SAMUEL W. JOHNSON, M. A.

# HOW CROPS GROW.

A TREATISE ON THE

## CHEMICAL COMPOSITION, STRUCTURE AND LIFE OF THE PLANT,

FOR STUDENTS OF AGRICULTURE.

WITH

NUMEROUS ILLUSTRATIONS AND TABLES OF ANALYSES.

BY

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# PREFACE.

The original edition of this work, first published in 1868, was the result of studies undertaken in preparing instruction in Agricultural Chemistry which the Author has now been giving for three and thirty years. Together with the companion volume, "How Crops Feed," it was intended to present concisely but fully the then present state of Science regarding the Nutrition of the higher Plants and the relations of the Atmosphere, Water, and the Soil, to Agricultural Vegetation. Since its first appearance, our knowledge of the subject treated of in the present volume has largely participated in the remarkable advances which have marked all branches of Science during the last twenty years and it has been the writers' endeavor in this revised edition to post the book to date as fully as possible without greatly enlarging its bulk or changing its essential character. In attempting to reach this result he has been doubly embarassed, first, by the great and rapidly increasing amount of recent publications in which the materials for revision must be sought, and, second, by the fact that official duties have allowed very insufficient time for a careful and comprehensive study of the literature. In conclusion, it is hoped that while the limits of the book make necessary the omission of a multitude of interesting details, little has been overlooked that is of real importance to a fair presentation of the subjects discussed.

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# HOW CROPS GROW.

## INTRODUCTION.

The object of agriculture is the production of certain plants and certain animals which are employed to feed, clothe and otherwise serve 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, or, finally, have been deduced from theory.

The *science* of agriculture is the rational theory and systematic 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 sufficient 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 has failed 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 vigor and in stature. Agriculture was practiced hundreds and thousands of years ago, with a success that does not compare unfavorably with ours. Nearly all the essential points of modern cultivation were regarded by the Romans before the Christian era. The annals of the Chinese show that their wonderful skill and knowledge were in use 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 great advances have been made during the last hundred years; 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 fifty 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 written by a Scotch nobleman, the Earl of Dundonald, and was published at London in 1795. It is entitled: "A Treatise showing the Intimate Connection 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 the want of knowledge in such authors as have written on agriculture of the intimate connection 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, 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." He further 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 fifty 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! 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. Cato and Columella knew indeed that ashes, bones, bird-dung and green manuring, as well as drainage and aeration 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 fertilizers; and the mining of fossil bones and of potash salts, are industries largely or entirely 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, the telegraph, the telephone and the electric light, are working and shall evermore continue to work progress in the art of 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 worth the name. The fancies of an ignorant and undisciplined mind are not theory as that term is properly understood. Theory, in the strict scientific sense, is always a deduction from facts, and the best deduction of which the stock of facts in our possession admits. It is therefore also 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 skillful 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 skillfully 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 labors 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.

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, zoölogy and physiology, are most intimately related to it. It is not less concerned with social and political economy. In this treatise it will not be attempted to touch, much less cover, all this ground, but some account will be given of certain subjects whose understanding will be of the most direct service to the agriculturist. The Theory of Agriculture, as founded on chemical, physical and physiological science, in so far as it relates to the Chemical Composition, the Structure and the Life 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 and change.

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 some seventy chemical elements or simple substances.

The elements of chemistry are forms of matter which have thus far resisted all attempts at their simplification or decomposition.

In ordinary life we commonly encounter but twelve kinds of matter 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,
Aluminum,
Manganese,
Chromium,
Nickel.

So far as human agency goes, these chemical elements are indestructible as to quantity, and not convertible one into another.

We distinguish various natural manifestations of force which, acting on or through matter, produce all material phenomena. In the subjoined scheme the recognized forces are to some extent classified and defined, in a manner that may prove useful to the reader.

| | | | | |
|---|---|---|---|---|
| Act at sensible and insensible distances | Repulsive | LIGHT | Radiant | Physical |
| | | HEAT | | |
| | Attractive and Repulsive | ELECTRICITY | Inductive | |
| | | MAGNETISM | | |
| Act only at insensible distances | Attractive | GRAVITATION | Cosmical | |
| | | COHESION | Molecular | |
| | | CRYSTALLIZATION | | |
| | | ADHESION | | |
| | | SOLUTION | | |
| | | OSMOSE | | |
| | | AFFINITY | Atomic | Chemical |
| | | VITALITY | Organic | Biological |

Within human experience the different kinds of force are mostly convertible each into the others, and must therefore be regarded as fundamentally one and the same. Force, like matter, is indestructible. Force acting on a body may either increase its *Kinetic Energy*, or be stored up in it as *Potential Energy*. Kinetic (or actual) energy is the energy of a moving body. Potential (or possible) energy is the energy which a body may be able to exert because of its state or position. A falling stone or running clock gives out actual energy. The stone while being raised, or the clock while winding, acquires and stores potential energy. In a similar manner kinetic solar energy, reaching the earth as light, heat and chemical force, not only sets in operation the visible activities of plants, but accumulates in them a store of potential energy which, when they serve as food or fuel, reappears as kinetic energy in the forms of animal heat, muscular and nervous activity, or as fire and light.

The sciences that more immediately relate to agriculture are Physics, Chemistry and Biology.

**Physics**, or "natural philosophy," is the science which considers the general properties of matter and such phenomena as are not accompanied by essential change in its obvious qualities. All the forces in the preceding scheme, save the last two, manifest themselves 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 recognized as such. The forces whose play does not disturb the evident characters of substances are physical.

**Chemistry** is 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 are, in fact, converted into other substances. Chemical attraction, affinity, or chemism, as it is variously termed, unites two or more elements into compounds, unites compounds together into more complex compounds; and, under the influence of heat, light, and other agencies, 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.

**Biology**, or physiology, unfolds the laws of the propagation, development, sustenance, and death of living organisms, both plants and animals.

When we assert that the object of agriculture is to develop from the soil 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,—the materials of which it is made,—the mode of its construction and organization,—how it feeds upon the soil and air,—how it serves as food to animals,—how the air, soil, plant, and animal stand related to each other in a 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 1.

# CHEMICAL COMPOSITION OF THE PLANT.

## CHAPTER 1.

## THE VOLATILE PART OF PLANTS.

### § 1.

### DISTINCTIONS AND DEFINITIONS.

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 peculiarly 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 organized, and becomes organic.

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

VOLATILE AND FIXED MATTER.—All plants and animals, taken as a whole, and all of their organs, consist of a volatile and 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, citric acid, etc., are completely volatile when in a state of purity, and leave no ash.

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 is not an entirely accurate distinction. What is found in the ashes of a tree or of a seed, in so far as it was an essential part of the organism, was 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.

ULTIMATE ELEMENTS THAT CONSTITUTE THE PLANT.—Chemistry has demonstrated that the volatile and destructible part of organic bodies is chiefly made up 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, and nitrogen.*

These fourteen bodies are *elements*, which means, in chemical language, that they cannot be 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-named 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.

## ELEMENTS OF THE VOLATILE PART OF PLANTS.

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

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

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

**Carbon**, in the free state, is a solid. We are familiar with it in several forms, as lamp-black, charcoal, black-lead, 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 gas, also called carbon dioxide.

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 is illustrated in the preparation of charcoal.

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

EXP. 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 figure 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.

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

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

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

Fig. 1.

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

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

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

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

Carbon, in most of its forms, is extremely indestructible under ordinary circumstances. Hence stakes and fence posts, if charred before setting in the ground, last much 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 coloring matters, which is taken advantage of in the refining of sugar. They also destroy noisome odors, and are used for purposes of disinfection.

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 this element.

**Oxygen.**—Carbon is a solid, and is recognized by our senses of sight and feeling. Oxygen, on the other hand, is an air or gas, invisible, odorless, tasteless, and not distinguishable in any way from ordinary air by the unassisted senses.

It exists in the free (uncombined) state in the atmosphere we breathe, but there is no means of obtaining it pure except from some of its compounds. Many metals unite readily with oxygen, forming compounds (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) be kept for a long time near the temperature at which it boils, it is slowly converted into a red powder (red precipitate, red oxide of mercury, or mercuric oxide), which on being more strongly heated is decomposed, yielding metallic mercury and gaseous oxygen in a pure state.

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

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

A tube of difficultly fusible glass, 8 inches long and ½ inch wide, contains the red oxide of mercury or potassium chlorate.* 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. The shelf has, beneath, a funnel-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 potassium chlorate 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.

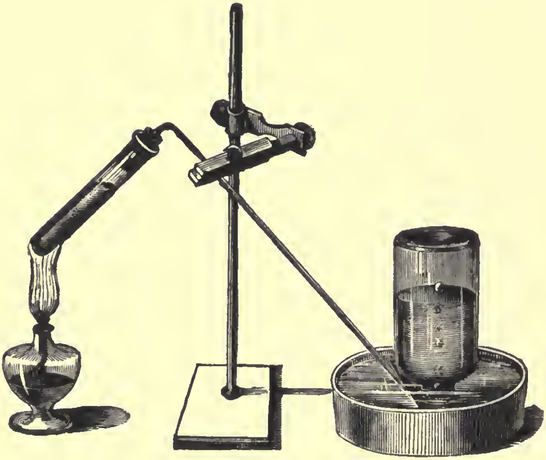

Fig. 2.

As this gas makes no peculiar impressions on the senses,

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* The potassium chlorate is best mixed with about one-quarter its weight of powdered black oxide of manganese, as this facilitates the preparation, and renders the heat of a common alcohol lamp sufficient.

we employ its behavior toward other bodies for its recognition.

EXP. 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.

*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.

Oxygen is the grand supporter of combustion, and nearly all 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 quantities 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 comparatively 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.

EXP. 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 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 acid gas*, which in its turn combines with lime, producing *carbonate of lime*. 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.

EXP. 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, ½ 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 two distinct *oxides of iron*, of which one,—ferric oxide,—will be found as a yellowish-red coating on the sides of the bottle; the other,—magnetic oxide,—will fuse to black, brittle globules, which falling, often melt quite into the glass.


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.

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 appears to be analogous

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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 few minutes in a well-stoppered bottle. On standing, the excess of lime will settle, and the perfectly clear liquid above it is ready for use.

in a chemical sense to actual burning, Liebig has proposed the term *eremacausis* (slow burning), to designate the chemical process of oxidation which takes place in decay, and which is concerned in many transformations, as in the making of vinegar and the formation of saltpeter.*

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

Oxygen has a nearly universal tendency to combine with other substances, and form with them new compounds. With carbon, as we have seen, it forms carbonic acid gas or carbon dioxide. With iron it unites in various proportions, giving origin to several distinct oxides. In decay, putrefaction, fermentation, and respiration, numberless new products are formed, the results of its chemical affinities.

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.**—This body is the other chief constituent of the atmosphere, of which it makes up about four-fifths the bulk, and in which its office would appear to be

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* Recent investigation has demonstrated that the oxidations which Liebig classed under the term eremacausis, are for the most part strictly dependent on the vital processes of extremely minute organisms, which are in general characterized by the terms microbes or microdemes, and are more specifically designated bacteria, i. e., "rod-shaped animalcules or plantlets."

mainly that of diluting and tempering 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.

EXP. 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 pepper-corn 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 inclosed nitrogen quite clear.

Fig. 5.

EXP. 9.—Another instructive method of preparing nitrogen is the following: A handful of green vitriol (protosulphate of iron or ferrous sulphate) is dissolved in half a pint of water, the solution is put into a quart bottle, a gill of ammonia-water 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, manifests no active properties, but is best characterized 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.

Exp. 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 cannot maintain respiration, so that animals perish if confined in it. Vegetation also dies in an atmosphere of this gas. For this reason it was formerly called Azote (against life). In general it is difficult to effect direct union of nitrogen with other bodies, but at a high temperature, in presence of alkalies, it unites with carbon, forming cyanides.

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

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

Hydrogen, like oxygen, is a gas, destitute, when pure, of either odor, taste, or color. It does not occur naturally in the free state, except in small quantity in the emanations from boiling springs and volcanoes. Its most simple preparation 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.

Exp. 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 should first be wiped free from the naphtha in which it is kept, and then be wrapped tightly in several folds of paper. On bringing it, thus prepared, under the mouth of the bottle, it floats upward, and when the water penetrates the paper, an abundant escape of gas occurs.

*Metallic iron,* when at a red heat, rapidly decomposes water, uniting with oxygen and setting hydrogen free, as may be shown by passing steam from boiling water through a gun-barrel filled with iron-turnings and heated to bright redness. Certain acids which contain hydrogen are decomposed by iron, zinc, and some other metals, their hydrogen being separated as gas, while the metal takes the place of the hydrogen with formation of a salt. Hydrochloric acid (formerly called muriatic acid) is a compound of hydrogen with chlorine, and may accordingly be termed *hydrogen chloride.* When this acid is poured upon zinc the latter takes the chlorine, forming *zinc chloride,* and hydrogen escapes as gas. Chemists represent such changes by the use of symbols (first letters of the names of chemical elements), as follows:

$$\begin{matrix}H\,Cl\\H\,Cl\end{matrix} + Zn = Zn\begin{matrix}Cl\\Cl\end{matrix} + \begin{matrix}H\\H\end{matrix} \text{ or}$$

$$2\,(H\,Cl) + Zn = Zn\,Cl_2 + H_2$$

EXP. 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 hydrochloric acid 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 for oxygen. The first portions that pass over are mixed with air, *and should be rejected, as the mixture is dangerously explosive.*

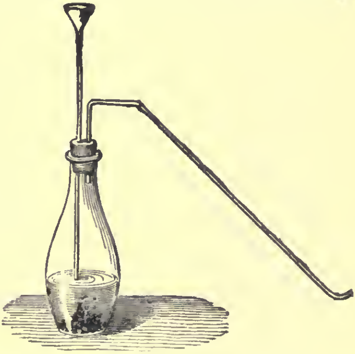

Fig. 6.

One of the most striking properties of free hydrogen is its levity. It is the lightest body in nature that has been weighed, 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 that is intensely hot, though scarcely luminous if the gas be pure. Finally, it is itself incapable of supporting the combustion of a taper.

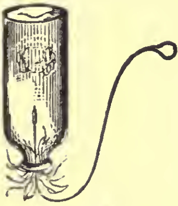

Fig. 7.

EXP. 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.

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 last experiment do not permit the collection or identification of this water; its production can, however, readily be demonstrated.

EXP. 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 dilute acid in the two-necked bottle. Thus

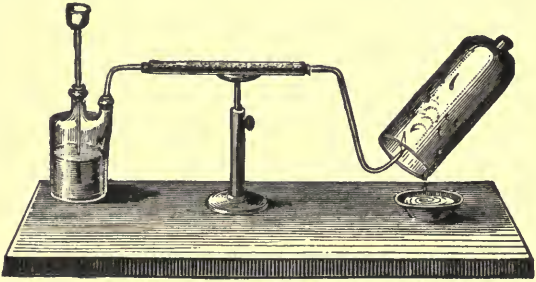

Fig. 8.

produced, it is mingled with spray, to remove which it is made to stream through a tube loosely filled with cotton. After *air has been entirely displaced* from the apparatus, the gas is ignited at the upcurved 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 organic 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, etc. The chief illuminating ingredient of coal gas (ethylene or olefiant gas), the coal or rock oils (kerosene), together with benzine and paraffine, are so-called hydro-carbons.

**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 color, and a peculiar odor and taste.

Uncombined sulphur is comparatively rare, the commercial supplies being almost exclusively of volcanic origin ; 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 peculiar nauseous taste, which is called *sulphurous acid gas* or *sulphur dioxide.*

EXP. 15.—Heat a bit of sulphur as large as a grain of wheat on a slip of iron or glass, over the flame of a spirit lamp, for observing its fusion, combustion, and the development of sulphur 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 an opaque white fume of sulphur dioxide.

Sulphur forms with oxygen another compound, the *trioxide,* which, in combination with water, constitutes common *sulphuric acid,* or *oil of vitriol.* This oxide is developed to a slight extent during the combustion of sulphur in the air and the acid 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 formerly as *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.

