards shown by Saussure that the heat evolved was in direct proportion to the oxygen absorbed. According to Vrolik and De Vriese, the temperature has a regular periodicity, and attains its maximum in the afternoon, between two and five.

Luminosity of flowers doubtful.

The asserted luminosity of flowers seems to be very questionable. The flowers which are stated to have exhibited it are all yellow or red, and the supposed effect may have been, and probably was, a mere optical deception.

§ 2. Maturation of Fruit.

Fruit while green behaves in the same way as the leaves.

During the growth of the fruit, while it is still green, it decomposes carbonic dioxide, and emits oxygen like the leaves. When the fruit begins to ripen certain textural changes become evident; carbonic dioxide and water are given out with a sensible rise of temperature, while oxygen is absorbed. The fruits first become sour from the pro-

Ripening accompanied by slow oxidations,

duction of acids. Subsequently a succession of slow oxidations appear to take place, tannin first, and afterwards the vegetable acids disappear, while the sugar becomes notably increased. The sugar does not seem to be derived from starch, which, according to Buignet, cannot be detected in green fruit except in Bananas, but from an astringent substance which forms a colourless combination with iodine.

A change similar to ripening takes place when green fruits are cooked, the reaction of the different proximate principles upon one another resulting in the formation of sugar. Cider apples have a rough and austere taste. This disappears, and they become sweet, after crushing and exposure to the air.

finally extending to the sugar.

When succulent fruits are ripe, the sugar in turn experiences oxidation. The first change has been called by Lindley, "bletting," intermediate between maturity and decay. It is especially marked in fruits of the Apple family. According to Berard, it is accompanied by loss of water.

The Period required for Ripening varies from a few days in the case of grasses to twelve months or more in the case of the Coniferæ.

§ 3. SEASON OF REST.

Plants require a season of rest.

The normal growth of all plants seems to require a season of rest. In temperate countries, this is brought about by the lowering of temperature in autumn; in hot countries, by the annual periods of heat and dryness. In the Canaries, from November to March is the growing season; it is also the coolest, the mean temperature being 19° C. (Asa Gray's *Text-Book*, p. 208.) This period of rest is necessary for the proper maturation of the plant tissues, to enable them to produce flower-buds. When the fruit-trees of northern climates are transported to more tropical ones, their continuous growth prevents their blossoming. The same thing will be caused by too rich a soil, or too mild and moist a winter atmosphere.

Forcing is an alteration of the seasons of rest and activity.

Forcing is a horticultural process by which the period of repose is altered. The cultivator can command heat and moisture, and so can compel a plant to grow at a season when vegetation is naturally in repose. In the growing season he can to a certain extent induce repose by dryness.

CHAPTER IV.

Death of the Plant.

The life of the majority of flowering plants is not really comparable to that of at least the higher animals. Hence they cannot be said to die in exactly the same sense that animals die.

Plants consist of repetitions of similar portions capable under certain conditions of independent existence.

A tree consists of a number of portions, each of which is supplied with all the necessary elements of an individual plant, except roots. While preserving its connexion with the parent plant roots are not required, though they can be developed when necessary, as in layering, when the plant's nourishment is partly curtailed by cutting the shoot half through.

The simplest form of flowering plant is the equivalent of a single part of the more compound plants, and consists of a simple axis which increases in length by the gradual unfolding of a terminal bud. When this terminal bud produces blossoms instead of leaves, the further growth of the axis is arrested, and the plant dies, unless new buds are developed from the axils of the leaves below. If these buds become detached, they reproduce the arrangement of the original plant; if they remain attached to the axis, a compound plant is produced. The buds of such a plant really correspond more truly than their aggregate does to the individual animal organism. Their interdependence is small, and their relation is one of growth, morphological, and not physiological, like that of the different organs of an individual animal. They possess frequently great indi-

Buds may sport from parental ype.

viduality of character, as when a particular bud of a plant sports away from the parental type conformed to by the rest. Instances of this bud variation are common. A good example is the production of nectarines occasionally by peach-trees (Darwin, *Animals and Plants under Domestication*, i. p. 341).

Buds capable of independent xistence.

They are capable of independent existence, which is not the case with a separate organ. A bud of one plant can be established on the nourishing tissues of another, and a shoot may, by putting out roots after detachment from the parent plant, perfectly reproduce its like. The connecting cellular tissues between the buds of plants play the part of roots. The growing parts may, however, also gain part of their food independently, as they do by the development of aërial roots in the Banyan. In the Screw-pine (*Pandanus*) the base of the stem and the old roots ultimately decay, and the plant is entirely maintained by the new roots, which continually sprout out higher and higher from the living structures of the stem.

A compound plant like a tree may be regarded, therefore, as made up of individual parts, capable under particular conditions of independent existence, but whose individuality is ordinarily to a great extent merged in the aggregate individuality of the whole plant. The organs of vegetables are transitory; hence life implies in vegetables continued growth.

Flowering sometimes terminates existence of plants.

In annuals, biennials, and plants like the American Aloe, and Talipot, the inflorescence eventually arrests the growth of the primary axis; and exhaustion prevents the development of buds producing secondary axes. Flowering in these cases terminates the existence of the plant. In perennials and trees, the axis is the only permanent structure; and while the production of leaf-buds cannot be continued without the axis supplying the necessary nutriment, the axis cannot obtain the nutriment without the due development of leaves. Hence the death of a tree may be caused either by the destruction of the axis, or by some cause checking

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the production of leaves. The process of death in trees is, however, usually slow ; even if they are violently uprooted by a storm, a portion of the trunk will often contain sufficient sap to start the dormant buds the year following ; but having no connexion with the ground, these buds are short-lived. It is, however, evident that, apart from accidental causes, the growth of a tree may be unlimited, and the number of known instances in which a great age has been attained is considerable.

Growth of perennial plants theoretically unlimited.

APPENDIX.

APPENDIX.

TABLE I.

COMPOSITION OF THE ASH OF AGRICULTURAL PLANTS AND PRODUCTS,

giving the Average of all trustworthy Analyses published up to August 1865, by Professor EMIL WOLFF, of the Royal Academy of Agriculture, at Hohenheim, Wirtemberg.*

No.	Substance.	No. of Analyses.	Per cent. of Ash.	Potash.	Soda.	Magnesia.	Lime.	Phosphoric Pentoxide.	Sulphuric Trioxide.	Silica.	Chlorine.
	I. MEADOW HAY AND GRASSES.										
1	Meadow hay	13	7·78	25·6	7·0	4·9	11·6	6·2	5·1	29·6	8·0
2	Young grass	1	9·32	56·2	1·8	2·8	10·7	10·5	4·0	10·3	2·0
3	Dead-ripe hay	1	7·73	7·6	2·9	3·4	12·9	4·4	0·7	63·1	5·7
4	Ripe grass in flower	4	7·10	24·9	4·2	2·1	7·5	7·8	3·8	39·6	5·4
5	Timothy	3	7·01	28·8	2·7	3·7	9·4	10·8	3·9	35·6	5·0
6	Other grasses	39	7·27	33·0	1·8	2·6	5·5	7·8	4·4	37·6	4·1
7	Oats, heading out	6	9·46	41·7	4·4	3·5	7·0	8·3	3·4	27·9	4·4
8	,, in flower	7	7·23	39·0	3·3	3·2	6·7	8·3	2·7	33·2	4·0
9	Barley, heading out	5	8·93	38·5	1·7	2·9	7·0	10·1	2·9	31·2	5·6
10	,, in flower	5	7·04	26·2	0·6	3·1	6·0	9·8	2·9	48·0	3·5
11	Winter wheat, heading out	2	9·73	34·7	1·9	1·5	4·9	7·4	2·8	41·9	5·3
12	,, ,, in flower	3	6·99	25·7	0·5	2·2	3·1	7·3	1·9	56·8	2·8
13	Winter rye, heading out	1	5·42	38·6	0·3	3·1	7·4	14·7	1·6	32·0	...
14	Green cereals, light	5	7·20	29·6	1·5	3·9	6·6	9·1	4·1	41·4	4·3
15	,, ,, heavy	5	9·21	35·6	3·4	4·7	8·3	8·1	4·8	30·0	5·6
16	German millet, green (*Panicum germ.*)	2	7·23	37·4	...	8·0	10·8	5·4	3·6	29·1	6·4
	II. CLOVER AND FODDER PLANTS.										
17	Red clover	56	6·72	34·5	1·6	12·2	34·0	9·9	3·0	2·7	3·7
	a. 15 to 25 per cent. potash	15	6·01	20·8	1·9	18·2	39·7	9·4	3·8	1·2	5·4
	b. 25 to 35 ,, ,,	23	6·74	29·8	1·6	11·8	35·6	10·6	3·0	2·7	2·9
	c. 35 to 50 ,, ,,	18	7·19	46·3	1·4	7·8	27·3	9·2	2·2	2·5	3·2
18	White clover	2	7·16	17·5	7·8	10·0	32·2	14·1	8·8	4·5	3·2
19	Lucerne	7	7·14	25·3	1·1	5·8	48·0	8·5	6·1	2·0	1·9
20	Sainfoin	2	5·39	39·4	1·7	5·8	32·2	10·4	3·3	4·0	3·0
21	Alsike clover	2	5·53	33·8	1·5	15·3	31·9	10·1	4·0	1·2	2·8
22	Kidney vetch	1	5·60	10·3	4·5	4·6	68·9	7·0	1·6	2·9	0·2
23	Green vetches	2	8·74	42·1	2·9	6·8	26·3	12·8	3·7	1·8	3·1
24	Green pea, in flower	1	7·40	40·8	0·2	8·2	28·7	13·2	3·5	2·6	1·8
25	Green rape, young	5	8·97	32·3	3·8	4·5	23·1	8·7	16·3	3·2	7·6

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* From Professor Wolff's *Mittlere Zusammensetzung der Asche aller land- und forstwirthschaftlich wichtigen Stoffe*, Stuttgardt, 1865. The above table being more complete and in most particulars more exact than the author's means of reference enable him to construct, and being moreover likely to be the basis of calculations by agricultural chemists for some years to come, has been reproduced here literally. The references and important explanations accompanying the original, want of space precludes quoting. In the table, ferric oxide, an ingredient normally present to the extent of less than one per cent., is omitted. Chlorine is often omitted, not because absent from the plant, but from uncertainty as to its amount. Carbonic dioxide is also excluded in all cases, for the sake of uniformity and facility of comparison.

COMPOSITION OF THE ASH OF AGRICULTURAL PLANTS AND PRODUCTS.