EXP. 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 a red vapor or gas, introduce the iron coil, previously heated to redness, into the sulphur vapor. The sulphur and iron unite; the iron, in fact, *burns* in the sulphur gas, giving rise to a black iron sulphide, in the same manner as in Exp. 7 it burned in oxygen gas and produced an iron oxide. The iron sulphide 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 odor of rotten eggs, and is, in fact, the chief cause of the noisomeness of this kind of putridity. This gas, commonly called *sulphuretted hydrogen,* or *hydrogen sulphide,* 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 or hydrochloric acid.

EXP. 17.—Place a lump of the iron sulphide prepared in Exp. 16 in a cup or wine-glass, add a little water, and lastly a little hydrochloric acid. Bubbles of hydrogen sulphide will shortly escape.

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

In plants, sulphur is always present, though usually in small proportion. The turnip, the onion, mustard, horseradish, and assafœtida owe their peculiar flavors to volatile oils of which sulphur is an ingredient.

Albumin, globulin, casein and similar principles, never absent from plant or animal, possess also a small content of sulphur. In hair and horn it occurs to the amount of three to five per cent.

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

**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 two distinct forms. In the more commonly occurring form, it is colorless or yellow, translucent, waxlike 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*. The other 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 yellow phosphorus is chiefly used. When burned in air or in oxygen gas this element forms a white substance—phosphorus pentoxide (formerly termed anhydrous phosphoric acid)—which dissolves in water, at the same time uniting chemically with a portion of the latter, and thus yielding a body of the utmost agricultural importance, viz., *phosphoric acid*.

**Exp. 18.**—Burn a bit of phosphorus under a bottle, as in Exp. 8, omitting the water on the plate. The snow-like cloud of phosphorus pentoxide gathers partly on the sides of the bottle, but mostly on the plate. It attracts moisture when exposed to the air, and hisses from development of heat when put into water. Dissolve a portion of it in hot water, and observe that the solution is acid to the taste. Finally evaporate the solution to dryness at a gentle heat. Instead of recovering thus the white opaque phosphorus pentoxide, the residue is a transparent mass of phosphoric acid, a compound of phosphorus, oxygen and hydrogen.

In nature phosphorus is usually found in the form of *phosphates,* which are phosphoric acid whose hydrogen has been partly or entirely replaced by metals.

In plants and animals, it exists for the most part as phosphates of calcium (or lime), magnesium (or magnesia), potassium (or potash), and sodium (or soda).

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

EXP. 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 90 per cent. is calcium phosphate.

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

EXP. 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. 19) until a white cloud or *precipitate* is perceived. This is a *calcium phosphate.* 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 phosphates of calcium, aluminium, and iron.

The tissues and juices of animals and plants generally contain small proportions of several highly complex "organic compounds" in which phosphoric acid is associated with the elements carbon, oxygen, hydrogen and nitrogen. Such substances are chlorophyll, lecithin and nuclein, to be noticed hereafter.

We have thus briefly considered the more important characters of those six bodies 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 are often termed the *organic elements* of vegetation, are chiefly compounded all the numberless products of life to be met with, either in the vegetable or animal world.

### 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 vegetable matter is here subjoined.

| | *Grain of Wheat.* | *Straw of Wheat.* | *Tubers of Potato.* | *Grain of Peas.* | *Hay of Red Clover.* |
|---|---|---|---|---|---|
| Carbon | 46.1 | 48.4 | 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 | 0.80 | 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—chemical affinity—in virtue of whose action these elements are held in their combinations and, in order to understand the language of chemical science, must know something of the views that now prevail as to the constitution of matter.

## § 3.

### CHEMICAL AFFINITY.—THE ATOMIC-MOLECULAR THEORY.

**Chemical Attraction or Affinity** *is that force or kind of energy which unites or combines two or more substances of unlike character, to a new body different from its ingredients.*

**Chemical Combination** differs essentially from mere mixture. Thus we may put together in a 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 with which we are acquainted.

In the atmosphere we have oxygen and nitrogen in a state of mere mixture, each of these gases exhibiting its own characteristic properties. When brought into chemical combination, they are capable of yielding a series of no less than five distinct compounds, one of which is the so-called laughing-gas, while the others form suffocating and corrosive vapors that are totally irrespirable.

**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 found united in nature, principally in the form of water; and water, if pure, is always composed of one-ninth hydrogen and eight-ninths oxygen by weight, or, since oxygen is, bulk for bulk, sixteen times heavier than hydrogen, of one volume or measure of oxygen to two volumes of hydrogen.

**Atoms.**—It is now believed that matter of all kinds consists of indivisible and unchangeable particles called *atoms*, which are united to each other by chemical attraction, and cannot ordinarily exist in the free state. On this view each particular kind of matter or chemical substance owes its individuality either to the special kinds or to the numbers of the atoms it consists of. Atoms may be defined as the smallest quantities of matter which can exist in chemical combination and the smallest of which we have any knowledge or conception.

**Atomic Weight of Elements.**—On the hypothesis that chemical union takes place between atoms of the elements, the simplest numbers expressing the proportions by weight* in which the elements 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 unit. 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 mentioned or described.

**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.

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) |
| Potassium | 39 | K (Kalium) |
| Sodium | 23 | Na (Natrium) |
| Calcium | 40 | Ca |
| Iron | 56 | Fe (Ferrum) |

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

† Now, chemists receive as the true atomic weights *double* the numbers that were formerly employed, those of hydrogen, chlorine and a few others excepted. The atomic weights here given are mostly whole numbers. The actual atomic weights, as experimentally determined, differ from the above by small fractions, which may be neglected.

**Multiple Proportions.**—When two or more bodies unite in several proportions, their quantities, when not expressed by the atomic weights, are twice, thrice, four, or more times, these weights; they are multiples of the atomic weights by some simple number. Thus, carbon and oxygen form two commonly occurring compounds, viz., *carbon monoxide,* consisting of one atom of each ingredient, and *carbon dioxide,* which contains to one atom, or 12 parts by weight, of carbon, two atoms, or 32 parts by weight, of oxygen.

**Molecules**[*] contain and consist of chemically-united atoms, and are the smallest particles of matter that can have an individual or physical existence. While the atoms compose and give character to the molecules, the molecules alone are sensibly known to us, and they give character to matter as we find it in masses, either solid, liquid or gaseous. In solids the molecules more or less firmly cohere together; in liquids they have but little cohesion, and in gases they are far apart and tend to separate from each other. The so-called "elements" are, in fact, mostly compounds whose molecules consist of two or more like atoms, while all other chemical substances are compounds whose molecules are made up of two or more unlike atoms.

**Molecular Weights of Compounds.**—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 car-

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[*] Latin diminutive, signifying *a little mass.*

[†] We must refer to recent treatises on chemistry for fuller information as to atoms and molecules and the methods of finding the atomic and molecular weights.

bonates of ammonium, which consists of four elements, ten atoms, and has a molecular weight of seventy-nine.

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 carbon dioxide gas and a molecule of water to produce a molecule of ammonium carbonate.

| | | | Atoms. | Atomic weights. | Molecular weights. | |
|---|---|---|---|---|---|---|
| Ammonium Carbonate 1 mol. | Ammonia 1 mol. | Hydrogen, | 3 | = 3 | =17 | =79 |
| | | Nitrogen, | 1 | = 14 | | |
| | Carbon dioxide 1 mol. | Carbon, | 1 | = 12 | =44 | |
| | | Oxygen, | 2 | = 32 | | |
| | Water, 1 mol. | Hydrogen, | 2 | = 2 | =18 | |
| | | Oxygen, | 1 | = 16 | | |

**Notation and Formulas 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 also *one part of it by weight* as compared with 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, carbon monoxide is represented by CO, mercuric oxide by HgO, and iron monosulphide by FeS. The symbol CO conveys to the chemist not only the fact of the existence of carbon monoxide, 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.

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, and its symbol is $H_2O$. In like manner the symbol of carbon 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* and if correct is a molecular formula and shows the composition of one molecule of the substance. Subjoined is a table of the molecular formulas of some of the compounds that have been already described or employed.

FORMULAS OF COMPOUNDS.

| *Name.* | *Formula.* | *Molecular Weight.* |
|---|---|---|
| Water | $H_2O$ | 18 |
| Hydrogen Sulphide | $H_2S$ | 34 |
| Iron Monosulphide | FeS | 88 |
| Mercuric Oxide | HgO | 216 |
| Carbon Dioxide | $CO_2$ | 44 |
| Calcium Chloride | $CaCl_2$ | 111 |
| Sulphur Dioxide | $SO_2$ | 64 |
| Sulphur Trioxide | $SO_3$ | 80 |
| Phosphorus Pentoxide | $P_2O_5$ | 142 |

**Empirical and Rational Formulas.**—It is obvious that many different formulas can be made for a body of complex character. Thus, the carbonate of ammonium, whose composition has already been stated (p. 33), and which contains

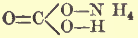
1 atom of Nitrogen,
1 atom of Carbon,
3 atoms of Oxygen, and
5 atoms of Hydrogen,

may be most compactly expressed by the symbol

$NCO_3H_5$.

Such a formula merely informs us what elements and how many atoms of each element 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* formulas, 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 real arrangement of the atoms in ammonium carbonate is believed to be expressed by the rational (or structural) formula



$$O{=}C\begin{cases}O{-}NH_4\\O{-}H\end{cases}$$

in which the carbon is directly united to oxygen, to which latter one hydrogen and the nitrogen are also linked, the remaining hydrogens being combined to the nitrogen.

**Valence.**—The connecting lines or dashes in the foregoing formula show the valence of the several atoms, i. e., their "atom-fixing power." The single dash from H indicates that hydrogen is *univalent* or has a valence of one. The two dashes connected with O express the *bivalence* of oxygen or that the atom of this element can combine with two hydrogens or other univalent atoms. The nitrogen is united on one hand with 4 hydrogen atoms, and also, on the other hand, satisfies half the valence of oxygen ; it is accordingly *quinquivalent*, i. e., has five units of valence. Carbon is *quadrivalent*, being joined to oxygen by four units of valence.

**Equations of Formulas** 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:

| *Potassium Chlorate.* |  | *Potassium Chloride.* |  | *Oxygen* |
|---|---|---|---|---|
| $2\,KClO_3$ | $=$ | $2\,KCl$ | $+$ | $3\,O_2$ |

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 compounds.

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

**Modes of Stating Composition of Chemical**

**Compounds.**—These are two: 1, *atomic* or *molecular* statements, and 2, *centesimal* statements, or proportions in one hundred parts (*per cent,* p. c., or %). 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 |
| Carbon Monoxide (CO), | 28 | 100.00 | Carbon Dioxide ($CO_2$), | 44 | 100.00 |

The conversion of one mode of statement 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 molecular 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, especially by heat, light and electricity.

## § 4.

## VEGETABLE ORGANIC COMPOUNDS, OR PROXIMATE PRINCIPLES.

We are now prepared to enter upon the study of the organic compounds, which constitute the vegetable structure, and which are produced from the elements carbon, oxygen, hydrogen, nitrogen, sulphur, and phosphorus, by chemical agency. 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, coloring matters, etc. 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 an intensely bitter "active principle," *caffeine*. 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, partly mechanical means, are conveniently termed *proximate principles*, and we shall notice them in some detail under eight principal classes, viz.:

1. WATER.
2. The CARBHYDRATES.
3. The VEGETABLE ACIDS.
4. The FATS and OILS.
5. The ALBUMINOIDS or PROTEIN BODIES and FERMENTS.
6. The AMIDES.
7. The ALKALOIDS.
8. PHOSPHORIZED SUBSTANCES.

**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 plants, is the immediate cause of the succulence of their tender portions, 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.)

| | *Average.* | *Range.* |
|---|---|---|
| Meadow grass | 71 | 60 to 78 |
| Red clover | 80 | 68 " 86 |
| Maize, as used for fodder | 82 | 71 " 93 |
| Cabbage | 85 | 80 " 94 |
| Potato tubers | 75 | 77 " 82 |
| Sugar beets | 81 | 76 " 90 |
| Carrots | 86 | 79 " 90 |
| Turnips | 91 | 86 " 93 |

In living plants, water is usually perceptible to the eye or feel, as *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, which is not recognizable 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.

EXP. 21.—Into a wide glass tube, like that shown in Fig. 2, place a spoonful of saw dust, 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 at least *two different conditions.* Red clover, for example, when growing or freshly cut, contains about 80 per cent of water. When the clover is dried, as for making hay, the greater share of this water escapes, so that the *air-dry* plant contains but about 15 per cent. On subjecting the air-dry clover to a temperature of 212 ° for some hours, the water is completely expelled, and the substance becomes really *dry,* i. e., *water-free.*

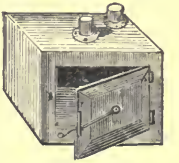


Fig. 9.

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 half 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, etc | 15 |
| Bean straw | 18 |
| Wheat (rye, oat) kernel | 14 |
| Maize kernel | 12 |

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, on crushing the fresh plant, is manifest to the sight and feel as a liquid. 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 *hygroscopic or combined water of vegetation*.

The amount of water contained in either fresh or air-dry vegetable matter is somewhat fluctuating, according to the temperature and the dryness of the atmosphere.

**2. The Carbhydrates.** This group falls into three subdivisions, viz. :

*a.* THE AMYLOSES, comprising Cellulose, Starch, Inulin, Glycogen, the Dextrins and Gums, having the formula $(C_6H_{10}O_5)n$.

*b.* THE GLUCOSES, which include Dextrose, Levulose, Galactose and similar sugars, having the composition $C_6H_{12}O_6$.

*c.* THE SUCROSES, viz.: Cane Sugar or Saccharose, Maltose, Lactose and other sugars, whose formula in most cases is $C_{12}H_{22}O_{11}$.

On account of their abundance and uses the Carbhydrates rank as the most important class of vegetable substances. Their name refers to the fact that they consist of Carbon, Hydrogen and Oxygen, the last two elements being always present in the same proportions that are found in water.

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

*a. The Amyloses.*

**Cellulose** $(C_6H_{10}O_5)n$.—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. 19 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.

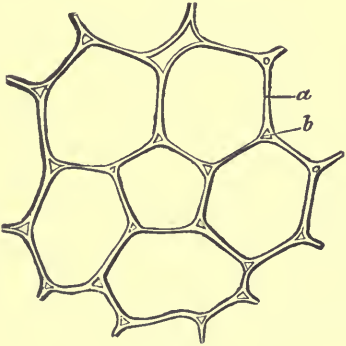


Fig. 10.

The outer coating, or wall, of the vegetable cell consists chiefly or entirely of 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.

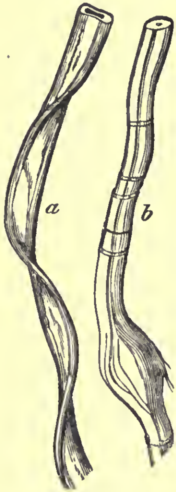


Fig. 11.

Nearly all plants and all their parts contain cellulose, but it is relatively most abundant in 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 proportion.

The fibers 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 fibers 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 fiber, and *b* the thicker and more durable fiber of linen.

Wood, or woody fiber, consists of long and slender cells of various forms and dimensions (see p. 293), 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 more or less intergrown with other substances.* The hard shells of nuts and stone fruits contain a basis of cellulose, which is impregnated with other matters.

When quite pure, cellulose is a white, often silky or spongy, and translucent body, its appearance varying

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* Wood was formerly supposed to consist of cellulose and so-called "lignin." On this view, according to F. Schulze, lignin impregnates (not simply incrusts) the cell-wall, 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 the cellulose, etc., have been removed. "Lignin" cannot be separated in the pure state, and has never been analyzed. What is thus designated is a mixture of several distinct substances. Fremy's lignose, lignone, lignin, and lignireose, as well as J. Erdman's glycolignose and lignose, are not established as chemically distinct substances.

somewhat according to the source whence it is obtained. In the air-dry state, at common temperatures, it usually contains about 10 % 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, as it naturally occurs, for the most part 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 tissues containing it, with successive solvents, until all other matters are removed.