No.	Substance.	No. of Analyses.	Per cent. of Ash.	Potash.	Soda.	Magnesia.	Lime.	Phosphoric Pentoxide.	Sulphuric Trioxide.	Silica.	Chlorine.
	III. ROOT CROPS.										
26	Potatoes	31	3·74	59·8	1·6	4·5	2·3	19·1	6·6	2·3	2·8
27	Artichokes	1	5·16	65·4	...	2·7	3·5	16·0	3·2	...	2·4
28	Mangolds	15	6·86	53·1	14·8	5·1	4·6	9·6	3·3	3·3	6·6
29	Sugar-beets	44	4·35	49·4	9·6	8·9	6·3	14·3	4·7	3·5	2·0
30	Turnips	15	8·28	39·3	11·4	3·9	10·4	13·3	14·3	2·4	4·1
31	Turnips, white	2	7·20	50·6	3·8	2·1	13·4	17·4	6·0	1·1	6·4
32	Swedes	2	7·68	51·2	6·7	2·6	9·7	15·3	8·4	0·5	5·1
33	Carrots	10	6·27	36·7	22·1	5·3	10·7	12·5	6·4	2·0	3·2
34	Chicory	7	5·21	40·4	7·7	6·3	8·7	14·5	9·2	6·1	3·7
35	Sugar-beet heads*	1	4·03	29·6	24·4	11·0	9·1	12·8	7·6	2·0	0·5
	IV. LEAVES AND STEMS OF ROOT CROPS.										
36	Potatoes, August	3	8·92	14·5	2·7	16·8	39·0	6·1	5·6	8·0	4·6
37	,, October	1	5·12	6·3	0·8	22·6	46·2	5·5	5·5	4·2	3·0
38	Mangolds	6	15·96	29·1	21·0	9·7	11·4	5·1	7·4	4·8	11·3
39	Sugar-beets	7	17·49	22·1	16·8	18·3	19·7	7·4	8·0	3·1	5·7
40	Turnips	16	13·68	22·9	7·8	4·5	32·4	8·9	9·9	3·8	8·2
41	Kohl-rabi	1	16·87	14·4	3·9	4·0	33·3	10·4	11·7	10·5	3·9
42	Carrots	7	13·57	14·1	23·1	4·6	33·0	4·7	7·9	5·6	7·1
43	Chicory	1	12·46	60·0	0·7	3·2	14·3	9·0	9·0	1·0	1·7
44	Cabbage	2	10·81	48·6	3·9	3·3	15·3	15·8	8·5	1·2	2·5
45	Cabbage-stalks	1	6·46	43·9	5·5	4·1	11·3	20·9	11·8	1·1	1·2
	V. REFUSE AND MANUFACTURED PRODUCTS.										
46	Sugar-beet cake	7	3·15	36·6	8·4	5·6	25·3	10·2	3·9	6·2	4·8
	a. Common cake	2	3·03	25·0	12·7	...	27·2	12·9	5·8	...	13·0
	b. Residue of maceration	2	3·53	35·3	9·4	11·8	27·9	6·0	2·3	...	0·9
	c. Residue from centrifugal machine	1	3·11	45·5	9·8	...	25·3	13·0	6·5	...	10·1
47	Beet molasses	3	11·28	71·1	10·5	0·4	6·0	0·5	2·1	0·7	...
48	Molasses residue †	1	19·02	89·8		0·9		0·1	1·7	...	1·6
49	Raw beet-sugar	1	1·43	33·3	28·0	...	8·5	...	22·9	0·9	5·8
50	Potato refuse: spirit manuf. †	1	11·10	46·3	6·6	8·8	6·2	20·0	7·3	3·4	2·1
51	Potato fibre: starch manuf. ‡	4	0·99	15·6	...	7·6	47·8	23·9	...	3·1	1·3
52	Potato juice §	2	23·45	69·5	...	3·5	1·0	16·8	3·6	0·1	7·5
53	Potato skins ‖	3	9·59	72·0	0·7	6·7	9·6	3·4	0·4	2·7	2·1
54	Fine wheat flour	1	0·47	36·0	0·9	8·2	2·8	52·0	...	...	...
55	Rye flour	1	1·97	38·4	1·8	8·0	1·0	48·3	...	...	...
56	Barley flour	1	2·33	28·8	2·5	13·5	2·8	47·3	3·1	...	...
57	Barley dust	1	5·62	18·9	1·4	7·7	2·5	28·9	...	20·0	...
58	Maize meal	1	...	28·8	3·5	14·9	6·3	45·0	...	...	...
59	Millet meal	1	1·35	19·7	2·3	25·8	...	47·3	2·7	...	...
60	Buckwheat grits	2	0·72	25·4	5·9	12·9	2·3	48·1	1·7	...	1·6
61	Wheat bran	1	6·43	24·0	0·6	16·8	4·7	51·8	...	1·1	...
62	Rye bran	1	8·22	27·0	1·3	15·8	3·5	47·9	...	...	...
63	Brewers' grains	2	5·17	4·2	0·8	10·1	11·6	38·0	0·8	32·2	...
64	Malt	1	2·78	17·3	...	8·4	3·8	36·5	...	33·2	...
65	Malt dust	1	6·56	34·9	...	1·4	1·5	21·0	6·3	29·5	...
66	Wine lees	1	4·60	53·4	0·5	3·2	15·5	15·5	7·8	...	0·5
67	Grape marc	2	4·04	49·4	2·2	6·1	13·0	20·8	4·4	3·5	0·6
68	Beer	1	...	37·5	7·8	4·9	2·2	32·7	...	10·2	...
69	Grape must	6	...	62·8	0·9	5·6	4·2	17·7	6·5	1·3	0·6
70	Rape cake	2	6·59	24·3	0·1	11·5	10·9	36·9	3·3	8·7	0·2

* Probably the crowns of the roots, removed in sugar-making. † The residue after fermenting and distilling off the spirit. ‡ Refuse of starch manufacture. § Undiluted. ‖ From boiled potatoes.

Composition of the Ash of Agricultural Plants and Products.

No.	Substance.	No. of Analyses.	Per cent. of Ash.	Potash.	Soda.	Magnesia.	Lime.	Phosphoric Pentoxide.	Sulphuric Trioxide.	Silica.	Chlorine.
	V. Refuse and Manufactured Products (*continued*).										
71	Linseed cake	1	6·24	23·3	1·4	15·9	8·6	35·2	3·4	6·5	0·6
72	Poppy cake	1	10·60	20·8	4·5	4·3	28·1	37·8	2·0	4·8	...
73	Walnut cake	1	5·36	33·1	...	12·2	6·7	43·8	1·2	1·6	0·2
74	Cotton seed cake	1	6·95	35·4	...	4·3	4·6	48·3	1·1	4·0	...
	VI. STRAW.										
75	Winter wheat	12	4·96	11·5	2·9	2·6	6·2	5·4	2·9	66·3	...
76	Winter rye	6	4·81	18·7	3·3	3·1	7·7	4·7	1·9	58·1	...
77	Winter spelt	2	5·56	11·2	0·4	0·9	4·8	8·3	1·8	71·4	...
78	Summer rye	3	5·55	23·4	...	2·8	8·9	6·5	2·6	55·9	...
79	Barley	17	5·10	21·6	4·5	2·4	7·6	4·3	3·7	53·8	...
80	Oats	6	5·12	22·0	5·3	4·0	8·2	4·2	3·5	48·7	...
81	Maize	1	5·49	35·3	1·2	5·5	10·5	8·1	5·2	38·0	...
82	Peas	21	5·74	21·8	5·3	7·7	37·9	7·8	5·6	5·7	6·1
83	Field beans	4	7·12	44·4	3·8	7·8	23·1	7·0	0·2	5·4	13·8
84	Garden beans	5	6·06	37·1	6·0	5·2	27·4	7·8	3·6	4·7	5·2
85	Buckwheat	6	6·15	46·6	2·2	3·6	18·4	11·9	5·3	5·5	7·7
86	Rape	12	4·58	25·6	10·3	5·7	26·5	7·0	7·1	6·7	12·4
87	Poppy	1	7·86	38·0	1·3	6·5	30·2	3·5	5·1	11·4	2·5
	VII. CHAFF, &c.										
88	Wheat	1	10·73	9·1	1·8	1·3	1·9	4·3	...	81·2	...
89	Spelt	2	9·50	9·5	0·3	2·5	2·4	7·3	2·3	74·2	...
90	Barley	1	14·23	7·7	0·9	1·3	10·4	2·0	3·0	70·8	...
91	Oats	1	9·22	13·1	4·8	2·6	8·9	0·3	2·5	59·9	...
92	Maize cobs	1	0·56	47·1	1·2	4·1	3·4	4·4	1·9	26·4	...
93	Linseed hulls	1	6·62	31·1	4·3	2·8	29·6	2·8	4·8	17·2	6·1
	VIII. TEXTILE PLANTS, &c.										
94	Flax straw	8	3·71	36·9	5·1	7·1	22·3	11·5	5·3	6·0	4·0
95	Rotted flax stems	2	2·40	9·0	4·8	5·4	51·4	5·9	3·1	13·8	...
96	Flax fibre	3	0·67	3·3	3·2	5·4	63·6	10·8	2·7	6·2	0·4
97	Flax: whole plant	2	4·30	34·2	4·8	9·0	15·5	23·0	4·9	2·6	5·9
98	Hemp: whole plant	2	4·60	18·3	3·2	9·6	43·4	11·6	2·8	7·6	2·5
99	Hop: whole plant	1	9·87	26·2	3·8	5·8	16·0	12·1	5·4	21·5	4·6
100	Hops	12	6·80	37·3	2·2	5·5	16·9	15·1	2·6	15·4	3·4
101	Tobacco	7	24·08	27·4	3·7	16·5	37·0	3·6	3·9	9·6	4·5
	IX. LITTER.										
102	Heath	8	4·51	13·2	5·3	8·4	18·8	5·1	4·4	35·2	2·1
103	Broom	2	2·25	36·5	2·5	12·4	17·1	8·6	3·5	10·3	2·7
104	Fern	5	7·01	42·8	4·5	7·7	14·0	9·7	5·1	6·1	10·2
105	Dutch rush	2	23·77	13·2	0·5	2·3	12·5	2·0	6·3	53·8	5·7
106	Sea-weed	8	14·39	14·5	24·0	9·5	13·9	3·1	24·0	1·7	10·1
107	Beech leaves in autumn	6	6·75	5·2	0·6	6·0	44·9	4·2	3·7	33·9	0·4
108	Oak ,, ,,	1	4·90	3·5	0·6	4·0	48·6	8·1	4·4	30·9	...
109	Scotch fir leaves	1	1·40	10·1	...	9·9	41·4	16·4	4·4	13·1	4·4
110	Spruce leaves	1	5·82	1·5	...	2·3	15·2	8·2	2·8	70·1	...
111	Reed	1	4·69	8·6	0·2	1·2	5·9	2·0	2·8	71·5	...
112	Marram	1	...	29·8	4·0	3·8	16·5	7·2	3·6	18·5	...
113	Sedge	11	8·08	33·2	7·3	4·2	5·3	6·7	3·3	31·5	5·6
114	Rush	7	5·30	36·6	6·6	6·4	9·5	6·4	8·7	10·9	14·2
115	Bulrush	2	8·65	9·7	10·3	3·0	7·2	6·5	5·6	43·3	...

COMPOSITION OF THE ASH OF AGRICULTURAL PLANTS AND PRODUCTS.