The "skeletonized" leaves, fruit vessels, etc., 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 fibers 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 potassium chlorate and dilute nitric acid for a number of days.

**EXP. 22.**—To 500 *cubic centimeters** (or one pint) of nitric acid of density 1.1, add 30 grams (or one ounce) of pulverized potassium chlorate, and dissolve the latter by agitation. Suspend in this mixture a number of leaves, etc.,† and let them remain undisturbed, at a temperature not above 65° F., until they are perfectly whitened, which may require from 10 to 20 days. The skeletons should be floated out from the solution on slips of paper, washed copiously in clear water, and dried under pressure between folds of unsized paper.

The fibers of the whiter and softer kinds of wood are now much employed in the fabrication of paper. For this purpose the wood is rasped

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* 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 exclusively employed in all scientific treatises and investigations. For small weights, the *gram*, abbreviated gm. (equal to 15½ grains, nearly), is the customary unit. The unit of measure by volume is the *cubic centimeter*, abbreviated c. c. (30 c. c. equal one fluid ounce nearly). Gram weights and glass measures graduated into cubic centimeters 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, etc., may be employed to furnish skeletons that will prove valuable in the study of the structure of these organs.

to a coarse powder by machinery, then heated with a weak soda lye, and finally bleached with chloride of lime.

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

**Cellulose Nitrates.**—Strong nitric acid transforms cellulose into various *cellulose nitrates* according to its concentration. In these bodies portions of the hydrogen and oxygen of cellulose are replaced by the atomic group (radicle), $NO_3$. Cellulose hexanitrate, $C_{12}H_{14}(NO_3)_6O_{10}$, is employed as an explosive under the name gun cotton. The collodion employed in photography is a solution in ether of the penta- and tetranitrates, $C_{12}H_{15}(NO_3)_5O_{10}$ and $C_{12}H_{16}(NO_3)_4O_{10}$. Sodium hydroxide changes these cellulose nitrates into cellulose and sodium nitrate.

Hot nitric acid of ordinary strength destroys cellulose by oxidizing it with final formation of carbon dioxide gas and oxalic acid.

**Cellulose Sulphates.**—When cold sulphuric acid acts on cellulose the latter may either remain apparently unaltered or swell up to a pasty mass, or finally dissolve to a clear liquid, according to the strength of the acid, the time of its action, and the quality (density) of the cellulose. In excess of strong oil of vitriol, cellulose (cotton) gradually dissolves with formation of various *cellulose sulphates*, in which OH groups of the cellulose are replaced by $SO_4$ of sulphuric acid. These sulphates are soluble in water and alcohol, and when boiled with water easily decompose, reproducing sulphuric acid, but not cellulose. Instead of the latter, dextrin and dextrose (grape sugar) appear.

**Soluble Cellulose,** or **Amyloid.**—In a cooled mixture of oil of vitriol, with about $\frac{1}{3}$ its volume of water, cellulose dissolves. On adding much water to the solution there separates a white substance which has the same composition as cellulose, but is readily converted into dextrin by cold dilute acid. This form of cellulose assumes a fine blue color when put in contact with iodine-tincture and sulphuric acid.

EXP. 23.—Fill a large test-tube first with water to the depth of two or three inches. Then add gradually three times that bulk of oil of vitriol, and mix thoroughly. When well cooled pour a part of the liquid on a slip of unsized paper in a saucer. After some time the paper is seen to swell up and partly dissolve. Now flow it with solution of iodine,* when these dissolved portions will assume a fine and intense *blue color*. This deportment is characteristic of cellulose, and may be employed for its recognition under the microscope. If the experiment be repeated, using a larger proportion of acid, and allowing the action to continue for a considerably longer time, the substance producing the blue color is itself destroyed, and addition of iodine has no effect.† Unaltered cellulose gives with iodine a *yellow* color.

Paper superficially converted into amyloid constitutes *vegetable parchment*, which is tough and translucent, much resembling bladder, and very useful for various purposes, among others as a substitute for sausage "skins."

EXP. 24.—Into the remainder of the cold acid of Exp. 23 dip a strip of unsized paper, and let it remain for about 15 seconds; then remove, and rinse it copiously in water. Lastly, soak 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 process for obtaining vegetable parchment depends upon the proper strength of the acid, and the time of immersion. If need be, repeat, varying these conditions slightly, until the result is obtained.

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 by animals which naturally feed on herbage, and therefore cellulose is ranked among the nutritive ingredients of cattle-food.

*Chemical composition of cellulose.*—This body is a com-

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* Dissolve a fragment of iodine as large as a wheat kernel in 20 c. c. of alcohol, and add 100 c. c. of water to the solution.

† According to Grouven, cellulose prepared from rye straw (and impure ?) requires several hours' action of sulphuric acid before it will strike a blue color with iodine (*2ter Salzmünder Bericht*, p. 467).

pound 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 $(C_6 H_{10} O_5)n$. The value of *n* in this formula is not certainly known, but is at least two, and the formula $C_{12}H_{20}O_{10}$ is very commonly adopted. In 100 parts it contains

| | |
|---|---|
| Carbon | 44.44 |
| Hydrogen | 6.17 |
| Oxygen | 49.39 |
| | 100.00 |

***Modes of estimating cellulose.***—In statements of the composition of plants, the terms *fiber*, *woody fiber*, 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. The methods are confessedly imperfect, because cellulose itself is dissolved to some extent, and a portion of other matters often remains unattacked.

The method of Henneberg, usually adopted (*Vs. St.*, VI, 497), is as follows: [illegible] grams of the finely divided substance are boiled for half an hour with 200 cubic centimeters 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 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. 113).

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 the crude cellulose thus prepared from the pea is perfectly white, that from wheat bran is brown, and that from rapecake is almost black in color, from impurities that cannot be removed by this method.

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

| | *Rye-straw fiber.* | *Flax fiber.* |
|---|---|---|
| Water | 8.65 | 5.40 |
| Ash | 2.05 | 1.14 |
| N | 0.15 | 0.15 |
| 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 fiber, analyzed by Henneberg, exhibit the following composition, compared with pure cellulose.

| | *Rye-straw fiber.* | *Flax fiber.* | *Wheat-straw fiber.* | *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 |

Fr. Schulze has proposed (1857) another method for estimating cellulose, which, though troublesome, is in most cases more correct than the one already described. Kühn, Aronstein, and H. Schulze (*Henneberg's Journal für Landwirthschaft*, 1866, pp. 289 to 297) have applied this method in the following manner: One part of the dry pulverized substance (2 to 4 grams), which has been previously extracted with water, alcohol, and ether, is placed in a glass-stoppered bottle, with 0.8 part of potassium chlorate and 12 parts of nitric acid of specific gravity 1.10, and digested at a temperature not exceeding 65° F. 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 165° F. 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 colored, 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 fiber is, however, purer than that procured by the other method, and the writers named obtained a somewhat larger quantity, by ½ to 1½ *per cent.* The results appear to vary but about one *per cent* from the truth. The observations of König (Vs. St. 16), and of Hoffmeister (Vs. St. 33, 155), show much larger differences in favor of Fr. Schulze's method.

Hugo Müller (Die Pflanzenfaser, p. 27) has described a method of obtaining cellulose from those materials which are employed in paper-making, which is based on the prolonged use of weak aqueous solution of bromine.

Trials made on hay and Indian-corn fodder with this method by Dr. Osborne, at the author's suggestion, gave results widely at variance with those obtained by Henneberg's method.

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

AMOUNT OF CELLULOSE IN PLANTS.

| | *Per cent.* | | *Per cent.* |
|---|---|---|---|
| Potato tuber | 1.1 | Red clover plant in flower | 10 |
| Wheat kernel | 3.0 | " " hay | 34 |
| Wheat meal. | 0.7 | Timothy | 23 |
| Maize kernel | 5.5 | Maize cobs | 38 |
| Barley " | 8.0 | Oat straw | 40 |
| Oat " | 10.3 | Wheat " | 48 |
| Buckwheat kernel | 15.0 | Rye " | 54 |

**Starch** $(C_6H_{10}O_5)n$ is of very general occurrence in plants. The cells of the seeds of wheat, corn, 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 pounds. The onion, and various plants of the lily tribe, are said to be entirely destitute of starch.

The preparation of starch from the potato is very simple. The potato tuber contains about 70 per cent. water, 24 per cent starch, and 1 per cent of cellulose, while the remaining 5 per cent consist 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 agitated on a fine sieve, in a stream of water. The washings run off milky from suspended starch, while the cell-tissue is retained by the sieve. The milky liquid is allowed to rest in vats until the starch is deposited. The water is then poured off, and the starch is collected and dried.

Wheat-starch may be obtained by allowing wheaten flour mixed with water to ferment for several weeks. In this process the gluten, etc., are converted into soluble matters, which are removed by washing, from the unaltered starch.

Starch is now most largely manufactured from maize. A dilute solution of caustic soda is used to dissolve the albuminoids (see p. 87). 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 nearly pure starch, the *corn-starch* of commerce.

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

*Arrow-root* is starch obtained by grating and washing the root-sprouts of *Maranta Indica*, and *M. arundinacea*, plants native to the East and West Indies.

EXP. 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 either a white powder which consists of minute, rounded grains, and hence has a slightly harsh feel, or occurs in 5 or 6-sided columnar masses which readily crush to a powder. Columnar starch acquires that shape by rapid drying of the wet substance. When observed under a powerful magnifier, the starch-grains often present characteristic forms and dimensions.

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

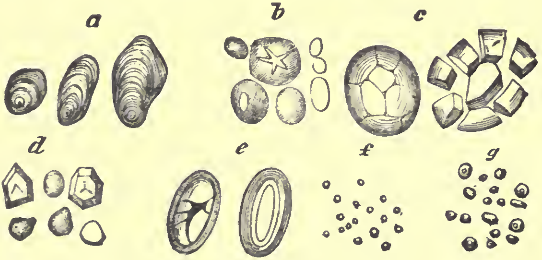

Fig. 12.

starch-grains of the parsnip are represented at *f*, and those of the beet at *g*.

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

The starch-grains have an organized structure, plainly seen in those from the potato, which are marked with curved lines or ridges surrounding a point or eye; *a*, Fig. 12. When a starch-grain is heated cautiously, it swells and exfoliates into a series of more or less distinct layers.

Starch, when air-dry, contains a considerable amount of water, which may range from 12 to 23 per cent. Most of this water escapes readily when starch is dried at 212°, but a temperature of 230° F. is needful to expel it completely. Starch, thus dried, has the same composition in 100 parts as cellulose, viz.:

| | |
|---|---|
| Carbon | 44.44 |
| Hydrogen | 6.17 |
| Oxygen | 49.39 |
| | 100.00 |

Starch-grains are unacted upon by cold water, unless broken (see Exp. 26), and quickly settle from suspension in it, having a specific gravity of 1.5.

*Iodine-Test for Starch.*—The chemist is usually able to recognize 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-grains, most commonly gives them a beautiful blue or violet color. This test may be used even in microscopic observations with the utmost facility. Some kinds of starch-grains are, however, colored red, some yellow, and a few brown, probably because of the presence of other substances.

Exp. 26.—Shake together in a test-tube 30 c. c. of water and starch of the bulk of a kernel of maize. Add solution of iodine drop by drop, agitating until a faint purplish color 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 preponderates, it settles to the bottom, leaving a colorless liquid, which shows the insolubility of starch in cold water; the starch itself has a purple or red tint. In the case iodine was used in excess, the deposited starch is blue-black.

By the prolonged action of dry heat, hot water, acids, or alkalies, starch is converted first into amidulin, then into dextrin, and finally into the sugars maltose and dextrose, as will be presently noticed.

Similar 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 likewise disintegrates the starch-grains and mostly dissolves the starch by converting it into maltose (sugar). It is much more promptly converted into sugar by the liquids of the large intestine. It is thus digested when eaten by animals. Starch is, in fact, one of the most important ingredients of the food of man and domestic animals.

The starch-grains are not homogeneous. After prolonged action of saliva, hot water, or of dilute acids on starch-grains, an undissolved residue remains which De-Saussure (1819) regarded as nearly related to cellulose. This residue is not changed by boiling water, but, under prolonged action of dilute acids, it finally dissolves. With iodine, after treatment with strong sulphuric acid, it gives the blue color characteristic of cellulose. Therefore it is commonly termed *starch-cellulose.*

Starch-cellulose amounts to 0.5 to 6 per cent of the starch-grains, varying with the kind of starch and the nature and duration of the solvent action. Whether it be originally present or a result of the treatment by acids, etc., is undecided.

The chemical composition of starch-cellulose is identical with that of the entire starch-grain, viz.: $(C_6H_{10}O_5)n$.

The starch-grains also contain a small proportion of amidulin, or soluble starch, presently to be noticed.

*Gelatinous Starch.* 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. On freezing gelatinous starch, the water belonging to it is separated as ice and on melting remains for the most part distinct.

Exp. 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.

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 various kinds of *Manihot*, cultivated in the West Indies and South America. *Cassava* is a preparation of the same starch, roasted. Sago is made in the islands of the East Indian Archipelago, from the pith of palms (*Sagus*). It is granulated by forcing the paste through metallic sieves. Both tapioca and sago are now imitated from maize starch.

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

In the subjoined table are given the proportions of starch in certain vegetable products, as determined by Dr. Dragendorff. The quantities are, however, somewhat variable. Since the figures below mostly refer to air-dry substances, the proportions of hygroscopic water found in the plants by Dragendorff are also given, the quantity of which, being changeable, must be taken into account in making any strict comparisons.

AMOUNT OF STARCH IN PLANTS.

| | *Water.* *Per cent.* | *Starch.* *Per cent.* |
|---|---|---|
| Wheat | 13.2 | 59.5 |
| Wheat flour | 15.8 | 68.7 |
| Rye | 11.0 | 59.7 |
| Oats | 11.9 | 46.6 |
| Barley | 11.5 | 57.5 |
| Timothy-seed | 12.6 | 45.0 |
| Rice (hulled) | 13.3 | 61.7 |
| Peas | 5.0 | 37.3 |
| Beans (white) | 16.7 | 33.0 |
| Clover-seed | 10.8 | 10.8 |
| Flaxseed | 7.6 | 23.4 |
| Mustard-seed | 8.5 | 9.9 |
| Colza-seed | 5.8 | 8.6 |
| Teltow turnips* | dry substance | 9.8 |
| Potatoes | dry substance | 62.5 |

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* A sweet and mealy turnip, grown on light soils, for table use.

*Starch is quantitatively estimated* by various methods.

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, is dried, and weighed. The value of this method depends upon the care employed in the operations. The amount of starch falls out too low, because it is impossible to break open all the minute cells of the substance analyzed.

2. In many cases starch may be estimated with great precision by conversion into sugar. For this purpose Sachsse heats 3 grams of air-dry substance, contained in a flask with reflux condenser, in a boiling water bath for 3 hours, with 200 c. c. of water and 20 c. c. of a 25 per cent hydrochloric acid. After cooling, the acid is nearly neutralized with sodium hydroxide, and the *dextrose* into which the starch has been converted is determined by Allihn's method, described on p. 65. Winton, Report Ct. Ag. Exp. St., 1887, p. 132.

3. For Dragendorff's method, see Henneberg's Journal, für Landwirthschaft, 1862, p. 206.

**Amidulin, or Soluble Starch.**—A substance soluble in cold water appears to exist in small quantity in the interior of ordinary starch-grains. It is not extracted by cold water from the unbroken starch, as shown by Exp. 26. On pulverizing starch-grains under cold water by rubbing in a mortar with sharp sand, the water, made clear by standing or filtration, gives with iodine the characteristic blue coloration. Exp. 27 shows that when starch is gelatinized by hot water, as in making starch paste, a small quantity of starch goes into actual solution.