No.	Substance.	No. of Analyses.	Per cent. of Ash.	Potash.	Soda.	Magnesia.	Lime.	Phosphoric Pentoxide.	Sulphuric Trioxide.	Silica.	Chlorine.
	X. GRAINS AND SEEDS OF AGRICULTURAL PLANTS.										
116	Wheat	78	2·07	31·1	3·5	12·2	3·1	46·2	2·4	1·7	...
117	Rye	14	2·03	30·9	1·8	10·9	2·7	47·5	2·3	1·5	...
118	Barley	34	2·55	21·9	2·8	8·3	2·5	32·8	2·3	27·2	...
119	Oats	20	3·07	15·9	3·8	7·3	3·8	20·7	1·6	46·4	...
120	Spelt	2	4·20	17·3	1·8	5·8	2·6	20·0	2·6	44·0	...
121	Maize	8	1·42	27·0	1·5	14·6	2·7	44·7	1·1	2·2	...
122	Paddy	3	7·84	18·4	4·5	8·6	5·1	47·2	0·6	0·6	...
123	Rice	3	0·39	23·3	4·8	13·4	2·9	51·0	0·6	3·0	...
124	Millet	2	4·49	11·9	1·0	8·4	1·0	23·4	0·2	52·3	...
125	,, pearled	1	1·42	18·9	5·8	18·6	...	53·6	1·5	...	...
126	Sorghum	1	1·86	20·3	3·3	14·8	1·3	50·9	...	7·5	...
127	Buckwheat	2	1·07	23·1	6·2	13·4	3·3	48·0	2·1	...	1·7
128	Rape seed	15	4·24	23·5	1·1	12·2	13·8	43·9	3·6	1·1	0·3
129	Flax ,,	3	3·65	32·2	1·8	13·2	8·4	40·4	1·1	1·1	0·1
130	Hemp ,,	2	5·48	20·1	0·8	5·6	23·5	36·3	0·2	11·8	0·1
131	Poppy ,,	1	6·12	13·6	1·0	9·5	35·4	31·4	1·9	3·2	4·4
132	Madia ,,	1	...	9·5	11·2	15·4	7·7	55·0	...	...	...
133	Mustard ,,	3	4·30	15·9	5·8	10·2	18·8	39·0	4·7	2·4	0·4
134	Mangold ,,	1	5·66	18·7	17·3	18·9	15·6	15·5	4·2	2·1	9·4
135	Turnip ,,	1	3·98	21·9	1·2	8·7	17·4	40·2	7·1	0·7	...
136	Carrot ,,	1	8·50	19·1	4·8	6·7	38·8	15·8	5·6	5·3	3·3
137	Peas	30	2·81	40·4	3·7	8·0	4·2	36·3	3·5	0·9	2·3
138	Vetches	1	2·40	30·6	10·6	8·5	4·8	38·1	4·1	2·0	1·1
139	Field beans	6	3·45	40·5	1·2	6·7	5·2	39·2	5·1	1·2	2·9
140	Garden beans	9	3·06	44·1	2·9	7·5	7·7	30·4	3·8	0·8	0·9
141	Lentils	1	2·06	27·8	9·9	2·0	5·1	29·1	...	1·1	3·3
142	Lupines	1	...	33·5	17·8	6·2	7·8	25·5	6·8	0·9	1·8
143	Clover seed	3	4·11	37·3	0·6	12·2	6·2	33·5	4·7	2·4	1·3
144	Sainfoin seed	1	4·47	28·6	2·8	6·6	31·6	23·9	3·2	0·8	1·1
	XI. FRUITS AND SEEDS OF TREES, &c.										
145	Grape seeds	2	2·81	28·6	...	8·6	33·9	24·0	2·5	1·1	0·3
146	Alder	2	5·14	37·6	1·6	8·0	30·7	13·0	3·4	3·2	0·1
147	Silver fir	1	...	21·8	7·1	16·8	1·5	39·7	...	11·7	0·3
148	Spruce	1	...	22·4	1·3	15·1	1·9	46·0	...	10·4	...
149	Beech mast	1	3·30	22·8	10·0	11·6	24·5	20·8	2·2	1·9	0·5
150	Acorns	2	...	64·5	0·7	5·4	7·0	16·2	2·8	1·1	1·7
151	Horse-chestnut	2	2·36	58·9	...	0·5	11·6	22·4	1·4	0·2	6·4
152	,, green husk	2	4·38	76·4	...	1·0	10·0	6·3	1·4	0·6	5·6
153	Apple, entire fruit	1	...	35·7	26·1	8·8	4·1	13·6	6·1	4·3	...
154	Pear ,, ,,	1	...	54·7	8·5	5·2	8·0	15·3	5·7	1·5	...
155	Cherry ,, ,,	1	...	51·9	2·2	5·5	7·5	16·0	5·1	9·0	1·1
156	Plum ,, ,,	1	...	59·2	0·5	5·5	10·0	15·1	3·8	2·4	...
	XII. LEAVES OF TREES.										
157	Mulberry	3	3·53	19·6	...	5·4	25·7	10·2	0·5	33·5	0·1
158	Horse-chestnut, spring	2	7·17	38·8	...	3·9	21·3	23·4	6·0	2·9	3·8
159	,, autumn	1	7·52	19·6	...	7·8	40·5	8·2	1·7	13·9	4·1
160	Walnut, spring	1	7·72	42·7	...	4·6	26·9	21·1	2·6	1·2	0·5
161	,, autumn	1	7·01	26·6	...	9·8	53·7	4·0	2·7	2·0	0·8
162	Beech, summer	2	4·83	18·5	1·8	8·6	36·5	7·8	3·1	15·2	1·2
163	,, autumn	6	6·75	5·2	0·6	6·0	44·9	4·2	3·7	33·9	0·4
164	Oak, summer	1	4·60	33·1	...	13·5	26·1	12·2	2·7	4·4	0·1
165	,, autumn	1	4·90	3·5	0·6	4·0	48·6	8·1	4·4	30·9	...
166	Scotch fir, autumn	1	1·40	10·1	...	9·9	41·4	16·4	4·4	13·1	4·4
167	Spruce ,,	1	5·82	1·5	...	2·3	15·2	8·2	2·8	77·1	...

Composition of the Ash of Agricultural Plants and Products.

No.	Substance.	No of Analyses.	Per cent. of Ash.	Potash.	Soda.	Magnesia.	Lime.	Phosphoric Pentoxide.	Sulphuric Trioxide.	Silica.	Chlorine.
	XIII. WOOD.										
168	Grape	8	2·75	29·8	6·7	6·8	37·3	12·9	2·7	0·8	0·8
169	Mulberry	1	1·60	6·5	14·3	5·7	57·3	2·2	10·3	3·6	4·2
170	Birch	2	0·31	11·6	5·8	8·9	60·0	8·5	0·3	4·8	0·6
171	Beech, trunk	2	0·65	16·1	3·4	10·8	56·4	5·3	1·0	4·7	0·1
172	Beech, branches	1	1·05	15·2	2·1	16·8	45·8	11·6	0·7	6·7	0·1
173	,, brushwood	1	1·45	14·1	2·2	10·8	48·0	12·3	1·2	9·8	0·1
174	Oak, trunk	2	...	10·0	3·6	4·8	73·5	5·5	1·4	1·1	0·2
175	,, small branches with bark.	1	...	19·8	...	7·5	54·0	9·3	1·6	3·1	...
176	Horse-chestnut twigs, autumn.	1	3·31	19·4	...	5·2	51·0	21·7	...	0·7	1·4
177	Walnut twigs, autumn	1	2·99	15·3	...	8·1	55·9	12·2	3·2	2·9	0·3
178	Poplar, young twigs	5	...	14·0	0·4	7·5	58·4	13·1	1·5	2·0	0·1
179	Willow ,, ,,	1	...	11·4	5·6	10·1	50·8	16·4	3·1	0·7	0·6
180	Elm ,, ,,	1	...	24·1	2·1	10·0	37·9	2·6	5·4	6·2	6·7
181	Elm, trunk	1	...	21·9	13·7	7·7	47·8	3·3	1·3	3·1	...
182	Linden	1	...	35·8	6·0	4·2	29·9	4·9	5·3	5·3	1·5
183	Apple-tree	2	1·29	12·0	1·6	5·7	71·0	4·6	2·9	1·8	0·2
184	Spruce	1	0·25	5·2	26·8	6·2	47·9	5·1	3·0	2·0	4·0
185	Silver fir	2	0·28	15·3	9·9	5·9	50·1	5·5	3·0	6·0	0·2
186	Scotch fir	6	0·31	11·8	4·6	9·1	50·1	5·8	2·3	15·0	0·4
187	Larch	1	0·32	15·3	7·7	24·5	27·1	3·6	1·7	3·6	0·6
	XIV. BARK.										
188	Birch	2	1·33	3·8	5·4	8·2	45·6	7·3	1·3	20·1	1·3
189	Beech	1	...	14·7	0·4	0·2	57·9	0·4	1·3	18·0	...
190	Horse-chestnut, young, autumn	1	6·57	24·2	...	4·0	61·3	7·0	1·1	1·1	1·2
191	Walnut ,, ,,	1	6·40	11·6	...	10·6	70·1	5·9	0·2	0·7	0·4
192	Elm	1	...	2·2	10·1	3·2	72·7	1·6	0·6	8·9	...
193	Linden	1	...	16·1	5·7	8·0	60·8	4·0	0·8	2·3	1·2
194	Spruce	1	2·81	5·3	4·2	4·7	62·4	2·6	1·0	15·7	0·2
195	Silver fir	1	3·30	8·0	3·2	3·0	69·8	2·5	1·6	8·4	1·0
196	Scotch fir	3	2·01	3·0	1·0	1·4	43·7	8·3	0·8	31·1	0·1

TABLE II.

COMPOSITION OF FRESH OR AIR-DRY AGRICULTURAL PRODUCTS, giving the Average quantity of Water, Sulphur, Ash, and Ash-ingredients, in 1,000 parts of substance, by Professor WOLFF.

Substance.	Water.	Ash.	Potash.	Soda.	Magnesia.	Lime.	Phosphoric Pentoxide.	Sulphuric Trioxide.	Silica.	Chlorine.	Sulphur.
I. HAY.											
Meadow hay	144	66·6	17·1	4·7	3·3	7·7	4·1	3·4	19·7	5·3	1·7
Dead-ripe hay	144	66·2	5·0	1·9	2·3	8·5	2·9	0·5	41·8	3·8	2·7
Red clover	160	56·5	19·5	0·9	6·9	19·2	5·6	1·7	1·5	2·1	2·1
White clover	160	60·3	10·6	4·7	6·0	19·4	8·5	5·3	2·7	1·9	2·7
Alsike clover	160	46·5	15·7	0·7	7·1	14·8	4·7	1·9	0·6	1·3	...
Lucerne	160	60·0	15·2	0·7	3·5	28·8	5·1	3·7	1·2	1·1	2·6
Sainfoin	160	45·3	17·9	0·8	2·6	14·6	4·7	1·5	1·8	1·4	...
Green vetches	160	73·4	30·9	2·1	5·0	19·3	9·4	2·7	1·3	2·3	1·5
Green oats	145	61·8	24·1	2·0	2·0	4·1	5·1	1·7	20·5	2·5	1·5
II. GREEN FODDER.											
Meadow grass, in blossom	700	23·3	6·0	1·6	1·1	2·7	1·5	1·2	6·9	1·9	0·6
Young grass	800	20·7	11·6	0·4	0·6	2·2	2·2	0·8	2·1	0·4	0·4
Rye grass	700	21·3	5·3	0·9	0·5	1·6	1·7	0·8	8·4	1·1	0·7
Timothy	700	21·0	6·1	0·6	0·8	2·0	2·3	0·8	7·5	1·1	0·8
Other grasses	700	21·8	7·2	0·4	0·6	1·2	1·7	1·0	8·2	0·9	0·7
Oats, beginning to head	820	17·0	7·1	0·8	0·6	1·2	1·4	0·6	4·7	0·8	0·3
,, in blossom	770	16·6	6·5	0·6	0·5	1·1	1·4	0·5	5·5	0·7	0·4
Barley, beginning to head	750	22·3	8·6	0·4	0·7	1·6	2·3	0·7	7·0	1·2	0·5
,, in blossom	680	22·5	5·9	0·1	0·7	1·4	2·2	0·7	10·8	0·8	0·7
Wheat, beginning to head	770	22·4	7·8	0·4	0·3	1·1	1·7	0·4	9·4	1·2	0·3
,, in blossom	690	21·7	5·6	0·1	0·5	0·7	1·6	0·4	12·3	0·6	0·5
Rye fodder	700	16·3	6·3	0·1	0·5	1·2	2·4	0·2	5·2	...	...
German millet	680	23·1	8·6	...	1·9	2·5	1·3	0·8	6·7	1·5	...
Red clover	800	13·4	4·6	0·2	1·6	4·6	1·3	0·4	0·4	0·5	0·5
White clover	810	13·6	2·4	1·1	1·4	4·4	2·0	1·2	0·6	0·4	0·6
Alsike clover	815	10·2	3·5	0·2	1·6	3·2	1·0	0·4	0·1	0·3	...
Lucerne	753	17·6	4·5	0·2	1·0	8·5	1·5	1·1	0·4	0·3	0·8
Sainfoin	785	11·6	4·6	0·2	0·7	3·7	1·2	0·4	0·5	0·3	...
Kidney vetch	780	12·3	1·3	0·5	0·6	8·5	0·9	0·2	0·4	...	...
Green vetches	820	15·7	6·6	0·5	1·1	4·1	2·0	0·6	0·3	0·5	0·3
,, peas	815	13·7	5·6	...	1·1	3·9	1·8	0·5	0·4	0·2	...
,, rape	850	13·5	4·4	0·5	0·6	3·1	1·2	2·2	0·4	1·0	0·6
III. ROOT CROPS.											
Potato	750	9·4	5·6	0·1	0·4	0·2	1·8	0·6	0·2	0·3	0·2
Artichoke	800	10·3	6·7	...	0·3	0·4	1·6	0·3	...	0·2	...
Beet	883	8·0	4·3	1·2	0·4	0·4	0·8	0·3	0·2	0·5	0·1
Sugar-beet	816	8·0	4·0	0·8	0·7	0·5	1·1	0·4	0·3	0·2	...
Turnip	909	7·5	3·0	0·8	0·3	0·8	1·0	1·1	0·2	0·3	0·4
White turnip	915	6·1	3·1	0·2	0·1	0·8	1·1	0·4	0·1	0·4	...
Kohl-rabi	877	9·5	4·9	0·6	0·2	0·9	1·4	0·8	0·1	0·5	...
Carrot	860	8·8	3·2	1·9	0·5	0·9	1·1	0·6	0·2	0·3	0·1
Sugar-beet heads*	840	6·5	1·9	1·6	0·7	0·6	0·8	0·5	0·1	0·1	...
Chicory	800	10·4	4·2	0·8	0·7	0·9	1·5	1·0	0·6	0·4	...