Ordinary insoluble starch may be largely converted into soluble starch by moderate heating, either for a long time to the temperature of boiling water or for a short space to 375° F. Maschke obtained a perfectly clear solution of potato-starch by heating it with 30 times its bulk of water in a sealed glass tube kept immersed for 8 days in boiling water. Zulkowski reached the same result by heating potato-starch (1 part) with commercial glycerine (16 parts). In this case the starch at first swells and the mixture acquires a pasty consistence, but, when the temperature rises to 375° F., the starch dissolves to a nearly clear thin liquid.

Amidulin also appears to be the first product of the action of diastase (the ferment of sprouting seeds) on starch and doubtless exists in malt.

Soluble starch is colored blue by iodine and is thrown down from its solution in water, or glycerine, by addition of strong alcohol. It redissolves in water or weak alcohol. Its concentrated aqueous solutions gelatinize on keeping and the jelly is no longer soluble in water. Dilute solutions when evaporated leave a transparent residue that is insoluble in water.

On boiling together diluted sulphuric acid and starch the latter shortly dissolves, and if as soon as solution has taken place, the acid be neutralized with carbonate of lime and removed by filtration, soluble starch remains dissolved. (Schulze's Amidulin.)

*Amylodextrin.* Nageli has described as Amylodextrin I and Amylodextrin II, two substances that result from the action of moderately strong acids on potato-starch at common temperatures. The starch when soaked for many weeks in 12% hydrochloric acid remains nearly unchanged in appearance, but the interior parts of the grains gradually dissolve out, being changed into amylodextrin II, which closely resembles and is probably identical with amidulin.

The starch-grains that remain unchanged in outward appearance, if tested with iodine solution from time to time, are at first colored blue, but after some days they take on a violet tinge and after prolonged action of the acid are made red and finally yellow by iodine. The grains, which are now but empty shells, may be freed from acid by washing with cold water, and then, if heated to boiling with pure water, they readily dissolve to a clear solution (amylodextrin I), from which Nageli, by freezing and by evaporation, obtained crystalline disks. These bodies, when dry, have the same composition as cellulose, starch, and amidulin.

**Dextrin** ($C_6H_{10}O_5$) was formerly thought to occur dissolved in the sap of all plants. According to Von Bibra's investigations, the substance existing in bread-grains, which earlier experimenters believed to be dextrin, is for the most part *gum*. Busse, who examined various young cereal plants and seeds, and potato tubers, for dextrin, found it only in old potatoes and young wheat plants, and there in very small quantity. According to Meissl, the soy bean contains 10 per cent of dextrin.

Dextrin is easily prepared artificially by the transformation of starch, or, rather, of amidulin derived from 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 for 30 minutes to the temperature of 415° F., the grains swell, burst open, and are gradually converted into a light-brown substance, which dissolves readily in water, forming a clear, gummy solution. This is dextrin, and thus prepared it is largely used in the arts, especially in calico-printing, as a cheap substitute for gum arabic. In the baking of bread it is formed from the starch of the flour, and often constitutes ten 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 dextrin. Dextrin is thus an important ingredient of those kinds of food which are prepared from the starchy grains by cooking.

Commercial dextrin appears either in translucent brown masses or as a yellowish-white powder. On addition of cold water, the dextrin readily dissolves, leaving behind a portion of unaltered starch. When the solution is mixed with strong alcohol, the dextrin separates in white flocks. With iodine, solution of commercial dextrin gives a fine purplish-red color.

There are doubtless several distinct dextrins scarcely distinguishable except by the different degrees to which they affect polarized light or by various chemical deportment (reducing effect on alkaline copper solutions). They are characterized as erythrodextrins, which give with iodine a red color, and achroodextrins, which give no color with iodine. Investigators do not agree as to the precise number of dextrins that result from the transformation of starch.

**Exp. 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 color. 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 dextrin. To a portion add twice its bulk of alcohol; dextrin is precipitated. To another portion, add solution of iodine; this shows the presence of dissolved but unaltered starch. To a third portion of the filtrate add one drop of strong sulphuric acid and boil a few minutes. Test with iodine, which, as soon as all starch is transformed, will give a red instead of a blue color.

Not only heat but likewise acids and ferments produce dextrins from starch and, according to some authors, from cellulose. In the sprouting of seeds, dextrin is abundantly formed from starch and hence is an ingredient of malt liquors.

The agencies that convert starch into the dextrins easily transform the dextrins into sugars (maltose or dextrose), as will be presently noticed.

The chemical composition of dry dextrin is identical with that of dry cellulose, starch, and amidulin.

**Inulin,** $C_{36}H_{62}O_{36}$, closely resembles starch in many points, and appears to replace that body in the roots of the American artichoke,* elecampane, dahlia, dandelion, chicory, and other plants of the same natural family (*compositæ*). It may be obtained in the form of minute white grains, which dissolve easily in hot water, and separate again as the water cools. According to Bouchardat, the juice of the dahlia tuber, expressed in winter, becomes a semi-solid white mass after reposing some hours, from the separation of 8 per cent of inulin.

Inulin, when pure, gives no coloration with iodine. It may be recognized in plants, where it occurs as a solution, usually of the consistence of a thin oil, by soaking a slice of the plant in strong alcohol. Inulin is insoluble in this liquid, and under its influence shortly separ-

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* *Helianthus tuberosus*, commonly known as Jerusalem artichoke, and cultivated in Europe under the name *topinambour*, is a native of the Northern Mississippi States.

ates as a solid in the form of spherical granules, which may be identified with the aid of the microscope, and have an evident crystalline structure.

When long heated with water it is slowly but completely converted into a kind of sugar (levulose); 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 composition,* inulin, dried at 212°, differs from cellulose and starch by containing for six times $C_6H_{10}O_5$, the elements of an additional molecule of water; $C_{36}H_{62}O_{36} = 6\ C_6H_{10}O_5 + H_2O$ *Kiliani.*

**Levulin** $(C_6H_{10}O_5)n$ coexists with inulin in the mature or frozen tubers of the artichoke, dahlia, etc., and, according to Muentz, is found in unripe rye-grain. It is a highly soluble, tasteless, gum-like substance resembling dextrin, but without effect on polarized light. It appears to be formed from inulin when the latter is long heated with water at the boiling point, or when the tubers containing inulin sprout. Dilute acids readily transform it into levulose, as they convert dextrin into dextrose.

GLYCOGEN $(C_6H_{10}O_5)n$ exists in the blood and muscles of animals in small quantity, and abundantly in the liver, especially soon after hearty eating. It is obtained by boiling minced fresh livers with water, or weak potash solution, and adding alcohol to the filtered liquid. It is a white powder which, with water, makes an opalescent solution. It is colored wine-red by iodine. Boiling dilute sulphuric acid converts it into dextrose. With saliva, it is said to yield dextrin, maltose and dextrose. According to late observations, glycogen occurs in the vegetable kingdom, having been identified in various fungi and in plants of the flax and the potato families.

**The Gums and Pectin Bodies.**—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, the gums of the Peach, Cherry and Plum, Gum Tragacanth and Bassora Gum, Agar-Agar and the Mucilages of various roots, viz., of mallow and comfrey; and of certain seeds, as those of flax and quince.

*Gum Arabic* exudes from the stems of various species of acacia that grow in the tropical countries of the East, especially in Arabia and Egypt. It occurs in tear-like, transparent, and, in its purest form, colorless 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 colors in calico-printing.

Gum Arabic is, however, commonly a mixture of at least two very similar gums, which are distinguished by their opposite effect on polarized light and by the different products which they yield when boiled with dilute acids.

*Cherry Gum.*—The gum which frequently forms glassy masses on the bark of cherry, plum, apricot, peach and almond trees, is a mixture in variable proportions of two gums, one of which is apparently the same as occurs in gum arabic, and is fully dissolved in cold water, while the other remains undissolved, but swollen to a pasty mass or jelly.

*Gum Tragacanth,* which comes to us from Persia and Siberia, has much similarity in its properties to the insoluble part of cherry gum, as it dissolves but slightly in water and swells up to a paste or jelly.

The so-called *Vegetable mucilages* much resemble the insoluble part of cherry gum and are found in the seeds of flax, quince, lemon, and in various parts of many plants.

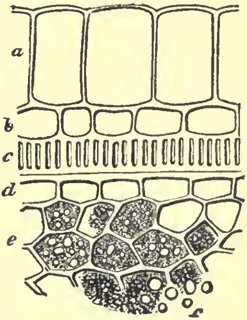

Fig. 13.

*Flax-seed mucilage* is procured by soaking unbroken flaxseed 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 by the same mixture. On drying, it forms a horny, colorless, and friable mass. Fig. 13 represents a highly magnified section of the ripe flaxseed. The external cells, *a*, contain the dry mucilage. When soaked in water, the mucilage swells, bursts the cells, and exudes.

*The Pectin Bodies.*—The flesh of beets, turnips, and similar roots, and of most unripe fruits, as apples, peaches, plums, and berries of various kinds, contain one or several bodies which are totally insoluble in water, but which, under the action of weak acids or alkaline solutions, become soluble and yield substances having gummy or gelatinous characters, that have been described under the names pectin, pectic acid, pectosic acid, metapectic acid, etc. Their true composition is, for the most part, not positively established. They are, however, closely related to the gums. The insoluble substance thus transformed into gum-like bodies, Fremy termed *pectose.*

The gums, as they occur naturally, are mostly mixtures. By boiling with dilute sulphuric or hydrochloric acid they are transformed into sugars.

In the present state of knowledge it appears probable that the common gums, for the most part, consist of a few chemically distinct bodies, some of which have been distinguished more or less explicitly by such names as Arabin, Metarabin, Pararabin, Galactin, Paragalactin, etc.

**Arabin, or Arabic Acid,** is obtained from some varieties of Gum Arabic* by mixing their aqueous solution with acetic acid and alcohol. It is best prepared from sugar-beet pulp, out of which the juice has been expressed, by heating with milk of lime; the pulp is thereby broken down, and to a large extent dissolves.

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* Those sorts of commercial Gum Arabic which deviate the plane of polarization of light to the left contain arabin in largest proportion.

The liquid, after separating excess of lime and adding acetic acid, is mixed with alcohol, whereupon arabin is precipitated. Arabin, thus prepared, is a milk-white mass which, while still moist, readily dissolves in water to a mucilage. It strongly reddens blue litmus and expels carbonic acid from carbonates. When dried at 212° arabin becomes transparent and has the composition $C_{12}H_{22}O_{11}$. Dried at 230° it becomes (by loss of a molecule of water) $C_{12}H_{20}O_{10}$, or 2 $C_6H_{10}O_5$.

Arabin forms compounds with various metals. Those with an alkali, lime, or magnesia as base are soluble in water. Gum arabic, when burned, leaves 3 to 4 per cent of ash, chiefly carbonates of potassium, calcium and magnesium. Arabic acid, obtained by Fremy from beets by the foregoing method, but not in a state of purity, was described by him as "metapectic acid." To Scheibler we owe the proof of its identity with the arabin of gum arabic.

**Metarabin.**—When arabin is dried and kept at 212° for some time, it becomes a transparent mass which is no longer freely soluble in water, but in contact therewith swells up to a gelatinous mass. This is designated metarabin by Scheibler. It is dissolved by alkalies, and thus converted into arabates, from which arabin may be again obtained.

The body named *pararabin* by Reichardt, obtained from beet and carrot pulp by treatment with dilute hydrochloric acid, is related to or the same as metarabin. Fremy's "pectin," obtained by similar treatment from beets, is probably impure metarabin.

EXP. 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 of water) to saturate the mass, and let it stand 48 hours. Squeeze the acid liquid, filter it, and add alcohol, when "pectin" will separate.

It may be that metarabin is identical with the "pectose" of the sugar beet, since both yield arabin under the influence of alkalies. It is evident that the composition found for dried arabin properly belongs to metarabin, and it is probable that arabin consists of metarabin $C_{12}H_{22}O_{11}$ *plus* one or several molecules of water, and that metarabin is an *anhydride* of arabin.

Arabin and metarabin, when heated with dilute sulphuric acid, are converted into a crystallizable sugar called *arabinose,* $C_5H_{10}O_5$. The gums that exude from the stems of cherry, plum and peach trees appear to consist chiefly of a mixture of freely soluble arabates with insoluble metarabin. Gum Tragacanth is perhaps mostly metarabin. All these gums yield, by the action of hot dilute acids, the sugar arabinose.

**Galactin,** $C_6H_{10}O_5$, discovered by Müntz in the seeds of alfalfa and found in other legumes, has the appearance, solubility in water and general properties of arabin, and is probably the right-polarizing ingredient of gum arabic. Boiled with dilute acids it is converted into the sugar *galactose,* $C_6H_{12}O_6$.

**Paragalactin,** $C_6H_{10}O_5$.—In the seeds of the yellow lupin exists up to 20 per cent of a body that is insoluble in water, but dissolves by warming with alkali solutions, and when heated with dilute acids yields galactose. According to Steiger it probably has the composition $C_6H_{10}O_5$. Maxwell has shown it to exist in other leguminous seeds, viz., the pea, horse-bean (Faba vulgaris) and vetch.

In the "Chinese moss," an article of food prepared in China from sea-weeds, and in the similar gum agar or "vegetable gelatine" of Japan, exists a substance which is insoluble in cold water, but with that liquid swells up to a bulky jelly, and yields galactose when heated with dilute acids. This corresponds to metarabin.

**Xylin, or Wood Gum.**—The wood of many deciduous trees, the vegetable ivory nut, the cob of Indian corn and barley husks, contain 6 to 20 per cent of a substance insoluble in cold water, but readily taken up in cold solution of caustic soda. On adding to the solution an acid, and afterwards alcohol, a bulky white substance separates, which may be obtained dry as a white powder or a translucent gum-like mass. It dissolves very slightly in boiling water, yielding an opalescent solution. The composition of this substance was found by Thomsen to be $C_6H_{10}O_5$.

Xylin differs from pararabin and pectose in not being soluble in milk of lime. It is converted by boiling with dilute sulphuric acid into a crystallizable sugar, *xylose,* whose properties have been but little investigated.

**Flax-seed Mucilage,** $C_6H_{10}O_5$, resembles metarabin, but by action of hot dilute acids is resolved into cellulose and a gum, which latter is further transformed into dextrose. The yield of cellulose is about four per cent.

**Quince-Seed Mucilage** appears to be a compound of cellulose and a body like arabin. On boiling with dilute sulphuric acid it yields nearly one-third its weight of cellulose, together with a soluble gum and a sugar, the last being a result of the alteration of the gum. The sugar is similar to arabinose.

*The Soluble Gums in Bread-grains.*—In the bread-grains, freely soluble gums occur often in considerable proportion.

TABLE OF THE PROPORTIONS (*per cent.*) OF GUM* IN VARIOUS AIR-DRY GRAINS OR MILL PRODUCTS.

(*According to Von Bibra, Die Getreidearten und das Brod.*)

| | | | |
|---|---|---|---|
| Wheat kernel | 4.50 | Barley flour | 6.33 |
| Wheat flour, superfine | 6.25 | Barley bran | 6.88 |
| Spelt flour (*Triticum spelta*) | 2.48 | Oat meal | 3.50 |
| Wheat bran | 8.85 | Rice flour | 2.00 |
| Spelt bran | 12.52 | Millet flour | 10.60 |
| Rye kernel | 4.10 | Maize meal | 3.05 |
| Rye flour | 7.25 | Buckwheat flour | 2.85 |
| Rye bran | 10.40 | | |

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* The "gum" in the above table (which dates from 1859), includes perhaps soluble starch and dextrin in some, if not all cases, and, according to O'Sullivan, barley, wheat and rye contain two distinct left-polarizing gums, which he terms *a-amylan* and *b-amylan*. These occur in barley to the extent of 2.3 per cent. By action of acids they yield dextrose.

The experiments of Grouven show that gum arabic is digestible by domestic animals. There is little reason to doubt that all the gums are digestible and serviceable as ingredients of the food of animals.