* Crowns of sugar-beet roots.

COMPOSITION OF FRESH OR AIR-DRY AGRICULTURAL PRODUCTS.

Substance.	Water.	Ash.	Potash.	Soda.	Magnesia.	Lime.	Phosphoric Pentoxide.	Sulphuric Trioxide.	Silica.	Chlorine.	Sulphur.
IV. LEAVES AND STEMS OF ROOT CROPS.											
Potato tops, end of August	825	15·6	2·3	0·4	2·6	5·1	1·0	0·9	1·2	0·7	0·6
,, ,, first of October	770	11·8	0·7	0·1	2·7	5·5	0·6	0·6	0·5	0·4	0·5
Mangold tops	907	14·8	4·3	3·1	1·4	1·7	0·8	1·1	0·7	1·7	0·5
Sugar-beet tops	897	18·0	4·0	3·0	3·3	3·6	1·3	1·4	0·6	1·0	...
Turnip tops	898	14·0	3·2	1·1	0·6	4·5	1·3	1·4	0·5	1·2	0·5
Kohl-rabi tops	850	25·3	3·6	1·0	1·0	8·4	2·6	3·0	2·6	1·0	...
Carrot tops	808	26·1	3·7	6·0	1·2	8·6	1·2	2·1	1·5	1·9	1·4
Chicory tops	850	18·7	11·2	0·1	0·6	2·7	1·7	1·7	0·2	0·3	...
Cabbage heads	885	12·4	6·0	0·5	0·4	1·9	2·0	1·1	0·1	0·3	0·5
Cabbage stems	820	11·6	5·1	0·6	0·5	1·3	2·4	0·9	0·2	0·1	...
V. MANUFACTURED PRODUCTS AND REFUSE.											
Sugar-beet cake	692	9·7	3·6	0·8	0·5	2·5	1·0	0·4	0·6	0·5	...
a. Common cake	692	9·3	2·3	1·2	...	2·5	1·2	0·5	...	1·2	...
b. Residue from centrifugal machine	820	5·6	2·6	0·5	...	1·4	0·7	0·4	...	...	...
c. Residue of maceration	885	4·1	1·5	0·4	0·5	1·1	0·3	0·1	...	0·1	...
Beet molasses	175	93·1	66·2	9·8	0·4	5·6	0·6	2·0	0·6	9·4	...
Molasses, residue	907	17·7	15·9		0·2		...	0·3	...	0·3	...
Raw beet-sugar	43	13·7	4·6	3·8	...	1·2	...	3·1	0·1	0·8	...
Potato refuse: spirit manuf.	947	5·9	2·7	0·4	0·5	0·4	1·2	0·4	0·2	0·1	...
Potato refuse: starch manuf.	806	1·9	0·3	...	0·1	0·9	0·5	...	0·1	...	...
Potato skins	300	67·1	48·3	0·5	4·5	6·4	2·3	0·3	1·8	1·4	...
Fine wheat flour	136	4·1	1·5	0·1	0·3	0·1	2·1	...	...	...	...
Rye flour	142	16·9	6·5	0·3	1·4	0·2	8·5	...	...	...	...
Barley flour	140	20·0	5·8	0·5	2·7	0·6	9·5	0·6	...	...	...
Barley dust	113	49·8	9·4	0·7	3·8	1·2	14·4	...	9·9	...	...
Maize meal	140	9·5	2·7	0·3	1·4	0·6	4·3	...	...	...	...
Millet meal	140	11·6	2·3	0·3	3·0	...	5·5	0·3	...	...	...
Buckwheat groats	140	6·2	1·6	0·4	0·8	0·1	3·0	0·1	...	0·1	...
Wheat bran	135	55·6	13·3	0·3	9·4	2·6	28·8	...	0·6	...	...
Rye bran	131	71·4	19·3	0·9	11·3	2·5	34·2	...	...	...	...
Brewers' grains	768	12·0	0·5	0·1	1·2	1·4	4·6	0·1	3·9	...	...
Malt	475	14·6	2·5	...	1·2	0·5	5·3	...	4·8	...	...
Dried malt	42	26·6	4·6	...	2·2	1·0	0·7	...	8·8	...	...
Malt dust	92	59·6	20·8	...	0·8	0·9	12·5	3·8	17·7	...	...
Wine lees	650	16·1	8·6	0·1	0·5	2·5	2·5	1·2	...	0·1	...
Grape marc	600	16·2	8·0	0·4	1·0	2·1	3·4	0·7	0·6	0·1	...
Beer	900	3·9	1·5	0·3	0·2	0·1	1·3	0·1	0·4	0·1	...
Wine	866	2·8	1·8	...	0·2	0·2	0·5	0·1	0·1	...	...
Rape cake	150	56·0	13·6	0·1	6·4	6·1	20·7	1·9	4·9	0·1	...
Linseed cake	115	55·2	12·9	0·8	8·8	4·7	19·4	1·9	3·6	0·3	...
Poppy cake	100	95·4	19·8	4·3	4·1	26·8	36·1	1·9	4·6	...	...
Walnut cake	136	46·4	15·4	...	5·7	3·1	20·3	0·5	0·7	0·1	...
Cotton seed cake	115	61·5	21·8	...	2·6	2·8	29·5	0·7	2·5	...	...
VI. STRAW.											
Winter wheat	141	42·6	4·9	1·2	1·1	2·6	2·3	1·2	28·2	...	1·6
Winter rye	154	40·7	7·6	1·3	1·3	3·1	1·9	0·8	23·7	...	0·9
Winter spelt	143	47·7	5·3	0·2	0·4	2·3	3·0	0·9	34·1	...	...
Summer rye	143	47·6	11·1	...	1·3	4·4	3·1	1·2	26·6	...	...
Barley	140	43·9	9·3	2·0	1·1	3·3	1·9	1·6	23·6	...	1·3
Oats	141	44·0	9·7	2·3	1·8	3·6	1·8	1·5	21·2	...	1·7
Maize	140	47·2	16·6	0·5	2·6	5·0	3·8	2·5	17·9	...	3·9
Peas	143	49·2	10·7	2·6	3·8	18·6	3·8	2·8	2·8	3·0	0·7
Field beans	180	58·4	25·9	2·2	4·6	13·5	4·1	0·1	3·1	8·1	2·2
Garden beans	150	51·5	19·1	3·1	2·7	14·1	4·1	1·8	2·4	2·7	2·1

COMPOSITION OF FRESH OR AIR-DRY AGRICULTURAL PRODUCTS.

Substance.	Water.	Ash.	Potash.	Soda.	Magnesia.	Lime.	Phosphoric Pentoxide.	Sulphuric Trioxide.	Silica.	Chlorine.	Sulphur.
VI. STRAW (*continued*).											
Buckwheat	160	51·7	24·1	1·1	1·9	9·5	6·1	2·7	2·8	4·0	...
Rape	170	38·0	9·7	3·9	2·1	10·1	2·7	2·7	2·6	4·7	1·4
Poppy	160	66·0	25·1	0·9	4·3	19·9	2·3	3·4	7·5	1·7	...
VII. CHAFF.											
Wheat	138	92·5	8·4	1·7	1·2	1·9	4·0	...	75·1	...	0·8
Spelt	130	82·7	7·9	0·2	2·1	2·0	6·0	1·9	61·4	...	...
Barley	140	122·4	9·4	1·1	1·6	12·7	2·4	3·7	86·7	...	...
Oats	143	79·0	10·4	3·8	2·1	7·0	0·2	2·0	47·3	...	...
Maize cobs	115	5·0	2·4	0·1	0·2	0·2	0·2	0·1	1·3	0·2	1·3
Linseed hulls	120	58·3	18·1	2·5	1·6	17·2	1·6	2·8	10·0	3·6	1·8
VIII. TEXTILE PLANTS, &c.											
Flax straw	140	31·9	11·8	1·6	2·3	8·3	4·3	2·0	2·2	1·5	1·4
Rotted flax stems	100	21·6	1·9	1·0	1·2	11·1	1·3	0·7	3·0	...	0·2
Flax fibre	100	6·0	0·2	0·2	0·3	3·8	0·7	0·2	0·3	...	...
Flax: whole plant	250	32·3	11·3	1·5	2·9	5·0	7·4	1·6	0·8	1·9	...
Hemp: whole plant	300	28·2	5·2	0·9	2·7	12·2	3·3	0·8	2·1	0·7	...
Hop: whole plant	250	74·0	19·4	2·8	4·3	11·8	9·0	3·8	15·9	3·4	2·0
Hops	120	59·8	22·3	1·3	2·1	10·1	9·0	1·6	9·2	0·2	4·8
Tobacco	180	197·5	54·1	7·3	20·7	73·1	7·1	7·7	19·0	8·8	...
IX. LITTER.											
Heather	200	36·1	4·8	1·9	3·0	6·8	1·8	1·6	12·7	0·8	...
Broom	160	18·9	6·9	0·5	2·8	3·2	1·6	0·7	1·9	0·5	...
Fern	160	58·9	25·2	2·7	4·5	8·3	5·7	3·0	3·6	6·0	...
Dutch rush	140	204·4	27·0	1·0	4·7	25·6	4·1	12·9	110·0	11·7	...
Sea-weed	180	118·0	17·1	28·3	11·2	16·4	3·7	28·3	2·0	11·9	...
Beech leaves	150	57·4	3·0	0·3	3·4	25·8	2·4	2·1	19·5	0·2	...
Oak leaves	150	41·7	1·5	0·2	1·7	20·2	3·4	1·8	12·9	...	...
Scotch fir leaves	160	11·8	1·2	...	1·1	4·9	1·9	0·5	1·5	0·5	...
Spruce leaves	160	48·9	0·7	...	1·1	7·4	4·0	1·4	34·3	...	...
Reed	180	38·5	3·3	0·1	0·5	2·3	0·8	1·1	27·5	...	...
Sedge	140	69·5	23·1	5·1	2·9	3·7	4·7	2·3	21·8	3·9	...
Rush	140	45·6	16·7	3·0	2·9	4·3	2·9	4·0	5·0	6·5	...
Bulrush	140	74·4	7·2	7·7	2·2	5·4	4·8	4·2	32·2	3·9	...
X. GRAINS AND SEEDS OF AGRICULTURAL PLANTS.											
Wheat	143	17·7	5·5	0·6	2·2	0·6	8·2	0·4	0·3	...	1·5
Rye	149	17·3	5·4	0·3	1·9	0·5	8·2	0·4	0·3	...	1·7
Barley	145	21·8	4·8	0·6	1·8	0·5	7·2	0·5	5·9	...	1·4
Oats	140	26·4	4·2	1·0	1·8	1·0	5·5	0·4	12·3	...	1·7
Spelt	148	35·8	6·2	0·6	2·1	0·9	7·2	0·6	15·8	...	...
Maize	136	12·3	3·3	0·2	1·8	0·3	5·5	0·1	0·3	...	1·2
Paddy	120	69·0	12·7	3·1	5·9	3·5	32·6	0·4	0·4	...	...
Rice	130	3·4	0·8	0·2	0·5	0·1	1·7	...	0·1	...	...
Millet	130	39·1	4·7	0·4	3·3	0·4	9·1	0·1	20·5	...	1·8
,, pearled	131	12·3	2·3	0·7	2·3	...	6·6	0·2	...	...	...
Sorghum	140	16·0	4·2	0·5	2·4	0·2	8·1	...	1·2	...	...
Buckwheat	141	9·2	2·1	0·6	1·2	0·3	4·4	0·2	...	0·2	...
Rape seed	120	37·3	8·8	0·4	4·6	5·2	16·4	1·3	0·4	0·1	8·2
Flax ,,	118	32·2	10·4	0·6	4·2	2·7	13·0	0·4	0·4	...	1·7
Hemp ,,	122	48·1	9·7	0·4	2·7	11·3	17·5	0·1	5·7	0·1	...
Poppy ,,	147	52·2	7·1	0·5	5·0	18·5	16·4	1·0	1·7	2·3	...
Mustard ,,	120	37·8	6·0	2·2	3·9	7·1	14·7	1·8	0·9	0·2	10·1
Mangold ,,	140	48·7	9·1	8·4	9·2	7·6	7·6	2·0	1·0	4·6	0·8
Turnip ,,	120	35·0	7·7	0·3	3·0	6·1	14·1	2·5	0·2	...	7·8
Carrot ,,	120	74·8	14·3	3·6	5·0	29·0	11·8	4·2	4·0	2·5	2·7
Peas	138	24·2	9·8	0·9	1·9	1·2	8·8	0·8	0·2	0·6	2·4
Vetches	136	20·7	6·3	2·2	1·8	0·6	7·9	0·9	0·4	0·2	...