*b. The Glucoses,* $C_6H_{12}O_6$ (or $C_5H_{10}O_5$), are a class of sugars having similar or identical composition, but differing from each other in solubility, sweetness, melting point, crystal-form and action on polarized light.

The glucoses, with one exception, contain in 100 parts:

| | |
|---|---|
| Carbon | 40.00 |
| Hydrogen | 6.67 |
| Oxygen | 53.33 |
| | 100.00 |

**Levulose, or Fruit Sugar (Fructose),** $C_6H_{12}O_6$, exists mixed with other sugars in sweet fruits, honey and molasses. Inulin and levulin are converted into this sugar by long boiling with dilute acids, or with water alone. When pure, it forms colorless crystals, which melt at 203°, but is usually obtained as a syrup. Its sweetness is equal to that of saccharose.

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

Dextrose is formed from starch and dextrin by the action of hot dilute acids, in the same way that levulose is produced from inulin. In the pure state it exists as minute, colorless crystals, and is, weight for weight, but two-thirds as sweet as saccharose or cane-sugar. It fuses at 295°.

Dextrose unites chemically to water. Hydrated glucose, $C_6H_{12}O_6H_2O$, occurs in commerce in an impure state as a crystalline mass, which becomes doughy at a slightly elevated temperature. This hydrate loses its crystal-water at 212°.

Dissolved in water, dextrose 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.

EXP. 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 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 successively into amidulin, dextrin, and dextrose. 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, until the sour taste disappears; filter from the calcium sulphate (gypsum) that is formed, and evaporate the solution of dextrose* at a gentle heat to a syrupy consistence. On long standing it may crystallize or granulate.

By this method is prepared the so-called grape-sugar, or starch-sugar of commerce, which is added to grape-juice for making a stronger wine, and is also employed for preparing syrups and imitating molasses. The syrups thus made from starch or corn are known in the trade as *glucose*.† Imitation-molasses is a mixture of dextrose-syrup with some dextrin to make it "ropy."

Even cellulose is convertible into dextrose by the prolonged action of hot acids. If paper or cotton be first dissolved in strong sulphuric acid, and the solution diluted with water and boiled, the cellulose is readily transformed into dextrose. Sawdust has thus been made to yield an impure syrup, suitable for the production of alcohol.

In the formation of dextrose from cellulose, starch, amidulin and dextrin, the latter substances take up the elements of water as represented by the equation

$$\underset{\textit{Starch, etc.}}{C_6H_{10}O_5} + \underset{\textit{Water.}}{H_2O} = \underset{\textit{Glucose.}}{C_6H_{12}O_6}$$

In this process, 90 parts of starch, etc., yield 100 parts of dextrose.

*Trommer's Copper test.*—A characteristic test for dextrose and levulose is found in their deportment towards an alkaline solution of copper, which readily yields up oxygen to these sugars, the copper being reduced to yellow cuprous hydroxide or red cuprous oxide.

EXP. 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, solution of caustic potash until it acquires a slip-

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* If the boiling has been kept up but an hour or so, the dextrose will contain dextrin, as may be ascertained by mixing a small portion of the still acid liquid with 5 times its bulk of strong alcohol, which will precipitate dextrin, but not dextrose.

† Under the name *glucose*, the three sugars levulose, dextrose and maltose were formerly confounded together, by chemists.

pery feel. Place in separate test tubes a few drops of solution of cane-sugar, a similar amount of the dextrin solution, obtained in Exp. 28; of solution of dextrose, from raisins, or from Exp. 30; and of molasses; add to each a little of the copper solution, and place them in a vessel of hot water. Observe that the saccharose and dextrin suffer little or no alteration for a long time, while the dextrose and molasses shortly cause the separation of cuprous oxide.

EXP. 32.—Heat to boiling a little white cane-sugar with 30 c. c. of water, and 3 drops of strong sulphuric acid, in a glass or porcelain dish, for 15 minutes, supplying the waste of water as needful, and test the liquid as in the last Exp. This treatment transforms saccharose into dextrose and levulose.

*The quantitative estimation of the sugars 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, etc., in a given volume of water, and the dextrose or levulose, or a mixture of both, being likewise made to a known volume of solution, the latter is allowed to flow slowly from a graduated tube into a measured portion of warm copper solution, until the blue color is discharged. Saccharose is first converted into dextrose and levulose, by heating with an acid, and then examined in the same manner.

Starch is transformed into dextrose by heating with hydrochloric acid or warming with saliva. The quantity of sugar stands in definite relation to the amount of copper separated, when the experiment is carried out under certain conditions. See Allihn, *Jour. für Pr. Chemie*, XXII, p. 52, 1880.

**Galactose**, $C_6H_{12}O_6$, is formed by treating right-polarizing gum arabic, galactin, or milk-sugar with dilute acids. It crystallizes, is sweet, melts at 289° and with nitric acid yields mucic acid (distinction from arabinose, dextrose and levulose).

**Mannose** (Seminose?) $C_6H_{12}O_6$ is a fermentable sugar prepared artificially by oxidation of mannite (see p. 74), and, according to E. Fischer, is probably identical with the Seminose found by Reiss as a product of the action of acids on a body existing in the seeds of coffee and in palm nuts. (*Berichte*, XXII, p. 365).

**Arabinose**, $C_5H_{10}O_5$, obtained from arabin (of left-polarizing gum arabic), and from cherry gum by action of hot dilute acids, appears in rhombic crystals. It is less sweet than cane sugar, and fuses at 320°.

***c.*** *The Sucroses*, $C_{12}H_{22}O_{11}$, are sugars which, boiled with dilute acids, undergo chemical change by taking up the elements of water and are thereby resolved into glucoses. In this decomposition one molecule of sucrose usually yields either two molecules of one glucose or a molecule each of two glucoses, $C_{12}H_{22}O_{11} + H_2O = C_6H_{12}O_6 + C_6H_{12}O_6$.

**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. When pure, it is a white solid, readily soluble in water, forming a colorless, ropy, and intensely sweet solution. It crystallizes in rhombic prisms (Fig. 14), which are usually small, as in granulated sugar, but in the form of rock-candy may be found an inch or more in length. The crystallized sugar obtained largely from the sugar-beet, in Europe, and that furnished in the United States by the sugar-maple and sorghum, when pure, are identical with cane-sugar.

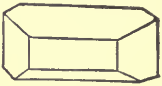


Fig. 14.

Saccharose also exists in the vernal juices of the walnut, birch, and other trees. It occurs 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, in the seeds of the pea and bean, and in a multitude of fruits.

EXP. 29.—Heat cautiously a spoonful of white sugar until it melts (at 356° F.) 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 vapors, and becomes burnt sugar, or *caramel*, which is used for coloring soups, ale, etc.

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.

SACCHAROSE IN PLANTS.

| | *Per cent.* | |
|---|---|---|
| Sugar-cane, average | 18 | Peligot. |
| Sugar-beet, “ | 10 | “ |
| Sorghum | 13 | Collier. |
| Maize, just flowered | 3¾ | Lüdersdorff. |
| Sugar-maple, sap, average | 2½ | Liebig. |
| Red maple, “ “ | 2½ | “ |

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

| | |
|---|---|
| Carbon | 42.11 |
| Hydrogen | 6.43 |
| Oxygen | 51.46 |
| | 100.00 |

Cane-sugar, by long boiling of its concentrated aqueous solution, and under the influence of hot dilute acids (Exp. 32) and yeast, loses its property of ready crystallization, and is converted into levulose and dextrose.

According to Dubrunfaut, a molecule of cane-sugar takes up the elements of a molecule (5.26 per cent.) of water, yielding a mixture of equal parts of levulose and dextrose. This change is expressed in chemical symbols as follows :

$$\underset{\textit{Cane-sugar.}}{C_{12}H_{22}O_{11}} + \underset{\textit{Water.}}{H_2O} = \underset{\textit{Levulose.}}{C_6H_{12}O_6} + \underset{\textit{Dextrose.}}{C_6H_{12}O_6}$$

This alterability on heating its solutions occasions a loss of one-third to one-half of the saccharose that is really contained in cane-juice, when this is evaporated in open pans, and is one reason why solid sugar is obtained from the sorghum in open-pan evaporation with such difficulty.

Molasses, sorghum syrup, and honey usually contain all three of these sugars.

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. The mannas of Syria and Kurdistan are of similar composition.

**Maltose**, $C_{12}H_{22}O_{11}.H_2O$, is formed in the sprouting of seeds by the action of a ferment, called *diastase*, on starch. It is also prepared by treating starch or glycogen with saliva. In either case the starch (or glycogen) takes up the elements of water, $2\ C_6H_{10}O_5 + H_2O = C_{12}H_{22}O_{11}$. Maltose in crystallizing unites with another molecule of water, which it loses at 212°. Maltose, thus dried, attracts moisture with great avidity.

Boiled with dilute acids one molecule of maltose yields two molecules of dextrose, $C_{12}H_{22}O_{11} + H_2O = 2\ C_6H_{12}O_6$. Maltose is also produced when starch and dextrin are heated with dilute acids, and thus appears to be an intermediate stage of their transformation into dextrose.

Maltose is accordingly an ingredient of some commercial "grape-sugars" made from starch by boiling with diluted sulphuric acid.

**Lactose, or Milk Sugar,** $C_{12}H_{22}O_{11} + H_2O$, is the sweet principle of the milk of animals. It is prepared for commerce by evaporating whey (milk from which casein and fat have been separated for making cheese). In a state of purity it forms transparent, colorless 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. Heated to 290° the crystals become water-free.

Lactose is said to occur with cane-sugar in the sapodilla (fruit of *Achras sapota*) of tropical countries. Treatment with dilute sulphuric acid converts it into galactose and dextrose.

$$\underset{\textit{Lactose.}}{C_{12}H_{22}O_{11}} + \underset{\textit{Water.}}{H_2O} = \underset{\textit{Galactose.}}{C_6H_{12}O_6} + \underset{\textit{Dextrose.}}{C_6H_{12}O_6}$$

**Raffinose,** $C_{18}H_{32}O_{16} + 5\ H_2O$ (?), first discovered by Loiseau in beet-sugar molasses, was afterwards found by Berthelot in eucalyptus manna, by Lippmann in beet-root, and by Boehm & Ritthausen in cotton-seed. It crystallizes in fine needles, and is but slightly sweet. It begins to melt at 190° with loss of crystal-water, which may be completely expelled at 212°. The anhydrous sugar fuses at 236°. It is more soluble in water and has higher dextrorotatory power than cane-sugar. Heated with dilute acids it yields dextrose, levulose and galactose.

$$C_{18}H_{32}O_{16} + 2\ H_2O = 3\ (C_6H_{12}O_6).$$

*The Sugars in Bread-Grains.*—The older observers assumed the presence of dextrose in the bread-grains.

Thus, Vauquelin found, or thought he found, 8.5% of this sugar in Odessa wheat. More recently, Peligot, Mitscherlich, and Stein 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 reinvestigated this question, and found in fresh-ground wheat, etc., a sugar having some of the characters of saccharose, and others of dextrose and levulose. Märcker and Kobus, in 1882, report maltose (which was unknown to the earlier observers) in sound barley, and maltose and dextrose in sprouted barley.

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 |

*Glucosides.*—There occur in the vegetable kingdom a large number of bodies, usually bitter in taste, which contain dextrose, or a similar sugar, chemically combined with other substances, or that yield it on decomposition. *Salicin,* from willow bark; *phloridzin,* from the bark of the apple-tree root; *jalapin,* from jalap; *aesculin,* from the horse-chestnut, and *amygdalin,* in seeds of almond, peach, plum, apple, cherry, and in cherry-laurel leaves, are of this kind. The sugar may be obtained from these so-called glucosides by heating with dilute acids.

The seeds of mustard contain the glucoside *myronic acid* united to potassium. This, when the crushed seeds are wet with water, breaks up into dextrose, mustard-oil, and acid potassium sulphate, as follows:

$$C_{10}H_{18}KNS_2O_{10} = C_6H_{12}O_6 + C_3H_5NCS + KHSO_4$$

The cambial juice of the conifers contains *coniferin,* crystallizing in brilliant needles, which yields dextrose and a resin by action of dilute acid, and by oxidation produces vanillin, the flavoring principle of the vanilla bean.

*Mutual Transformations of the Carbhydrates.*—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.*—In germination, the starch which is largely contained in seeds is converted into amidulin, dextrin, maltose and dextrose. It thus acquires solubility, and passes into the embryo to feed the young plant. Here these are 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 sugar 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.)

In some years the sugar-beet yields a large amount of arabin, in others but little.

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

Thus, Stepf found no dextrin, 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 dextrin, but neither sugar nor gum. The sample of maize examined by Stepf contained 3.05 p. c. gum and 3.71 p. c. sugar; that analyzed by Fresenius yielded 2.33 p. c. dextrin.

Märcker & Kobus made comparative analyses of well-cured and of sprouted barley, with the following results *per cent:*

| | *Sound.* | *Grown.* |
|---|---|---|
| Starch | 64.10 | 57.98 |
| Soluble starch | 1.76 | 1.17 |
| Dextrin | 1.10 | 0.00 |
| Dextrose | 0.00 | 4.92 |
| Maltose | 3.12 | 7.92 |

The various gums are a result of the transformation of cellulose, as Mohl first showed by microscopic study.

*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, dextrin, and probably the gums, are all converted into dextrose or other sugars, and from these, in the liver especially, glycogen is formed.

*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 amidulin, dextrin, maltose and dextrose. Cellulose and starch acted upon for some time by strong nitric acid give compounds from which dextrin may be separated. Cellulose nitrate sometimes yields gum (dextrin) 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. Inulin and the gums yield glucoses, but no dextrin, when boiled with weak acids.

*d.* It will be noticed that while physical and chemical agencies produce these metamorphoses mostly in one direction, under the influence of life they go on in either direction.

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

*The Chemical Composition of the Carbhydrates.*—It has already appeared that the substances just described stand very closely related to each other in chemical composition. In the following table their composition is expressed in formulæ.

CHEMICAL FORMULÆ OF THE CARBHYDRATES.

| *Amyloses.* | | Dried |
|---|---|---|
| Cellulose, | | $C_6 H_{10} O_5$ |
| Soluble cellulose,<br>Amyloid, | | $C_6 H_{10} O_5$* |
| Starch, | | $C_6 H_{10} O_5$ |
| Soluble starch,<br>Amidulin,<br>Amylodextrin, | | $C_6 H_{10} O_5$ * |
| Dextrin, | | $C_6 H_{10} O_5$ |
| Inulin, | $6 (C_6 H_{10} O_5) + H_2 O =$ | $C_{36} H_{62} O_{31}$ |
| Levulin, | $2 (C_6 H_{10} O_5) + H_2 O =$ | $C_{12} H_{22} O_{11}$ |
| Glycogen, | | $C_6 H_{10} O_5$ |
| Pectin, | | (?) |
| Arabin,<br>Metarabin, | $2 (C_6 H_{10} O_5) + H_2 O$ | $C_{12} H_{22} O_{11}$ |
| Galactin, | | $C_6 H_{10} O_5$ |
| Paragalactin, | | $C_6 H_{10} O_5$ |
| Flax-seed mucilage, | | $C_6 H_{10} O_5$ |
| Quince-seed mucilage, | $C_6 H_{10} O_5 + 2 (C_6 H_{10} O_5) - H_2O =$ | $C_{18} H_{28} O_{14}$ |
| *Glucoses.* | Crystallized | |
| Levulose, | $C_6 H_{12} O_6$ | $C_6 H_{12} O_6$ |
| Dextrose, | $C_6 H_{14} O_7$ and $C_6 H_{12} O_6$ | $C_6 H_{12} O_6$ |
| Galactose, | $C_6 H_{12} O_6$ | $C_6 H_{12} O_6$ |
| Mannose, | $C_6 H$[illegible] $O_6$ | $C_6 H_{12} O_6$ |
| Arabinose, | $C_5 H_{10} O_5$ | $C_5 H_{10} O_5$ |
| *Sucroses.* | | |
| Saccharose, | $C_{12} H_{22} O_{11}$ | $C_{12} H_{22} O_{11}$ |
| Maltose, | $C_{12} H_{24} O_{12}$ | $C_{12} H_{22} O_{11}$ |
| Lactose, | $C_{12} H_{24} O_{12}$ | $C_{12} H_{22} O_{11}$ |
| Raffinose, | $C_{18} H_{42} O_{21}$ | $C_{18} H_{32} O_{16}$ |

As above formulated, it is seen that all these bodies, except arabinose, contain 6 atoms of carbon, or a number which is some simple multiple of 6, united to as much hydrogen and oxygen as form in most cases 5, 6 or 11 molecules of water ($H_2O$). Being thus composed of carbon and the elements of water they are termed *Carbhydrates.*

The mutual convertibility of the carbhydrates is the

---

* These soluble bodies when dried probably lose water which is essential to their composition, as on drying they become insoluble.

easier to understand since it takes place by the loss or gain of several molecules of water.