COMPOSITION OF FRESH OR AIR-DRY AGRICULTURAL PRODUCTS.

Substance.	Water.	Ash.	Potash.	Soda.	Magnesia.	Lime.	Phosphoric Pentoxide.	Sulphuric Trioxide.	Silica.	Chlorine.	Sulphur.
X. GRAINS AND SEEDS OF AGRICULTURAL PLANTS (*continued*).											
Field beans	141	29·6	12·0	0·4	2·0	1·5	11·6	1·5	0·4	0·8	2·3
Garden beans	148	26·1	11·5	0·8	2·0	2·0	7·9	1·0	0·2	0·3	2·5
Lentils	134	17·8	7·7	1·8	0·4	0·9	5·2	...	0·2	0·6	...
Lupines	138	34·0	11·4	6·0	2·1	2·7	8·7	2·3	0·3	0·6	...
Clover seed	150	36·9	13·8	0·2	4·5	2·3	12·4	1·7	0·9	0·5	...
Sainfoin seed	160	37·6	10·8	1·1	2·5	11·9	9·0	1·2	0·3	0·4	2·8
XI. FRUIT AND SEEDS OF TREES, &c.											
Grape seeds	120	24·7	7·1	...	2·1	8·4	5·9	0·6	0·3	0·1	...
Alder ,,	140	44·2	16·6	0·7	3·5	13·6	5·7	1·5	1·4	...	...
Beech mast	180	27·1	6·2	2·7	3·1	6·7	5·6	0·6	0·5	0·1	...
Acorns, fresh	560	9·6	6·2	0·1	0·5	0·7	1·6	0·5	0·2	0·1	...
,, dried	158	18·3	11·8	0·1	1·0	1·3	3·3	0·5	0·4	0·3	...
Horse-chestnuts, fresh	492	12·0	7·1	...	0·1	1·4	2·7	0·2	...	0·8	...
,, green husk	818	8·0	6·1	...	0·1	0·8	0·5	0·1	0·1	0·4	...
Apple: whole fruit	840	2·7	1·0	0·7	0·2	0·1	0·4	0·2	0·1	...	...
Pear: ,, ,,	800	4·1	2·2	0·4	0·2	0·3	0·6	0·2	0·1	...	...
Cherry: ,, ,,	780	4·3	2·2	0·1	0·2	0·3	0·7	0·2	0·4	0·1	...
Plum: ,, ,,	820	4·0	2·4	...	0·2	0·4	0·6	0·2	0·1	...	...
XII. LEAVES OF TREES.											
Mulberry	670	11·7	2·3	...	0·6	3·0	1·2	0·1	4·1	...	...
Horse-chestnut, spring	700	21·5	8·3	...	0·8	4·6	5·0	1·3	0·6	0·8	...
,, autumn	600	30·1	5·9	...	2·4	12·2	2·5	0·5	4·2	1·2	...
Walnut, spring	700	23·2	9·9	...	1·1	6·2	4·9	0·6	0·3	0·1	...
,, autumn	600	28·4	7·6	...	2·8	15·3	1·1	0·8	0·6	0·2	...
Beech, summer	750	12·1	2·2	0·2	1·1	4·4	0·9	0·4	0·8	0·1	...
,, autumn	550	30·5	1·6	0·2	1·8	13·7	1·3	1·1	10·3	0·1	...
Oak, summer	700	13·8	4·6	...	1·9	3·6	1·7	0·4	0·6	...	...
,, autumn	600	19·6	0·7	0·1	0·8	9·5	1·6	0·9	6·1	...	...
Scotch fir, autumn	550	6·3	0·6	...	0·6	2·6	1·3	0·3	0·8	0·3	...
Spruce, autumn	550	26·2	0·4	...	0·6	4·0	2·1	0·7	18·4	...	...
XIII. WOOD (AIR-DRY).											
Grape	150	23·4	7·0	1·6	1·6	8·7	3·0	0·6	0·2	0·2	...
Mulberry	150	13·7	0·9	2·0	0·8	7·8	0·3	1·4	0·5	0·6	...
Birch	150	2·6	0·3	0·2	0·2	1·5	0·2	...	0·1	...	...
Beech, trunk	150	5·5	0·9	0·2	0·6	3·1	0·3	0·1	0·3	...	...
,, branches	150	8·9	1·4	0·2	1·5	4·1	1·0	0·1	0·6	...	...
,, brushwood	150	12·3	1·7	0·3	1·3	5·9	1·5	0·1	1·2	...	...
Oak, trunk	150	5·1	0·5	0·2	0·2	3·7	0·3	0·1	0·1	...	...
,, small branches with bark	150	10·2	2·0	...	0·8	5·5	0·9	0·2	0·3	...	...
Horse-chestnut, young wood in autumn	150	28·1	5·5	...	1·5	14·3	5·9	...	0·2	0·4	...
Walnut	150	25·5	3·9	...	2·0	14·2	3·1	0·8	0·7	0·1	...
Apple-tree	150	11·0	1·3	0·2	0·6	7·8	0·5	0·3	0·2	...	...
Spruce	150	2·1	0·1	0·6	0·1	1·0	0·1	0·1	0·1	...	...
Silver fir	150	2·4	0·4	0·2	0·1	1·2	0·1	0·1	0·2	...	...
Scotch fir	150	2·6	0·3	0·1	0·2	1·3	0·2	0·1	0·4	...	...
Larch	150	2·7	0·4	0·2	0·7	0·7	0·1	0·1	0·1	...	...
XIV. BARK.											
Birch	150	11·3	0·4	0·6	0·9	5·2	0·8	0·2	2·3	0·2	...
Horse-chestnut, young in aut.	150	55·9	13·5	...	2·2	34·3	3·9	0·6	0·6	0·7	...
Walnut, ,, ,, ,,	150	54·4	6·3	...	5·8	38·1	3·2	0·1	0·4	0·2	...
Spruce	150	23·9	1·3	1·0	1·1	14·9	0·6	0·2	3·8	0·1	...
Silver fir	150	28·1	2·3	0·9	0·8	19·6	0·7	0·5	2·3	0·3	...
Scotch fir	150	17·1	0·5	0·2	0·2	7·5	1·4	0·1	5·3	...	...

TABLE III.

PROXIMATE COMPOSITION OF AGRICULTURAL PLANTS AND PRODUCTS,

giving the Average quantities of Water, Organic Matter, Ash, Albuminoids, Carbo-hydrates, &c., Crude Fibre, Fat, &c., by Professors WOLFF and KNOP.*

Substance.		Water.	Organic Matter.†	Ash.	Albuminoids.	Carbo-hydrates, &c.‡	Crude fibre.§	Fat, &c.‖
HAY.								
Meadow hay, medium quality		14·3	79·5	6·2	8·2	41·3	30·0	2·0
Aftermath		14·3	79·2	6·5	9·5	45·7	24·0	2·4
Red clover, full blossom		16·7	77·1	6·2	13·4	29·9	35·8	3·2
,, ripe		16·7	77·7	5·6	9·4	20·3	48·0	2·0
White clover, full blossom		16·7	74·8	8·5	14·9	34·3	25·6	3·5
Alsike clover		16·7	75·0	8·3	15·3	29·2	30·5	3·3
,, ripe		16·7	78·3	5·0	10·2	23·1	45·0	2·2
Lucerne, young		16·7	74·6	8·7	19·7	32·9	22·0	3·3
,, in blossom		16·7	76·9	6·4	14·4	22·5	40·0	2·5
Yellow lucerne, early blossom		16·7	77·2	6·1	15·2	26·9	35·1	3·0
Sainfoin, in blossom		16·7	77·1	6·2	13·3	36·7	27·1	2·5
Crimson clover, do.		16·7	76·1	7·2	12·2	30·1	33·8	3·0
Trefoil do.		16·7	77·3	6·0	14·6	36·5	26·2	3·3
Vetches, in blossom		16·7	75·0	8·3	14·2	35·3	25·5	2·5
Peas ,,		16·7	76·3	7·0	14·3	36·8	25·2	2·6
Field spurrey, in blossom		16·7	73·8	9·5	12·0	39·8	22·0	3·2
,, ,, after blossom		16·7	75·5	7·8	7·8	41·7	26·0	2·5
Serradilla, after blossom (*Ornithopus sativus*)		16·7	77·7	5·6	14·6	29·2	33·9	1·5
,, before blossom		16·7	75·8	7·5	15·3	37·2	26·1	1·9
Italian rye grass	Cut in blossom.	14·3	77·9	7·8	8·7	51·4	16·9	2·8
Timothy		14·3	81·2	4·5	9·7	48·8	22·7	3·0
Annual meadow grass		14·3	83·3	2·4	10·1	47·2	25·9	2·9
Crested dog's tail		14·3	80·2	5·5	9·5	48·0	22·6	2·8
Soft brome grass		14·3	80·7	5·0	14·8	35·0	31·0	1·8
Cocksfoot		14·3	81·1	4·6	11·6	40·7	28·9	2·7
Barley grass		14·3	80·4	5·3	9·6	42·0	27·2	2·0
Meadow foxtail		14·3	79·0	6·7	10·6	39·5	29·0	2·5
Oat grass		14·3	75·8	9·9	11·1	35·3	29·4	2·7
Rye grass		14·3	79·2	6·5	10·2	38·9	30·2	2·7
Hard Fesuæ		14·3	81·0	4·7	10·4	37·5	33·2	2·9
Sweet-scented vernal grass		14·3	80·3	5·4	8·9	40·2	31·2	2·9
Soft grass		14·3	80·2	5·5	9·9	36·7	33·6	3·1
Smooth meadow grass		14·3	80·6	5·1	8·9	39·1	32·6	2·3
Rough meadow grass		14·3	78·6	7·1	8·4	37·6	32·6	3·2
Yellow oat grass		14·3	79·8	5·9	6·4	42·6	30·8	2·2
Quaking grass		14·3	78·3	7·4	5·2	42·8	30·3	2·6
Average of all the grasses		14·3	79·9	5·8	9·5	41·7	28·7	2·6

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* *Landwirthschaftlicher Kalender*, 1867, through Knop's *Agricultur-Chemie*, 1868, pp. 715–20. This table is, as regards water and ash, a repetition of Table II.; but as it includes the newer analyses of 1865–67, the averages of water and ash do not in all cases agree with those of the former tables. It gives besides the proportions of nitrogenous and non-nitrogenous compounds, *i.e.* Albuminoids and Carbo-hydrates, &c. It also states the averages of Crude fibre and of Fat, &c. The discussion of the data of this table belongs to the subjects of Food and Cattle-feeding; they are, however, inserted here, as it is believed they are not to be found elsewhere in the English language.—† Organic matter here signifies the combustible part of the plant.—‡ Carbo-hydrates, &c., includes fat, starch, sugar, pectine, &c., all in fact of Organic matter, except Albuminoids and Crude fibre.—§ Crude fibre is impure cellulose obtained by the processes described on pages 45 and 46.—‖ Fat, &c., is the ether-extract, p. 80, and contains besides fat, wax, chlorophyll, and in some cases resins.