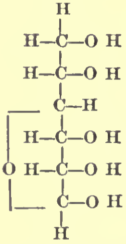
The formulæ given are the simplest that accord with the results of analysis. In case of many of the amyloses it is probable that the above formulæ should be multiplied by 2, 4, or 6, or even more, in order to reach the true molecular weight.

*Isomerism.*—Bodies which—like cellulose and dextrin, or like levulose and dextrose—are identical in composition, and yet are characterized 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 measure.*

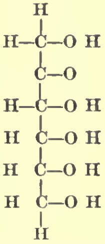
We must suppose that the particles of isomeric bodies which are composed of the same kinds of matter, and in the same quantities, exist in different states of arrangement. The mason can build, from a given number of bricks and a certain amount of mortar, a simple wall, an aqueduct, a bridge or a castle. The composition 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 differ from dextrin by a difference in the relative positions of the atoms of carbon, hydrogen, and oxygen in the molecules which compose them.

By use of "structural formulæ" it is sought to represent the different arrangement of atoms in the molecules of isomeric bodies. In case of substances so complex as the sugars, attempts of this kind have but recently met with success. The following formulæ exhibit to the chemist the probable differences of constitution between dextrose and levulose.

Dextrose.



Levulose.



To those familiar with advanced Organic Chemistry the foregoing formulæ, to some extent, "account for" the chemical characters of these sugars, and explain the different products which they yield under decomposing influences.

### APPENDIX TO THE CARBHYDRATES.

Nearly related to the Carbhydrates are the following substances:—

*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 colorless crystals and has a sweetish taste. It may be obtained from dextrose and levulose by the action of nascent hydrogen as liberated from sodium amalgam and water. $C_6H_{12}O_6 + H_2 = C_6H_{14}O_6$.

*Dulcite*, $C_6H_{14}O_6$, is a crystalline substance found in the common cow-wheat (*Melampyrum nemorosum*) and in Madagascar manna. It is obtained from milk-sugar by the action of sodium amalgam.

The isomeres mannite and dulcite, when acted on by nitric acid, are converted into acids which are also isomeric. Mannite yields saccharic acid, which is also formed by treating cane-sugar, dextrose, levulose, dextrin and starch with nitric acid. Dulcite yields, by the same treatment, mucic acid, which is likewise obtained from arabin and other gums. Milk-sugar yields both saccharic and mucic acid. Saccharic acid is very soluble in water. Mucic acid is quite insoluble. Both have the formula $C_6H_{10}O_8$.

*The Pectin-bodies.* The juice of many ripe fruits, when mixed with alcohol, yields a jelly-like precipitate which has long been known under the name of *pectin*. When the firm flesh of acid winter-fruits is subjected to heat, as in baking or stewing, it sooner or later softens, becomes soluble in water and yields a gummy liquid from which by adding alcohol the same or a similar gelatinous substance is separated. Fremy supposes that in the pulp "pectose" exists which is transformed by acids and heat into pectin.

Exp. 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. Pectin 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.

*Pectosic and Pectic Acids.* These bodies, according to Fremy, compose the well-known fruit-jellies. They are both insoluble or nearly so in cold water, and remain suspended in it as a gelatinous mass. Pectosic acid is soluble in hot water, and is supposed to exist in those fruit-jellies which liquefy on heating but gelatinize on cooling. Pectic acid is stated to be insoluble in hot water. According to Fremy, pectin is changed into pectosic and pectic acids and finally into metapectic acid by the action of heat and during the ripening process.

Exp. 35.—Stew a handful of sound cranberries, covered with water, just long enough to make them soft. Observe the speedy solution of the firm pulp or "pectose." Strain through muslin. The juice contains soluble pectin, 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, that dissolves on warming, and reappears again on cooling—Fremy's pectosic acid. By further heating, the juice may form a jelly which is permanent when hot—pectic acid.

Other ripe fruits, as quinces, strawberries, peaches, grapes, apples, etc., 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.

Scheibler having shown that Fremy's metapectic acid of beets is arabic acid, it is probable that Fremy's pectin, pectic acid and pectosic acid of fruits, are bodies similar to or identical with the gums already described. The pectin bodies of fruits have not yet been certainly obtained in a state of purity, since the analyses of preparations by various chemists do not closely agree.

**The Vegetable Acids.**—Nearly every family of the vegetable kingdom, so far as investigated, contains one or more *organic acids* peculiar to itself. Those of more general occurrence which alone concern us here are few in number and must be noticed very concisely.

The vegetable acids rarely occur in plants in the free state, but are for the most part united to metals or to organic bases in the form of salts. The vegetable acids consist of carboxyl, COOH, united generally to a hydrocarbon group. They are monobasic, dibasic or tribasic, according as they contain one, two or three carboxyls.

The *Monobasic Acids*, to be mentioned here, fall into two groups, viz.: Fatty acids and Oxyfatty acids.

The Fatty Acids constitute a remarkable "homologous series," the names and formulæ of a number of which are here given:

| | | | *Found in* |
|---|---|---|---|
| Formic | acid, | $H, COOH$ | Pine needles, red ants, guano. |
| Acetic | " | $CH_3COOH$ | Vinegar and many vegetable juices. |
| Propionic | " | $C_2H_5COOH$ | Yarrow-flowers. |
| Butyric | " | $C_3H_7COOH$ | Butter, limburger cheese, parsnip seeds. |
| Valeric | " | $C_4H_9COOH$ | Valerian root, old cheese. |
| Caproic | " | $C_5H_{11}COOH$ | Butter, cocoanut oil. |
| Oenanthylic | " | $C_6H_{13}COOH$ | (Artificial.) |
| Caprylic | " | $C_7H_{15}COOH$ | Butter, cocoanut oil, limburger cheese, fusel oil. |
| Pelargonic | " | $C_8H_{17}COOH$ | Rose-geranium. |
| Capric | " | $C_9H_{19}COOH$ | Butter, cocoanut oil. |
| Umbellic | " | $C_{10}H_{21}COOH$ | Seeds of California laurel. |
| Lauric | " | $C_{11}H_{23}COOH$ | Laurel oil, butter, bayberry tallow. |
| Tridecylic | " | $C_{12}H_{25}COOH$ | (Artificial.) |

| | | | |
|---|---|---|---|
| Myristic | acid, | $C_{13}H_{27}COOH$ | Nutmeg oil. |
| Isocetic | " | $C_{14}H_{29}COOH$ | Seeds of Jatropha. |
| Palmitic | " | $C_{15}H_{31}COOH$ | Butter, tallow, lard, palm oil. |
| Margaric | " | $C_{16}H_{33}COOH$ | (Artificial.) |
| Stearic | " | $C_{17}H_{35}COOH$ | Tallow, lard. |
| Nondecylic | " | $C_{18}H_{37}COOH$ | (Unknown.) |
| Arachic | " | $C_{19}H_{39}COOH$ | Butter, peanut oil. |
| Medullic | " | $C_{20}H_{41}COOH$ | Marrow of ox. |
| Behenic | " | $C_{21}H_{43}COOH$ | Oil of Moringa oleifera. |
| ——— | | $C_{22}H_{45}COOH$ | (Unknown.) |
| Lignoceric | " | $C_{23}H_{47}COOH$ | Beech-wood tar. |
| Hyenic | " | $C_{24}H_{49}COOH$ | Hyena-fat. |
| ——— | | $C_{25}H_{51}COOH$ | (Unknown.) |
| Cerotic | " | $C_{26}H_{53}COOH$ | Beeswax, carnauba wax, wool-fat. |

It is to be observed that these fatty acids make a nearly complete series, the first of which contains one carbon and two hydrogen atoms, and the last 27 carbon and 54 hydrogen atoms, and that each of the intermediate acids differs from its neighbors by $CH_2$. The first two acids in this series are thin, intensely sour, odorous liquids that mix with water in all proportions ; the third to the ninth inclusive are oily liquids whose consistency increases and whose sourness and solubility in water diminish with their greater carbon content. The tenth and other acids are at common temperatures nearly tasteless, odorless, and fatty solids, which easily melt to oily liquids whose acid properties are but feebly manifest. Of these acids a few only require further notice.

**Acetic Acid**, $C_2H_4O_2$, or $CH_3COOH$, formed in the "acetic fermentation" from cider, malt, wine and whisky, alcohol being in each case its immediate source, exists free in vinegar to the extent of about 5 per cent. When pure, it is a strongly acid liquid, blistering the tongue, boiling at 246°, and solidifying at about 60° to a white crystalline mass. In plants, acetic acid is said to exist in small proportion, mostly as acetate of potassium.

**Butyric Acid**, $C_4H_8O_2$, or $CH_3CH_2CH_2COOH$, in the free state, occurs in rancid butter, whose disagreeable odor is largely due to its presence. In sweet butter it exists only as a glyceride or fat of agreeable qualities.

The other acids of this series are mostly found in vegetable and animal fats or fatty oils. (See p. 85.)

OXYFATTY ACIDS.—The acids of this class differ from the corresponding fatty acids by having an additional atom of oxygen, or by the substitution of OH for H in the latter. There are two acids of this class that may be briefly noticed, viz.: oxyacetic, or glycollic acid, and oxypropionic or lactic acid.

**Glycollic Acid,** $C_2H_4O_3$ or $HOCH_2COOH$, exists in the juices of plants (grape-vine), and like acetic acid may be formed by oxidizing alcohol.

**Lactic,** $C_3H_6O_3$, or $CH_3CH\ (OH)\ COOH$, is the acid that is formed in the souring of milk, where it is produced from the milk-sugar by a special organized ferment. It is also formed in the "lactic fermentation" of cane-sugar, starch and gum, and exists accordingly in sour-kraut and ensilage.

The fatty and oxyfatty acids are *monobasic,* i.e., they contain one carboxyl, COOH, and each acid forms one salt only, with potassium, for instance, in which the hydrogen of the carboxyl is replaced by the metal. Thus, potassium acetate is $CH_3COOK$.

The oxyfatty acids are especially prone to form *anhydrides* by loss of the elements of water. Lactic acid cannot be obtained free from admixed water when its aqueous solutions are evaporated, without being partially converted into an anhydride. Gentle heat up to 270° changes it, with loss of water, into so-called *lactolactic acid,** $C_6H_{10}O_5$, a solid, scarcely soluble in water, but that slowly reproduces lactic acid by contact with water, and dissolves in alkalies to form ordinary lactates. Lactolactic acid, heated to 290°, loses water with formation of *lactide,*† $C_6H_8O_4$, a solid nearly insoluble in water, but also convertible into lactic acid by water, and into lactates by alkalies.

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* $2\,(C_3H_6O_3) = C_6H_{10}O_5 + H_2O$

† $C_6H_{10}O_5 = C_6H_8O_4 + H_2O$

*Dibasic Acids.*—The acids of this class requiring notice are

| | | |
|---|---|---|
| *Oxalic acid,* | $C_2H_2O_4$, or | $\begin{array}{l}COOH\\ \vert\\ COOH\end{array}$ |
| *Malonic acid,* | $C_3H_4O_4$, or | $CH_2 \left\langle \begin{array}{l}COOH\\ COOH\end{array}\right.$ |
| *Succinic acid,* | $C_4H_6O_4$, or | $\begin{array}{l}CH_2{-}COOH\\ \vert\\ CH_2{-}COOH\end{array}$ |
| *Malic acid (Oxysuccinic acid),* | $C_4H_6O_5$, or | $\begin{array}{l}CH_2{-}COOH\\ \vert\\ CH(OH){-}COOH\end{array}$ |
| *Tartaric acid (Dioxysuccinic acid),* | $C_4H_6O_6$, or | $\begin{array}{l}CH(OH)\ \ COOH\\ \vert\\ CH(OH)\ \ COOH\end{array}$ |

The salts formed by union of these acids with metallic bases are either *primary* or *secondary*, according as the metal enters into one or two of the carboxyls.

**Oxalic acid**, $C_2H_2O_4$, exists largely in the common sorrel, and is found in greater or less quantity in nearly all plants. The pure acid presents itself in the form of colorless, brilliant, transparent crystals, not unlike Epsom salts in appearance (Fig. 15), but having an intensely sour taste.

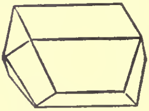
Fig. 15.

Primary potassium oxalate (formerly termed acid oxalate of potash), HOOC—COOK, occasions the sour taste of the juice of sorrel, from which it may be obtained in crystals by evaporating off the water. It may also be prepared by dissolving oxalic acid in water, dividing the solution into two equal parts, neutralizing * one of these by adding solution of potash and then mixing the two solutions and evaporating until crystals form.

Secondary potassium oxalate (neutral oxalate of potash), KOOC—COOK, is the result of fully neutralizing oxalic acid with potash solution. It has no sour taste.

Primary calcium oxalate exists dissolved in the cells of plants so long as they are in active growth. Secondary calcium oxalate is extremely insoluble in water, and

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* As described in Exp. 38.

very frequently occurs within the plant as 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.

Secondary ammonium oxalate is employed as a test for calcium.

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

EXP. 37.—Add to any solution of lime, as lime-water (see note, p. 20), or hard well-water, a few drops of solution of ammonium oxalate. Secondary 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 ammonium oxalate is a test for lime only in solutions containing no free mineral acid. (Acetic and oxalic acids, however, have little effect upon the test.)

**Malonic acid** and **Succinic acid** occur in plants in but small quantities. The former has been found in sugar-beets, the latter in lettuce and unripe grapes.

**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 the garden rhubarb, and primary potassium malate may be obtained in crystals by simply evaporating the juice of the leaf-stalks of this plant. It is likewise abundant as calcium 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 gray sandy powder during the evaporation of the sap.

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

**Tartaric acid,** $C_4H_6O_6$, is abundant in the grape, from the juice of which, during fermentation, it is deposited as *argol.* This, on purification, yields the cream of tartar (bitartrate of potash) of commerce. Tartrates of potassium and calcium exist in small quantities in tamarinds, in the unripe berries of the mountain ash, in the berries of the sumach, in cucumbers, potatoes, pineapples, and many other fruits. The acid itself may be obtained in large glassy crystals (see Fig. 16), which are very sour to the taste.

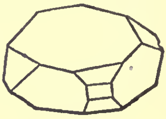
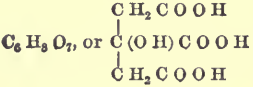


Fig. 16.

Of the *Tribasic Acids* known to occur in plants, but one need be noticed here, viz., *citric acid.*



$$C_6H_8O_7, \text{ or } \begin{array}{l} CH_2COOH \\ | \\ C(OH)COOH \\ | \\ CH_2COOH \end{array}$$

**Citric acid** 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 in tobacco leaves, in the tubers of the artichoke (*Helianthus*), in the bulbs of onions, in beet-roots, in coffee-berries, in seeds of lupin, vetch, the pea and bean, and in the needles of the fir tree, mostly as potassium or calcium salt. It also exists in cows' milk.

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

*Relations of the Vegetable Acids to each other, and to the Amyloses.*—Oxalic, malic, tartaric and citric acids usually occur together in our ordinary fruits, and 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. Tartaric acid can be artificially transformed into malic acid, and this into succinic acid.

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

Cellulose, starch, dextrin, the sugars, yield oxalic acid when heated with potash or nitric acid. Commercial oxalic acid is thus made from sawdust.

Gum (Arabic), sugar and starch yield tartaric acid by the action of nitric acid.

*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 forming *salts* by its interaction with *bases.* The strongest acids, i. e., those bodies whose acid characters are most highly developed, if soluble, so as to have any effect on the nerves of taste, are sour, viz., sulphuric acid, phosphoric acid, nitric acid, etc.

*Bases* are the opposite of acids. The strongest bases, when soluble, are bitter and biting to the taste, and corrode the skin. Potash, soda, lime, and ammonia 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, *alkali-earths.*

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

$$NaOH + HCl = NaCl + H_2O$$

*Sodium hydroxide. Hydrochloric acid. Sodium chloride. Water.*

In general, salts having a metallic base are formed by substituting the metal for the hydrogen of the acid ; or if an *organic acid,* for the hydrogen that is united to oxygen, i.e., of carboxyl, COOH.

Ammonia, $NH_3$, and many organic bases unite directly to acids in forming salts.

| | | | | |
|---|---|---|---|---|
| $NH_3$ | + | $HCl$ | = | $NH_4Cl$ |
| *Ammonia.* | | *Hydrochloric acid.* | | *Ammonium chloride.*[*] |
| $NH_3$ | + | $CH_3COOH$ | = | $CH_3COONH_4$ |
| *Ammonia.* | | *Acetic acid.* | | *Ammonium Acetate.* |

*Test for acids and alkalies.*—Many vegetable colors 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 color when concentrated, but, on mixing with much pure water, becomes orange or yellowish-orange. Acids do not affect this color, while alkalies turn it to an intense carmine or violet-carmine, which is restored to orange by acids.

EXP. 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 these 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 color 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 sulphate of ammonia, 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.

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 colors 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 colors. This is true of common salt, glauber salts or sulphate of sodium, and saltpeter or nitrate of potassium. Others exhibit the properties of their base, though in a reduced degree. Carbonate of ammonium, for example, has much of the odor, taste, and

---

[*] Also termed ammonic chloride, ammonia hydrochlorate, ammonia hydrochloride, and formerly muriate of ammonia.

[†] Tinctures, in the language of the apothecary, are *alcoholic* solutions. Tincture of litmus (procurable of the 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 purple, and the bases a green color.

effect on vegetable colors that belong to ammonia. Carbonate of sodium has the taste and other properties of caustic soda in a greatly mitigated form. On the other hand, sulphates of aluminum, iron, and copper, have slightly acid characters.

5. Fats and Oils (Wax).—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, colza, cotton, bayberry, peanut, butternut, beech, hickory, almond, sunflower, etc., contain 10 to 70 per cent of oil, which may be in great part removed by pressure. In some plants, as the common bayberry 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. 17, 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 sulphide of carbon, which dissolve all fats with readiness, but scarcely affect the other vegetable principles.

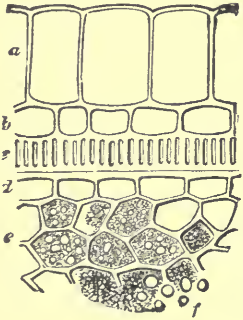


Fig. 17.

Many plants yield small quantities of wax, which often 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 blossom contain, in the dry state, 10 per cent of fat and wax (Arendt). Scarcely two of these oils, fats, or kinds of wax, are exactly alike in their properties. They differ more or less in taste, odor, and consistency, as well as in their chemical composition.

The "oils" are the simplest in chemical composition, and have the lowest melting points. The "fats" have larger content of carbon, and higher points of fusion. The varieties of wax are most complex in composition, and have the highest melting points and greatest content of carbon. These differences are mostly gradational. In chemical constitution these bodies are alike.

**Exp. 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 fatty oils must not be confounded with the *ethereal, essential,* or *volatile oils,* which, however, do not occur to much extent in agricultural plants. The former can 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 odors, 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.

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—e.g., tallow, olive oil, and butter—consist mainly of three substances, which we may briefly notice. These elementary fats are *Stearin, Palmitin,* and *Olein*,* and they consist of carbon, oxygen, and hydrogen, the first-named element being greatly preponderant.

**Stearin** is represented by the formula $C_{57}H_{110}O_6$. It is the most abundant ingredient of the common fats, and exists in largest proportion in the harder kinds of tallow.

EXP. 40.—Heat mutton or beef tallow in a bottle that may be tightly corked, with ten times its bulk of concentrated ether, until a clear solution is obtained. Let cool slowly, when stearin will crystallize out in pearly scales.

**Palmitin**, $C_{51}H_{98}O_6$, receives its name from the palm oil, of Africa, in which it is a large ingredient. It forms a good part of butter, and is one of the chief constituents of beeswax, and of bayberry tallow.

**Olein**, $C_{57}H_{104}O_6$, 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 stearin and the palmitin solidify, leaving the olein still in the liquid state.

Other elementary fats, viz., butyrin, laurin, myristin, etc., occur in small quantity in butter, and in various vegetable oils. Flaxseed oil contains linolein; castor oil, ricinolein, etc.

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

CENTESIMAL COMPOSITION OF THE ELEMENTARY FATS.

| | *Stearin.* | *Palmitin.* | *Olein.* |
|---|---|---|---|
| Carbon | 76.6 | 75.9 | 77.4 |
| Hydrogen | 12.4 | 12.2 | 11.8 |
| Oxygen | 10.0 | 11.9 | 10.8 |
| | 100.0 | 100.0 | 100.0 |

*Saponification.*—The fats are characterized by forming soaps when heated with strong potash or soda-lye. They are by this means decomposed, and give rise to *fatty*

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* *Margarin*, formerly thought to be a chemically-distinct fat, is a mixture of stearin and palmitin. *Oleomargarine* is the commercial designation of an artificially-obtained mixture of fats, animal or vegetable, that has nearly the consistence of dairy butter.

*acids*, which remain combined with the alkali-metal, and to *glycerin*, a substance which acts as a base. The fats are therefore termed glycerides.

EXP. 41.—Heat a bit of tallow with 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 the three fatty acids, corresponding to the elementary fats from which it was produced.

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

The chemical act of saponification consists in the re-arrangement of the elements of one molecule of fat and three molecules of water into three molecules of fatty acid, and one molecule of glycerin.

$$\underset{\textit{Palmitin.}}{C_{51}H_{98}O_6} + \underset{\textit{Water.}}{3\,(H_2O)} = \underset{\textit{Palmitic acid.}}{3\,(C_{16}H_{32}O_2)} + \underset{\textit{Glycerin.}}{C_3H_8O_3}$$

Saponification is likewise effected by the influence of strong acids and by heating with water alone to a temperature of near 400° F.

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

*Relations of Fats to Carbhydrates.*—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 van-

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* Oleic acid differs from stearic acid in containing two atoms less of hydrogen, and is one of a series that bear this relation to the fatty acids of corresponding content of carbon.

ishes 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 versa.* In germination the oil of the seed is converted back again into starch, sugar, etc.

The *Estimation of Fat* (including wax) is made by warming the pulverized and dry substance repeatedly with renewed quantities of ether, or sulphide of carbon, as long as the solvent takes up anything. On evaporating the solutions, the fat remains, and after drying thoroughly, may be weighed. The ether extract thus obtained is usually accompanied by a small amount of other substances, especially chlorophyll and lecithin, and is hence properly termed *crude fat.*

PROPORTIONS OF CRUDE FAT IN VARIOUS VEGETABLE PRODUCTS.

| | *Per cent.* | | *Per cent.* |
|---|---|---|---|
| Meadow grass | 0.8 | Turnip | 0.1 |
| Red clover (green) | 0.7 | Wheat kernel | 1.6 |
| Cabbage | 0.4 | Oat " | 1.6 |
| Meadow hay | 3.0 | Maize " | 7.0 |
| Clover hay | 3.2 | Pea " | 3.0 |
| Wheat straw | 1.5 | Cotton seed | 34.0 |
| Oat straw | 2.0 | Flax " | 34.0 |
| Wheat bran | 1.5 | Colza " | 45.0 |
| Potato tuber | 0.3 | | |

6. THE ALBUMINOIDS OR PROTEIDS.—The bodies of this class essentially differ from those of 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, perhaps *phosphorus.*

These bodies, though found in some proportion in all parts of plants, being everywhere necessary to growth, are chiefly accumulated in the seeds, especially in those of the cereal and leguminous grains.

The *albuminoids* or *proteids** that occur in plants are so similar, in many characters, to those which constitute a large portion of every animal organism, that we may advantageously consider them in connection with the latter.

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* The nomenclature of these substances is unavoidably confused. They are often termed nitrogenous or nitrogenized bodies, also albuminous bodies, and protein bodies. The term albuminoids has been latterly restricted, by some authors, to the substances of which gelatine is a type. The word albuminates is applied to syntonin and casein.

Three familiar representatives of this class of bodies are, *albumin*, or the white of egg; *fibrin*, or the clot of blood, and *casein*, which yields the curd of milk.

*General Characters.*—Many of these substances occur in two very distinct modifications, one form being soluble in water, or in highly-diluted acids or alkalies, or in salt-solutions, the other insoluble in these liquids.

Some of the *soluble proteids* we find naturally dissolved in the juices of living plants and animals. Some may be obtained in the solid form by evaporating off at a very gentle heat the water which is naturally associated with them. They then appear as nearly colorless or yellowish, amorphous solids, destitute of odor or taste, which dissolve again in water, but are insoluble in alcohol.

Soluble compounds of proteids with magnesium or iron occur in plants, or may be obtained from the blood of animals, in the form of white or red crystals.

Solutions of most of the albuminoids are readily *coagulated* by heat and by concentrated mineral acids, the albuminoids being thereby themselves chemically changed and made insoluble. Some coagulate spontaneously.

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 odorless and tasteless.

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

*Tests for the Albuminoids.*—The chemist employs the behavior 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

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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.

distinction of this class of substances from all others, even in microscopic observations.

1. Solution of *iodine* colors them intensely yellow or bronze.

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

3. In contact with *nitric acid*, especially when hot, they are stained a deep and vivid yellow. Silk and wool, which consist largely of proteids, are commonly dyed or printed yellow by means of nitric acid.

4. A solution of *mercuric nitrate* in excess of nitric acid,* tinges them of a deep red color. This test enables us to detect albumin, for example, even where it is dissolved in 20,000 parts of water.

5. With *caustic soda* and very dilute solution of *copper sulphate*, successively applied, the proteids give a violet color which is intensified by warming. (Biuret test.)

The **Albumins** are soluble in water; the solutions as naturally occurring, unless very dilute, are coagulated by heat.

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

EXP. 42.—Beat or whip the white of an egg so as to destroy the delicate transparent membrane in the cells of which the albumin is held, and agitate a portion of it with water; observe that it mostly *dissolves* in the latter. The solution is turbid from presence of globulin.

EXP. 43.—Heat a part of the undiluted white of egg in a tube or cup. At 165° F. it becomes opaque, white, and solid (coagulates), and is converted into the insoluble modification. A higher heat is needful to coagulate solutions of albumin, in proportion as they are diluted with water.

EXP. 44.—Add strong alcohol to a portion of the solution of albumin of Exp. 42. It precipitates the albumin, which for a time remains soluble in water, but later coagulates and becomes insoluble.

EXP. 45.—Observe that albumin is coagulated by strong acids applied in small quantity, especially by nitric acid.

EXP. 46.—Put a little albumin, either soluble or coagulated, into each of five test tubes. To one, add solution of iodine; to a second, strong hydrochloric acid; to a third, nitric acid; to a fourth, nitrate of mercury, and to the last a few drops of solution of copper sulphate, and then a little caustic soda or potash solution. Observe the characteristic colorations that appear immediately, or after a time, as described above. In the last four cases the reaction is hastened by a gentle heat.

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* This solution, known as Millon's reagent, is prepared by dissolving mercury in its own weight of nitric acid of sp. gr. 1.4, heating toward the close of the process, and finally adding to the liquid twice its bulk of water.

*Serum Albumin* occurs dissolved in the blood, in milk, and in nearly all the liquids of the healthy animal body except the urine. Its characters are slightly different from those of egg-albumin. The albumin of the blood may be separated by heating blood-serum (the clear yellow liquid that floats above the clot). The albumin of milk coagulates when milk-serum (whey) is heated to near boiling.

On boiling entire milk, albumin coagulates, and, mixed with fat and casein, is deposited as a tough coating on the sides of the vessel.

Animal albumin remains, when its solutions are evaporated at a temperature below 140° F., as a yellowish translucent and friable solid, which easily dissolves in water.

*Vegetable Albumin.*—In the juices of all plants is found in small quantity a substance which agrees in many respects with animal albumin, and has been termed ***vegetable albumin.*** 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 such a body 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 coloring matters, in its chemical reactions and composition closely approaches the coagulated albumin of eggs.

The juice of succulent vegetables, as cabbage, yields a similar substance 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 an albuminoid from these grains.

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

EXP. 47.—Prepare impure vegetable albumin from potatoes, cabbage, or flour, as above described, and apply the nitrate of mercury test.

As already intimated, albumin is chemically changed or decomposed in the process of coagulation. Coagulated albumin is not readily dissolved by dilute acids or by dilute aqueous solutions of alkali.

The so-called vegetable albumin is mostly known only after coagulation by heat, and has been but imperfectly studied. According to Ritthausen, the coagulum obtained by heating the juice of potato tubers or the aqueous extracts of peas and horse-beans (*Vicia faba*) is soluble in dilute potash and in acetic acid; it is therefore not albumin. Sidney Martin reports a genuine albumin in the juice of the papaw, but its composition has not been determined.

**Fibrin.**—*Animal Fibrin* is insoluble in water, alcohol and salt-solutions; it swells up in dilute acids, dissolves in alkalies, and is coagulated by heat.

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 hereby separates into two portions, a clear, pale-yellow liquid—the serum—and the clot. As already stated, the serum contains albumin. On persistently squeezing and washing the clot with water, the coloring matter of the blood is removed, and a white stringy mass remains, which consists chiefly of fibrin, being a decomposition-product of another albuminoid, *fibrinogen.*

In very dilute hydrochloric acid, fibrin swells up, but does not dissolve. When freshly prepared, it absorbs oxygen from the air and gives off carbon dioxide. Heating to 176° to 212° coagulates and shrinks it, and renders it less elastic and incapable of absorbing oxygen.

EXP. 48.—Observe the separation of blood into serum and clot; coagulate the albumin 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 coloring matter ceases to run off. Warm it with nitric acid as a test.

*Flesh-Fibrin.*—If a piece of lean beef or other dead animal muscle be repeatedly squeezed and washed in water, the coloring matters are gradually removed and a white residue is obtained which resembles blood-fibrin in its external characters, and as it represents the fibers of the original muscle, and was supposed to be a simple albuminoid, it was formerly designated flesh-fibrin. It is, however, a mixture consisting largely of *myosin* (see p. 97). It mostly dissolves in very dilute hydrochloric acid to a clear liquid, from which addition of much common salt, or of a little alkali, throws down *syntonin.* The term flesh-fibrin is therefore no longer properly employed to designate a distinct chemical substance.

*Vegetable fibrin.*—When wheat-flour or rye-flour is mixed with a little water to a thick dough, and this is washed and kneaded for some time in water, the starch and albumin 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."

EXP. 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 reagent.

Gluten is a mixture of several albuminoids, and contains also some starch and fat. When boiled with alcohol it is partially dissolved.* The portion insoluble in

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* The dissolved portion Ritthausen found to consist of two distinct albuminoid or rather *glutinoid* bodies, viz.:

*Gliadin*, or vegetable glue, is very soluble in water and alcohol. It strongly resembles animal glue and chiefly gives to wheat dough its tenacious qualities.