PROXIMATE COMPOSITION OF AGRICULTURAL PLANTS AND PRODUCTS.

Substance.	Water.	Organic Matter.	Ash.	Albuminoids.	Carbo-hydrates, &c.	Crude fibre.	Fat, &c.
STRAW.							
Winter wheat	14·3	80·2	5·5	2·0	30·2	48·0	1·5
Winter rye	14·3	82·5	3·2	1·5	27·0	54·0	1·3
Winter spelt	14·3	79·7	6·0	2·0	27·7	50·5	1·4
Winter barley	14·3	80·2	5·5	2·0	29·8	48·4	1·4
Summer barley	14·3	78·7	7·0	3·0	32·7	43·0	1·4
,, ,, with clover	14·3	77·7	8·0	6·0	34·7	37·5	1·7
Oat	14·3	80·7	5·0	2·5	38·2	40·0	2·0
Vetch fodder	14·3	79·7	6·0	7·5	28·2	44·0	2·0
Pea	14·3	81·7	4·0	6·5	35·2	40·0	2·0
Bean	17·3	77·7	5·0	10·2	33·5	34·0	1·0
Lentil	14·3	79·2	6·5	14·0	27·2	36·6	2·0
Lupine	14·2	81·4	4·4	4·9	34·7	41·8	1·5
Maize	14·0	82·0	4·0	3·0	39·0	40·0	1·1
CHAFF AND HULLS.							
Wheat	14·3	73·7	12·0	4·5	33·2	36·0	1·4
Spelt	14·3	77·2	8·5	2·9	32·8	41·5	1·3
Rye	14·3	78·2	7·5	3·5	28·2	46·5	1·2
Barley	14·3	72·7	13·0	3·0	38·7	30·0	1·5
Oat	14·3	67·7	18·0	4·0	29·7	34·0	1·5
Vetch	15·0	77·0	8·0	8·5	32·5	36·0	2·0
Pea	14·3	79·7	6·0	8·1	36·6	35·0	2·0
Bean	15·0	77·0	8·0	10·5	29·5	37·0	2·0
Lupine	14·3	82·9	2·8	2·5	47·2	33·0	2·5
Rape	14·0	77·5	8·5	3·5	40·0	34·0	1·6
Maize cobs	14·0	83·2	2·8	1·4	44·0	37·8	1·4
GREEN FODDER.							
Grass, before blossom	75·0	22·9	2·1	3·0	12·9	7·0	0·8
,, after ,,	69·0	29·0	2·0	2·5	15·0	11·5	0·7
Red clover, before blossom	83·0	15·5	1·5	3·3	7·7	4·5	0·7
,, full ,,	78·0	20·3	1·7	3·7	8·6	8·0	0·8
White ,, ,, ,,	80·5	17·5	2·0	3·5	8·0	6·0	0·8
Alsike clover, early blossom	85·0	13·5	1·5	3·3	5·7	4·5	0·6
,, ,, full ,,	82·0	16·2	1·8	3·3	6·3	6·6	0·6
Lucerne, very young	81·0	17·3	1·7	4·5	7·8	5·0	0·6
,, in blossom	74·0	24·0	2·0	4·5	7·0	12·5	0·7
Yellow lucerne, early blossom	78·0	20·1	1·9	4·0	6·6	9·5	0·8
Sainfoin, in blossom	80·0	18·5	1·5	3·2	8·8	6·5	0·6
Crimson clover, in blossom	81·5	16·9	1·6	2·7	6·7	7·5	0·6
Trefoil, in blossom (*Medicago lupulina*)	80·0	18·5	1·5	3·5	9·0	6·0	0·8
Serradilla ,, (*Ornithopus sativus*)	80·0	18·7	1·3	3·6	7·0	8·1	0·4
Vetches ,,	82·0	16·2	1·8	3·1	7·6	5·5	0·6
Peas ,,	81·5	17·0	1·5	3·2	8·2	5·6	0·6
Oats, early blossom	81·0	17·6	1·4	2·3	8·8	6·5	0·5
Rye	72·9	25·5	1·6	3·3	14·9	7·3	0·9
Maize, late, end August	84·3	14·6	1·1	0·9	8·7	5·0	0·5
,, early ,,	82·2	16·7	1·1	1·1	10·9	4·7	0·5
German millet, in blossom (*Panicum germanicum*)	65·6	32·0	2·4	5·9	15·0	11·5	1·5
Sorghum saccharatum	74·0	25·1	0·9	2·5	15·3	7·3	1·4
Sorghum vulgare	77·3	21·6	1·1	2·9	11·9	6·7	?
Field spurrey, in blossom	80·0	18·0	2·0	2·3	10·4	5·3	0·7
Cabbage	89·0	9·8	1·2	1·5	6·3	2·0	0·4
,, stalks	82·0	16·1	1·9	1·1	12·2	2·8	0·8
Mangold leaves	90·5	6·7	1·8	1·9	4·6	1·3	0·5
Carrot ,,	82·2	14·2	3·6	3·2	8·0	3·0	1·0
Poplar and elm leaves	70·0	28·0	2·0	6·0	15·5	6·5	1·5
Artichoke stem	80·0	17·3	2·7	3·3	10·6	3·4	0·8
Rape leaves	dry	75·5	24·5	20·0	47·5	8·0	2·0

Proximate Composition of Agricultural Plants and Products.

Substance.	Water.	Organic Matter.	Ash.	Albuminoids.	Carbo-hydrates, &c.	Crude fibre.	Fat, &c.
ROOTS AND TUBERS.							
Potato	75·0	24·1	0·9	2·0	21·0	1·1	0·3
Jerusalem artichoke	80·0	18·9	1·1	2·0	15·6	1·3	0·5
Chervil parsnip	76·0	23·1	0·9	3·2	17·0	1·0	0·6
Kohl-rabi	88·0	10·8	1·2	2·3	7·3	1·2	0·2
Mangolds (about 3 lbs. weight)	88·0	11·1	0·9	1·1	9·1	0·9	0·1
Sugar-beets (1—2 lbs.)	81·5	17·7	0·8	1·0	15·4	1·3	0·1
Swedes (about 3 lbs.)	87·0	12·0	1·0	1·6	9·3	1·1	0·1
Carrot (about ½ lb.)	85·0	14·0	1·0	1·5	10·8	1·7	0·2
Giant carrot (1—2 lbs.)	87·0	12·2	0·8	1·2	9·8	1·2	0·2
Turnips (Stoppelrübe)	91·5	7·7	0·8	0·8	5·9	1·0	0·1
,, (Turnipsrübe)	92·0	7·2	0·8	1·1	5·1	1·0	0·1
Parsnip	88·3	11·0	0·7	1·6	8·4	1·0	0·2
Pumpkin	94·5	4·5	1·0	1·3	2·8	1·0	0·1
GRAINS AND SEEDS.							
Rice	14·6	84·9	0·5	7·5	76·5	0·9	0·5
Winter wheat	14·4	83·6	2·0	13·0	67·6	3·0	1·5
Wheat flour	12·6	86·7	0·7	11·8	74·1	0·7	1·2
Spelt	14·8	81·3	3·9	10·0	54·8	16·5	1·5
Winter rye	14·3	83·7	2·0	11·0	69·2	3·5	2·0
Rye flour	14·0	84·4	1·6	10·5	72·5	1·5	1·6
Winter barley	14·3	83·4	2·3	9·0	65·9	8·5	2·5
Summer ,,	14·3	83·1	2·6	9·5	66·6	7·0	2·5
Oats	14·3	82·7	3·0	12·0	60·9	10·3	6·0
Maize	14·4	83·5	2·1	10·0	68·0	5·5	7·0
Millet	14·0	83·0	3·0	14·5	62·1	6·4	3·0
Buckwheat	14·0	83·6	2·4	9·0	59·6	15·0	2·5
Vetches	14·3	83·4	2·3	27·5	49·2	6·7	2·7
Peas	14·3	83·2	2·5	22·4	52·3	9·2	2·5
Beans (field)	14·5	82·0	3·5	25·5	45·5	11·5	2·0
Lentils	14·5	82·5	3·0	23·8	52·0	6·9	2·6
Lupines	14·5	82·0	3·5	34·5	33·0	14·5	6·0
Acorns without shell, dry	20·0	78·4	1·6	5·0	68·8	4·6	4·3
,, with shell, fresh	56·0	43·0	1·0	2·0	36·5	4·5	2·3
Chestnuts without shell, fresh	49·2	49·0	1·8	3·0	45·2	0·8	2·5
Madia seed	8·4	86·9	4·7	22·9	46·0	18·0	41·0
Linseed	12·3	82·7	5·0	20·5	55·0	7·2	37·0
Rape seed	11·0	85·1	3·9	19·4	55·4	10·3	40·0
Hemp ,,	12·2	83·6	4·2	16·3	55·2	12·1	33·6
Poppy ,,	14·7	78·3	7·0	17·5	54·7	6·1	41·0
Horse chestnut	30·0	68·8	1·2	10·5	58·3	4·0	2·30
CAKES, REFUSE.							
Sugar-beet cake	70·0	26·6	3·4	1·8	18·5	6·3	0·2
,, ,, ,, residue from centrifugal machine	82·0	16·8	1·2	1·0	12·2	3·6	0·1
,, ,, ,, ,, ,, maceration	92·6	6·6	0·8	0·8	4·4	1·4	0·1
Potato residue	94·8	4·6	0·6	1·0	3·0	0·6	0·1
Rye ,,	89·0	10·5	0·5	2·1	6·8	1·6	0·4
Maize ,,	89·0	10·5	0·5	2·0	7·2	1·3	1·2
Molasses ,,	92·0	6·3	1·7	1·2	5·1	...	...
Brewers' grains	76·6	22·2	1·2	4·9	11·1	6·2	1·6
Malt dust	8·0	85·2	6·8	23·0	44·7	17·5	2·5
Fresh malt, with sprouts	47·5	50·8	1·7	6·5	39·5	4·3	1·5
Dry malt, without ,,	4·2	93·1	2·7	8·8	76·3	8·0	2·5
Wheat bran	13·1	81·8	5·1	14·0	50·0	17·8	3·8
Rye bran	12·5	83·0	4·5	14·5	53·5	15·0	3·5
Rape cake	15·0	77·6	7·4	28·3	33·5	15·8	9·0
Linseed cake	11·5	80·7	7·9	28·3	41·3	11·0	10·0
Gold of pleasure cake	15·0	78·1	6·9	28·5	37·1	12·5	8·5
Poppy cake	10·0	81·6	8·4	32·5	37·7	11·4	8·1
Hemp ,,	10·5	85·5	4·0	27·0	36·5	22·0	6·2

PROXIMATE COMPOSITION OF AGRICULTURAL PLANTS AND PRODUCTS.

Substance.	Water.	Organic Matter.	Ash.	Albuminoids.	Carbo-hydrates, &c.	Crude fibre.	Fat, &c.
CAKES, REFUSE (*continued*).							
Beechmast cake	10·0	84·8	5·2	24·0	31·3	20·5	7·5
,, ,, without shells	12·5	79·8	7·7	37·3	36·9	5·5	7·5
Beet molasses	16·7	72·5	10·8	8·0	64·5	...	...
Potato fibre	82·6	17·1	0·3	0·8	15·0	1·3	0·1
COFFEE, TEA.							
Coffee berry	12·0	93·0	7·0	10·0	49·0	34·0	12·0
Cocoa seeds	11·0	85·0	4·0	20·0	52·0	13·0	44·0
Black tea	15·0	79·0	6·0	5·0	32·0	40·0	2·0
Green ,,	15·0	79·0	6·0	5·0	27·0	45·0	2·0

TABLE IV.

DETAILED ANALYSES OF BREAD GRAINS.

	Albuminoids.	Starch.	Gum and Sugar.	Fat.	Bran and Crude fibre.	Ash.	Water.	Analyst.
WHEAT.								
From Elsass	14·6	59·7	7·2	1·2	1·7	1·6	14·0	Boussingault.
,, Saxony	11·8	64·4	1·4	2·6	2·5	1·6	15·6	Wunder.
,, America	10·9	63·4	3·8	1·2	8·3	1·6	10·8	Polson.
,, Flanders	10·7	61·0	9·2	1·0	1·8	1·7	14·6	Péligot.
,, Odessa	14·3	59·6	6·3	1·5	1·7	1·4	15·2	,,
,, Tanganrock	13·6	57·9	7·9	1·9	2·3	1·6	14·8	,,
,, Poland	21·5	53·4	6·8	1·5	1·7	1·9	13·2	,,
,, Hungary	13·4	62·2	5·4	1·1	1·7	1·7	14·5	,,
,, Egypt	20·6	55·4	6·0	1·1	1·8	1·6	14·8	,,
RYE.								
From Hesse	13·6	50·5	8·9	0·9	10·1	1·8	15·0	Fresenius.
,, France	11·6	56·5	10·2	1·9	3·5	2·2	14·1	Payen.
,, Saxony	9·1	64·9	0·4	2·3	3·5	1·4	18·3	A. Müller.
,, ,,	9·6	56·7	6·4	2·1	8·5	3·3	16·5	Wolff.
BARLEY.								
	10·5	50·3	5·5	2·0	13·6	3·8	15·7	Wolff.
	13·2	53·7	4·2	2·6	11·5	2·8	12·0	Polson.
From Salzmünde, Prussia	9·3	60·4	1·2	2·0	9·7	2·4	15·0	Grouven.
OATS.								
	8·8	55·4	2·5	6·4	9·6	2·7	14·6	A. Müller.
	15·7	32·2	...	...	...	4·1	12·9	Krocker.
	10·2	...	...	6·1	10·0	2·7	12·6	Anderson.
BUCKWHEAT.								
Husked, from Vienna	2·6	78·9	3·8	0·9	1·0	...	12·7	Bibra.
,, ,, ,,	3·6	76·7	4·3	1·3	1·3	...	13·7	,,
,,	13·1	...	...	3·9	3·5	2·5	13·0	Boussingault.
Unhusked	8·5	37·8	...	...	...	2·0	14·2	Horsford and Krocker.
,,	9·1	45·0	7·1	0·4	22·0	2·4	14·0	Zenneck.
MAIZE.								
From Saxony	8·8	58·0	5·3	9·2	4·9	3·2	10·5	Hellriegel.
,, America	8·8	54·4	2·7	4·6	15·8	1·7	12·0	Polson.
,, Galacz	9·1	49·5	2·9	4·5	20·4	1·8	10·8	,,
,, Switzerland	...	51·2	6·7	3·8	12·5	...	10·6	Bibra.

DETAILED ANALYSES OF BREAD GRAINS.

	Albuminoids.	Starch.	Gum and Sugar.	Fat.	Bran and Crude fibre.	Ash.	Water.	Analyst.
RICE.								
From Piedmont	7·5	...	...	0·5	0·9	0·5	14·6	Boussingault.
,, Patna	7·2	79·9	1·6	0·1	0·5	0·9	9·8	Polson.
,, Piedmont	7·8	...	...	0·2	3·4	0·3	13·7	Péligot.
,, East Indies	5·9	73·9	2·3	0·9	2·0	...	14·0	Bibra.
MILLET.								
Husked. Hagenau	20·6	...	...	3·0	2·4	2·2	14·0	Boussingault.
,, Nuremberg	10·3	57·0	11·0	8·0	2·0	...	12·2	Bibra.

TABLE V.

DETAILED ANALYSES OF POTATOES. By GROUVEN.

(Agricultur-Chemie, 2te Auf., pp. 495, 355.)

	White Potatoes, newly dug.				Various Sorts. Average of 19 Analyses.
	Unmanured.		Manured.		
Water	74·95		78·01		76·00
Albumen	0·47	= 2·11	0·89	= 3·19	2·80
Caseine	0·04		0·03		
Gliadine and mucidine	0·29		0·25		
Veg. fibrine	1·31		2·02		
Gum and pectine	0·76		1·56		1·81
Organic acids	2·00		1·50		...
Fat	0·07		0·05		0·30
Starch	17·33		13·40		15·24
Cellulose	1·90		1·24		1·01
Ash	0·88		1·05		0·95
	100·		100·		

TABLE VI.

DETAILED ANALYSES OF SUGAR BEETS.

	Water.	Albuminoids.	Sugar.	Org. Acids, pectine, &c.	Crude fibre.	Ash.	Analyst.
Hohenheim	81·5	0·87	11·90	3·47	1·35	0·89	Wolff.
Moeckern	84·1	0·82	9·10	3·90	1·05	0·99	Ritthausen.
,, 2 lbs.	81·7	0·84	11·21	3·86	1·36	0·94	,,
,, ½ lb.	79·5	0·90	12.07	5·09	1·52	0·88	,,
Bickendorf, 1½ lbs.	80·0	0·70	12·90	5·00	1·20	0·70	Grouven.
Slanstädt, 2 lbs.	80·0	0·68	13·37	5·21		0·74	Stöckhardt.
Lockwitz, 1½ ,,	79·9	0·65	13·32	5·53		0·60	,,
Tharand, 1½ ,, manured	82·7	0·93	12·34	3·24		0·79	,,
,, 2 ,, ,,	81·8	1·16	10·15	5·77		1·12	,,
,, 3¼ ,, ,,	82·1	1·14	9·25	6·36		1·15	,,
,, 4 ,, ,,	82·5	1·05	8·45	7·07		0·93	,,
Silesia, unmanured	84·4	1·14	9·80	3·96		0·69	Bretschneider.
,, manured with sodium nitrate	82·7	1·42	11·57	3·63		0·68	,,
,, manured with tricalcic phosphate	84·1	1·20	9·82	4·04		0·77	,,
Average	81·5	0·95	11·5	3·7	1·3	0·85	

TABLE VII.

COMPOSITION OF FRUITS, according to FRESENIUS (Ann. Ch. u. Ph., 101, p. 219).

		Soluble Matters.						Seeds, Skins and Insoluble Matters.					Water.	
		Sugar.*	Free acid.†	Albuminoids.	Pectine-bodies. Gum. Organic Acids in combination.	Soluble Ash-ingredients.	Total Soluble Matters.	Seeds.	Skins and Cellulose.	Pectose.	Insoluble Ash-ingredients.‡	Total Insoluble Matters.		
GOOSEBERRIES.														
1. Large, red, prickly	1854	8·063	1·358	0·441	0·969	0·317	11·148	2·481	0·512	0·294	(0·146)	3·287	85·565	100·000
2. Small, red, prickly	1854	6·030	1·573	0·445	0·513	0·452	9·013	2·442		0·515	(0·069)	2·957	88·030	100·000
3. ,, ,, ,,	1855	8·239	1·589	0·358	0·522	0·504	11·212	2·529		1·428	(0·247)	3·957	84·831	100·000
4. Medium yellow, nearly smooth	1854	6·383	1·078	0·578	2·112	0·200	10·351	3·380	0·442	0·308	(0·100)	4·130	86·519	100·000
5. ,, ,, ,, ,,	1855	7·507	1·334	0·369	2·113	0·277	11·600	2·081		0·955	(0·170)	3·036	85·364	100·000
6. Large, red, smooth	1855	6·483	1·664	0·306	0·843	0·553	9·849	2·803		0·390	(0·133)	3·193	86·958	100·000
CURRANTS.														
7. Red, medium, ripe	1854	4·78	2·31	0·45	0·28	0·54	8·36	4·45	0·66	0·69	(0·11)	5·80	85·84	100·00
8. ,, ,, ,,	1855	6·44	1·84	0·49	0·19	0·57	9·53	4·48		0·72	(0·23)	5·20	85·27	100·00
9. Very large cherry currants	1855	5·647	1·695	0·356	0·007	0·620	8·35	3·940		2·380	(0·185)	6·320	85·355	100·000
10. White	1854	6·61	2·26	0·77	0·18	0·54	10·36	4·94		0·53	(0·12)	5·47	84·17	100·00
11. ,,	1855	7·692	2·258	0·300		0·560	10·810	4·144		0·24	...	4·384	84·806	100·000
12. ,,	1856	7·12	2·53	0·68	0·19	0·70	11·22	4·85		0·51	(0·14)	5·36	83·42	100·00
STRAWBERRIES.														
13. Wild	1854	3·247	1·650	0·619	0·145	0·737	6·398	6·032		0·292	(0·315)	6·331	87·271	100·000
14. ,,	1855	4·550	1·332	0·567	0·049	0·603	7·101	5·580		0·300	(0·345)	5·880	87·019	100·000
15. Ananas	1855	7·575	1·133	0·359	0·119	0·480	9·666	1·960		0·900	(0·154)	2·860	87·474	100·000
RASPBERRIES.														
16. Red, wild	1854	3·597	1·980	0·546	1·107	0·270	7·500	8·460		0·180	(0·134)	8·640	83·860	100·000
17. Red, garden	1855	4·708	1·356	0·544	1·746	0·481	8·835	4·106		0·502	(0·296)	4·608	86·557	100·000
18. White, garden	1855	3·703	1·115	0·665	1·397	0·380	7·260	4·520		0·040	(0·081)	4·560	88·180	100·000

* Saccharose and Fructose. † Expressed as hydrated malic acid. ‡ Already included in Seeds, Skins, &c.

TABLE VII. (COMPOSITION OF FRUITS, &c.) *continued.*

		Soluble Matters.						Seeds, Skins, and Insoluble Matters.					Water.	
		Sugar.*	Free Acid.†	Albuminoids.	Pectine-bodies. Gum, Organic Acids in combination.	Soluble Ash-ingredients.	Total Soluble Matters.	Seeds.	Skins and Cellulose.	Pectose.	Insoluble Ash-ingredients.‡	Total Insoluble Matters.		
19. BLACKBERRIES		4·441	1·188	0·310	1·444	0·414	8·000	4·210		0·384	(0·074)	5·594	86·406	100·000
20. WHORTLEBERRIES		5·780	1·341	0·794	0·555	0·858	9·328	12·864		0·256	(0·550)	13·120	77·552	100·000
21. MULBERRIES, black		9·192	1·860	0·394	2·031	0·566	14·043	0·905		0·345	(0·089)	1·250	84·707	100·000
GRAPES.														
22. Austrian, white	1854	13·780	1·020	0·832	0·498	0·360	16·490	2·592		0·941	(0·117)	3·533	79·977	100·000
23. Kleinberger	1855	10·590	0·820	0·662	0·220	0·377	13·629	1·770		0·750	(0·077)	2·520	84·870	100·000
24. Riessling, Oppenheim	1855	13·52	0·71	4·07			18·30	...	...	...	...	5·66	76·04	100·00
25. ,, ,,	1855	15·14	0·50	3·46			19·10	...	...	...	...	6·52	74·38	100·00
26. Riessling, Johannisberg	1850	19·24	0·66	2·95			22·93	...	...	...	...	...	...	...
27. Assmanshäuser, red	1856	17·28	0·75	...			...	...	...	...	...	...	...	...
CHERRIES.														
28. Sweet, pale red	1854	13·110	0·351	0·903	2·286	0·600	17·250	5·480	0·450	1·450	(0·090)	7·380	75·370	100·000
				3·529										
29. Sweet, white	1855	8·568	0·961			0·835	13·435	3·244	0·464	0·401	(0·070)	4·109	82·456	100·000
30. Sweet, black	1855	10·700	0·560	1·010	0·670	0·600	13·540	5·730	0·366	0·664	(0·078)	6·760	79·700	100·000
31. Sour	1855	8·772	1·277	0·825	1·831	0·565	13·270	5·182	0·808	0·246	(0·067)	6·236	80·494	100·00
PLUMS.														
32. Green Gage, common, yellow, *Mirabelle*	1854	3·584	0·582	0·197	5·772	0·570	10·725	5·780	0·179	1·080	(0·082)	7·039	82·236	100·000
33. Do. med. size, yellowish green, *Reineclaude*	'54	2·960	0·960	0·477	10·475	0·318	15·190	3·250	0·680	0·010	(0·039)	3·940	80·841	100·000
34. Do. large, green, very sweet and juicy ,,	1855	3·405	0·870	0·401	11·074	0·398	16·148	2·852	1·035	0·245	(0·037)	4·132	79·720	100·000
									0·509					
35. Blue, medium size, tart	1854	1·996	1·270	0·475	2·313	0·496	6·550	4·190			(0·041)	4·699	88·751	100·000
36. Black, fair flavour	1855	2·252	1·331	0·426	5·851	0·553	10·413	3·329	1·020		(0·063)	4·349	85·238	100·000

PRUNES.														
37. Common, moderately sweet, weight 16 grammes	1855	5·793	0·952	0·785	3·646	0·734	11·910	3·540	1·990	0·630	(0·094)	6·160	81·930	100·000
38. Large Italian, very sweet, weight 19 grammes	1855	6·730	0·841	0·832	4·105	0·590	13·098	3·124	0·972	1·534	(0·066)	5·630	81·272	100·000
APRICOTS.														
39. Handsome, rather large, weight 47 grammes	1854	1·140	0·898	0·832	5·929	0·820	9·619	4·300	0·967	0·148	(0·071)	5·415	84·966	100·000
40. Very delicate, large, weight 60 grammes	1854	1·531	0·766	0·389	9·283	0·754	12·723	3·216	0·944	1·002	(0·104)	5·266	82·011	100·000
PEACHES.														
41. Large Holland	1855	1·580	0·612	0·463	6·313	0·422	9·390	4·629	0·991		(0·042)	5·620	84·990	100·000
42. ,, ,,	1855	1·565	0·734	11·058		0·913	14·270	6·764	2·420		(0·163)	9·184	76·546	100·000
APPLES.														
43. Large, English Reinette	1853	9·25	0·53	1·80			11·58	...	...	...	...	2·39	86·03	100·00
44. ,, ,, ,,	1854	5·96	0·39	0·52	7·61	0·22	14·70	0·07	1·71	1·49	(0·06)	3·27	82·03	100·00
45. ,, ,, ,,	1855	6·83	0·85	0·45	6·47	0·36	14·96	1·95		1·05	(0·03)	3·00	82·04	100·00
46. White table apple	1854	7·58	1·04	0·22	2·72	0·44	12·00	0·38	1·42	1·16	(0·03)	2·96	85·04	100·00
47. Borsdorfer	1853	7·61	0·61	6·85			15·07	...	...	...	...	2·44	82·49	100.00
48. White, *Matapfel*	1853	8·98	1·01	3·35			13·34	...	...	...	...	4·53	82·13	100.00
49. English Winter Goldpearmain	1853	10·36	0·48	5·11			15·95	...	...	...	...	2·18	81·87	100.00
PEARS.														
50. Sweet, red pear	1854	7·000	0·074	0·260	3·281	0·285	10·900	0·390	3·420	1·340	(0·050)	5·150	83·950	100·000
51. ,, ,, ,,	1855	7·940	trace	0·237	4·409	0·284	12·870	3·518		0·605	(0·049)	4·123	83·007	100·000

* Saccharose and Fructose.

† Expressed as hydrated malic acid.

‡ Already included in Seeds, Skins, &c.

TABLE VIII.

FRUITS ARRANGED ACCORDING TO THEIR PERCENTAGE OF SUGAR (average), FRESENIUS.

	Per cent.		Per cent.
Peaches	1·6	Currants	6·1
Apricots	1·8	Prunes	6·3
Plums	2·1	Gooseberries	7·2
Greengages	3·1	Red pears	7·5
Yellow plums	3·6	Apples	8·4
Raspberries	4·0	Morella cherries	8·8
Blackberries	4·4	Mulberries	9·2
Strawberries	5·7	Sweet cherries	10·8
Whortleberries	5·8	Grapes	14·9

TABLE IX.

FRUITS ARRANGED ACCORDING TO THEIR PERCENTAGE OF FREE ACID EXPRESSED AS HYDRATE OF MALIC ACID (average), FRESENIUS.

	Per cent.		Per cent.
Red pears	0·1	Blackberries	1·2
Yellow plums	0·6	Morella cherries	1·3
Sweet cherries	0·6	Plums	1·3
Peaches	0·7	Whortleberries	1·3
Grapes	0·7	Strawberries	1·3
Apples	0·8	Gooseberries	1·5
Prunes	0·9	Raspberries	1·5
Greengages	0·9	Mulberries	1·9
Apricots	1·1	Currants	2·0

TABLE X.

FRUITS ARRANGED ACCORDING TO THE PROPORTIONS BETWEEN ACID, SUGAR, PECTINE, AND GUM, &c. (averages), FRESENIUS.

	Acid.	Sugar.	Pectine, Gum, &c.
Plums	1	1·6	3·1
Apricots	1	1·7	6·4
Peaches	1	2·3	11·9
Raspberries	1	2·7	1·0
Currants	1	3·0	0·1
Greengages	1	3·4	11·8
Blackberries	1	3·7	1·2
Whortleberries	1	4·3	0·4
Strawberries	1	4·4	0·1
Gooseberries	1	4·9	0·8
Mulberries	1	4·9	1·1
Yellow plums	1	6·2	9·9
Morella cherries	1	6·9	1·4
Prunes	1	7·0	4·4
Apples	1	11·2	5·6
Sweet cherries	1	17·3	2·8
Grapes	1	20·2	2·0
Red pears	1	94·6	44·4

TABLE XI.

FRUITS ARRANGED ACCORDING TO THE PROPORTIONS BETWEEN WATER, SOLUBLE MATTERS, AND INSOLUBLE MATTERS

(averages), FRESENIUS.

	Water.	Soluble Matters.	Insoluble Matters.
Raspberrries	100	9·1	6·9
Blackberries	100	9·3	6·5
Strawberries	100	9·4	5·2
Plums	100	9·7	0·9
Currants	100	11·0	6·6
Whortleberries	100	12·1	16·9
Gooseberries	100	12·2	3·6
Yellow plums	100	13·0	1·5
Apricots	100	13·3	2·1
Red pears	100	14·3	5·5
Peaches	100	14·6	2·1
Prunes	100	15·3	3·2
Sour cherries	100	16·5	1·3
Mulberries	100	16·6	1·5
Apples	100	16·9	3·6
Greengages	100	18·5	1·2
Cherries	100	18·6	1·5
Grapes	100	22·8	5·8

TABLE XII.

PROXIMATE COMPOSITION OF SOME AGRICULTURAL PLANTS AND PRODUCTS (*Additional Analyses*).

	Water.	Ash.	Albuminoids.	Amyloids, &c.	Fibre.*	Oil.
Wheat bran	14·00	6·10	14·08	53·02	8·30	4·50
Linseed cake, American	12·00	6·20	28·80	34·30	6·30	12·40
,, Black Sea	11·58	6·73	31·94	29·37	7·50	12·88
,, St. Petersburg	12·98	6·23	29·51	30·82	9·34	11·12
,, East Indian	12·88	5·73	24·78	35·40	8·56	12·65
Rape cake	7·60	9·85	30·66	33·52	8·05	10·25
Cotton cake	12·47	6·57	21·87	31·43	19·19	8·46
Palm-nut kernel meal	6·96	3·16	14·30	41·06	14·50	20·02
Swedes	89·00	·60	1·40	7·84	·90	·26
Turnips	92·00	·68	1·15	5·01	1·00	·16

* The percentages of *fibre* in this and in Table XIV. were determined by boiling fifty grains of each material for two hours with ten ounces of water containing one per cent. of SO_3, and then also for two hours with ten ounces of water containing one per cent. of NaHO. The residual fibre may certainly be put down as indigestible, but it is doubtful whether part of the carbo-hydrates dissolved by this process should not also be so designated.

TABLE XIII.

PROPORTION OF OIL IN VARIOUS AIR-DRY SEEDS, according to Berjot.

(Knop's *Agricultur-Chemie*, p. 725.)

(The air-dry seeds contain 10 to 12 per cent. of hygroscopic water.)

Colza, common	40—45	Gold of Pleasure	35
,, *Schirmraps*	44	Water-melon	36
,, red India	40	Charlock	15—42
,, white ,,	40	Orange	40
Flax	34	Colocynth	16
Poppy	40—50	Cherry	42
Sesame	53	Almond	40
Mustard, white	30	Potato	16
,, black	29	Buckthorn	16
Hemp	28	Currant	26
Pea-nut	38	Beech-nut	24

TABLE XIV.

PROPORTION OF INDIGESTIBLE FIBRE IN SOME AGRICULTURAL PRODUCTS.

(The differences in the following results serve to account in part for the very variable proportions of fibre obtained in the analyses of products containing *oil*.)

	Percentage of Fibre,* determined in the	
	Presence of Oil.	Absence of Oil.
Linseed cake	14·28	11·60
Cotton cake, undecorticated	17·40	16·78
Wheat bran	10·15	8·31
Maize meal	4·84	1·36

* See note to Table XII.

TABLE XV.

PERCENTAGES OF NITROGEN AND ALBUMINOIDS* IN WHEAT GRAINS OF DIFFERENT DENSITY AND ASPECT.

(Church: *Practice with Science*, i. 347.)

Variety of Wheat.		Nitrogen.		Albuminoids.	
		Dense and Translucent Grains.	Light and Opaque Grains.	Dense and Translucent Grains.	Light and Opaque Grains.
Spalding, red	1864	1·79	1·40	11·33	8.86
Hallett's, rough-chaffed, white	1865	2·09	1·52	13·23	9·62
Archer's prolific	1865	1·71	1·42	10·82	8·95

* See page 295.

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