*Mucedin* resembles gliadin, but is less soluble in strong alcohol, and is insoluble in water. When moist, it is yellowish-white in color, has a silky luster, and slimy consistence. It exists also in gluten made from rye grain. (Ritthausen, *Jour. für Prakt. Chem.*, 88, 141, *and* 99, 463.)

strong alcohol Liebig first designated as *vegetable fibrin.* Ritthausen found this to be a mixture of two bodies, which he distinguished as gluten-casein and gluten-fibrin. The latter is extracted from gluten by hot weak alcohol and separates on partially removing the alcohol by evaporation.

The albuminoids of crude gluten dissolve in very dilute potash-solution (½ to 1 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, the *gluten-casein* of Ritthausen remains undissolved.

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

Vegetable fibrin is readily soluble in hot dilute alcohol, but slightly so in cold dilute, and not at all in absolute alcohol. On prolonged heating with alcohol, it becomes insoluble in that liquid. It does not dissolve in water. It has no fibrous structure like animal fibrin, but forms, when dry, a tough, horn-like mass. In composition it approaches washed muscle, but differs considerably from blood-fibrin.

Wheat contains or yields* but a small proportion of fibrin and less appears to exist in hard than in the soft wheats. Rye contains less than wheat. Barley, from which no gluten can be got, yields to alcohol a small proportion of fibrin.

*Maize-fibrin, Zein.*—The meal of Indian corn, unlike that of wheat and rye, when made into a dough, forms no gluten, but it yields to warm, weak alcohol some 7 per cent of fibrin quite similar to that from wheat, though of somewhat different composition.

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* Weyl and Bischof believe that gluten does not pre-exist in wheat and rye, just as fibrin does not exist in living blood, but is a result of chemical change during the wetting and kneading of the flour to a dough. According to them a strong solution of common salt extracts from wheat flour vegetable globulin (see p. 97), and the residue, when kneaded with water, forms no gluten. If, however, the salt solution of globulin, in contact with the flour, is largely diluted with water, the flour will yield gluten by kneading.

**Casein.**—*Animal Casein* is the peculiar albuminoid of milk, in which it exists dissolved to the amount usually of 3 to 6 per cent. By saturating milk with magnesium sulphate the casein separates as an opaque white precipitate. Thus obtained it is freely soluble in water. Casein is also precipitated from milk by adding a little acetic or other acid, but is then nearly insoluble in water, has a decided acid reaction, and reddens blue litmus. The spontaneous curdling of milk, after standing at ordinary temperatures for some time, appears to be directly due to the lactic acid which develops from milk-sugar as the milk sours. When milk is swallowed by a mammalian animal it curdles directly, and in the making of cheese the casein of milk is coagulated by the use of rennet, which is an infusion of the membrane lining the calf's stomach. Coagulated casein, though insoluble in water, dissolves in very dilute acids, and also in very dilute alkalies.

The coherent cheese curd which is separated from milk by rennet is doubtless a decomposition-product of casein, and carries with it a considerable portion of the phosphates and other salts of the milk. These salts are not found in the casein precipitated by acids, being kept in solution by the latter, but casein appears to contain a small amount of phosphorus (equivalent to 0.9 per cent phosphoric oxide) in organic combination. Skim-milk cheese, when new, consists mainly of coagulated casein with a little fat. Cheese made from entire milk contains most of the fat of the milk.

EXP. 50.—Observe the coagulation of casein when milk is treated with a few drops of dilute hydrochloric acid. Test the curd with nitrate of mercury.

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

**Vegetable Casein.**—Several distinct substances have been described as vegetable caseins. Our knowledge with regard to them is in many important respects very deficient. Even their elementary composition is a matter of uncertainty.

*Gluten-Casein.*—That part of the gluten of wheat which is insoluble in cold alcohol is digested in a highly dilute solution of potash, and the clear liquid is made faintly acid by acetic acid. The curdy white precipitate thus obtained, after washing with water, alcohol and ether, and dried, is the gluten-casein of Ritthausen. It is insoluble in water, and in solutions of common salt, easily soluble in weak alkalies and coagulated by acids. Ritthausen obtained this body from wheat, rye, barley, and buckwheat.

*Legumin* is the name that has been applied to the chief albuminoid of oats, peas, beans, lupins, vetches, and other legumes. It is extracted from the pulverized seeds by dilute alkalies, and is thrown down from these solutions by acids. From some leguminous seeds it may be partially extracted by pure water, probably because of the presence of alkali-phosphates which serve to dissolve it. It is generally mixed with *conglutin*, from which it may be separated by soaking in weak brine (a 5 per cent solution of common salt). Thus obtained, it is insoluble in pure water and in brine, but soluble in dilute alkalies, and has a decided acid reaction. Legumin, as existing in the horse-bean (*Vicia faba*), is soluble in brine, but after solution in alkali and precipitation with acids, is insoluble in salt solution. The casein, animal or vegetable, that is thrown down from salt-solution by acids is evidently a chemical compound of the original proteid with the acid (acid-proteid).

EXP. 52.—Prepare a solution of vegetable casein from crushed peas, almonds, or pea-nuts, by soaking them for some hours in warm water, to which a few drops of dilute ammonia-water or potash-lye has been added, and allowing the liquid to settle clear. Precipitate the casein by addition of an acid to the solution.

The Chinese are said to 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 practiced with milk-cheese, viz.: salting, pressing, and keeping until the odor and taste of cheese are developed. It is cheaply sold in the streets of Canton under the name of *Tao-foo.* Vegetable casein appears to occur in small quantity in 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 albumin by boiling and filtering.

The **Globulins** are insoluble in water, but dissolve in neutral salt-solutions. Some dissolve only in salt-solutions of moderate strength and are thrown down from these solutions by more salt. Others are soluble in saturated salt-solutions. They are coagulated by heat. Some *animal globulins* may first be noticed.

*Vitellin* is obtained from the yolk of eggs; fat and pigment are first removed by ether, and the white residue is dissolved in a solution of common salt (1 of salt to 10 of water). Addition of water to the filtered solution separates the vitellin as a white, flocky mass.

*Paraglobulin* exists in blood serum, and may be thrown down by saturating the serum with magnesium sulphate. It may be obtained in transparent microscopic disks that are probably crystalline. Its solutions in brine coagulate by heat, like albumin.

*Fibrinogen.*—When blood fresh from the veins of the horse is mixed directly with a saturated aqueous solution of magnesium sulphate, fibrinogen dissolves, and the liquid, after filtering from the red corpuscles, upon mixing with a saturated brine of common salt, deposits this body in white flocks, which unite to a tough, elastic mass. Its solutions in brine coagulate at a lower temperature than those of paraglobulin.

Fresh-drawn blood, after standing a short time, coagulates of itself to a more or less firm clot. Under the microscope this process is seen to consist in the rapid formation of an intricate net-work of delicate threads or fibrils. These are *fibrin,* and come from the coagulation of fibrinogen. Coagulation here appears to be induced by a ferment whose effect is suspended by strong saline solutions, but is renewed when these are mixed with much water. This ferment occasions decomposition of the fibrinogen, fibrin being one of the products. The fibrin-ferment is supplied from ruptured white blood-corpuscles. The chemical composition of fibrinogen and fibrin, as determined by analysis, is quite the same.

*Myosin.*—Lean beef or other dead muscle-tissue, after mincing and washing with water to remove coloring matters, is soaked in 10 per cent salt-solution. Myosin dissolves and is precipitated from the filtered brine by diluting with water. It dissolves also in dilute hydrochloric acid and in dilute potash solution. Strong hydrochloric acid converts it into syntonin. Myosin does not exist in living muscle, but is formed after death, during *rigor mortis,* from the juices of the muscles by a process of coagulation. Its formation is accompanied by the development of lactic and carbonic acids. Myosin is the chief ingredient of what was formerly known as muscle-fibrin.

*Vegetable Globulins* occur abundantly in seeds where they are chief ingredients of the so-called aleurone or protein-granules. From these protein-granules, or from the pulverized seeds, the globulins are extracted by salt-solutions and by weak alkalies. The globulin which water alone extracts from many seeds is dissolved by help of the salts, which are there present. Such saline extracts are coagulated by heat and thus globulins have figured, no doubt, as "vegetable albumin." Some globulins are only known in the amorphous or granular state; others occur as crystals.

*Conglutin* exists abundantly, according to Ritthausen, in the seeds of peach, almond, lupin, radish, pea-nut, hickory-nut, and hazel-nut, where it is usually associated with legumin. It may be separated by weak brine, in which it is invariably soluble, while legumin, after separation from alkali-solutions, is undissolved by brine. The conglutin obtained from lupins and pea-nuts differs somewhat from that found in the hazel-nut, and in almond and peach seeds. Conglutin cannot be crystallized from salt-solutions, as readily happens with vegetable vitellin.

*Vegetable Vitellin.*—Applying this designation to albuminoids which are insoluble in water, but dissolve in saturated salt-solutions, and are thence precipitated by water, we find vitellin more or less abundantly in seeds of squash, hemp, sunflower, lupin, bean, pea, Brazil-nut, castor-bean, and various other plants. It may be extracted from squash seeds by common-salt-solution (of 10 per cent) or dilute alkali. Diluting the brine with water or neutralizing the alkali with acids precipitates the vitellin, which, after washing with water, alcohol and ether, may be obtained in crystals (microscopic octahedrons) by dissolving in warm brine and slowly cooling. From seeds of hemp and castor-bean Ritthausen obtained crystals identical in appearance and composition with those of squash seeds, but soluble in water, probably because of the presence of alkali salts.

*Vegetable Myosin.*—Weyl and Bischof consider that cereal and leguminous seeds contain or yield myosin analogous to muscle-myosin, which differs from vitellin (and conglutin) in being precipitated from its solution in weak brine by saturating the same with salt. They find that wheat-flour contains but little if any proteid besides myosin, and that when this is removed from the flour by salt-solution or by very weak soda-lye or by hydrochloric acid of 0.1%, the residue is incapable of yielding gluten. Gluten is therefore a decomposition-product of myosin. These results are confirmed by the recent work of Martin (*Jour. of Physiology,* 1887). Zoeller found that the pulp of potatoes, after starch and soluble matters had been removed by copious washings with water, yielded to 10% salt-solution an albuminoid which separated when the brine was saturated by addition of salt in excess. He also precipitated myosin from the juice of the tubers by saturating it with salt.

The myosins are precipitated by conversion into *alkali-proteids,* when their brine-solutions are deprived of salt by dialysis or when these solutions are kept for some hours at 100° F. (*Sidney Martin.*)

*Vegetable Paraglobulin* is recently stated to exist in papaw-juice, and in the seeds of lequirity, *Abrus precatorius.* It is distinguished from myosin by requiring a higher temperature for coagulation from salt-solutions and in not suffering conversion into an insoluble alkali-proteid by dialysis or long heating to 100° F. (*Martin.*)

**Acid-Proteids** are bodies formed from proteids by the prolonged action of acids. They are insoluble in water, alcohol and brines, but easily soluble in dilute acids or alkalies, and are precipitated by neutralizing these solutions. The solutions of acid-proteids in acids are not coagulable by heat. The albumins and globulins are gradually converted into acid-proteids by cold, highly dilute acids, and more rapidly by stronger acids and gentle heat. *Syntonin* is the acid-proteid resulting from solution of muscle-flesh, or myosin, in weak hydrochloric acid, and is thrown down when the solution is neutralized by an alkali, as a white gelatinous substance. Acid-proteids may exist in seeds such as the oat, lupin, pea, bean, etc., which contain so much free acid, or acid salt, that the water extract is strongly acid to test-papers.

**Alkali-Proteids, or Albuminates.**—The action of dilute alkali-solutions on most proteids converts them into bodies which, like acid-proteids, are insoluble in water and salt-solutions, but soluble in dilute acids and alkalies, and are thrown down from these solutions by neutralization. Dilute acids do not convert them into acid-proteids. Alkali-proteids are said to exist generally in the young cells of the animal, and may also occur in plants in the alkaline juices of the cambium. The "vegetable caseins," viz., legumin and gluten-casein, as they occur in the alkaline juices or extracts of plants, are probably bodies of this class, and when precipitated by acids unite to the latter, forming compounds with an acid reaction. Casein of milk has been by some considered to be an alkali-proteid, but is probably distinct.

**Proteoses and Peptones.**—These terms designate bodies that result from the chemical alteration of albuminoids, under the influence of "ferments" which exist in plants, but which have been most fully studied as they occur in the digestive apparatus of animals.

The albuminoids, as found in plants, are mostly insoluble in the vegetable juices, and those which are soluble (probably because of the presence of salts, acids or alkalies) are mostly incapable of freely penetrating the cell-membranes which inclose them, and cannot circulate in the vegetable juices, and likewise, when they become the food of animals, cannot leave the alimentary canal so as to become incorporated with the blood until they have been chemically changed. During the processes of animal digestion the albuminoids of whatever kind undergo solution and conversion into bodies which are freely soluble in water, and rapidly penetrate the moist membranes of the intestines, and thus enter into the circulation. These bodies have been prepared for purposes of study by a partly artificial digestion, carried on in glass vessels with help of the digestive ferments obtained from the stomach (pepsin) or pancreas (trypsin) of animals.*

It appears from Kühne and Chittenden's investigations that a series of soluble and diffusible products are formed from each albuminoid with progressive diminution of carbon and increase of oxygen, and, in some cases, of nitrogen. The first-formed products are termed *pro-*

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* Reference may be had to Chittenden's Studies in Physiological Chemistry, Connecticut Acad., Vols. II and III, 1887 and 1889.

*teoses* (*albumoses, caseoses, globuloses,* etc.) ; those last produced they designate *peptones,* but investigators are not as yet agreed as to the precise application of these terms. What have been formerly called peptones are now considered to be largely proteoses.

The composition of some of these bodies may be seen from the following analyses by Chittenden and Painter :

| | C. | H. | N. | S. | O. |
|---|---|---|---|---|---|
| Casein | 53.30 | 7.07 | 15.91 | 0.82 | 22.03 |
| Protocaseose | 52.50 | 7.15 | 15.73 | 0.96 | 23.86 |
| Deuterocaseose | 51.59 | 6.98 | 15.73 | 0.75 | 25.03 |
| Casein-Peptone | 49.94 | 6.51 | 16.30 | 0.68 | 26.57 |

Of the several products which have been analyzed and classed as proteoses and peptones, it is not certain that any one is a strictly homogeneous substance. It is more than probable that some of them are mixtures. The proper use of these names is provisional, to characterize certain evidently distinct stages of albuminoid metamorphosis, whose exact nature can only be cleared up by further investigation.

The peptones may be defined as the final products of the action of the peptic ferment. They are soluble in water and freely diffusible through animal membranes. The albumoses (or proteoses) are intermediate between the albuminoids and the peptones, being mostly soluble in water but not freely diffusible.

The proteoses much resemble the albuminoids from which they are derived, not only in composition, but in many of their properties. The peptones have less resemblance, but appear capable of partially reverting to proteoses, as some of the latter are said to yield coagulable albuminoids when kept in the moist state.

Weak acids and alkalies also convert the albuminoids into proteoses and peptones, and probably the acid-proteids, perhaps also the alkali-proteids, already mentioned, contain proteoses in admixture. Since pepsin-digestion requires the aid of a free acid and trypsin-digestion succeeds best in presence of a free alkali, the conditions under which the proteoses of digestion are formed are in part identical with those that give rise to the acid-proteids and alkali-proteids.

Peptones have been found in small proportions in the water-extract of various plants, e. g., seedlings, lupins, barley-malt, young grass, alfalfa, etc. (*Vs. St.*, XXIV, 363, 371, 440, and XXXII, 389.)

Vines has found a proteose in considerable quantity in the seeds of lupin, peony, and wheat and in the Brazil-nut and castor-bean, and considers bodies of this class to be of general occurrence in the protein-granules of plants.

The proteose (hemialbumose*) from lupins has, exclusive of 0.81 p. c. of ash, the following composition per cent according to Vines :

| C. | H. | N. | S. | O. |
|---|---|---|---|---|
| 52.58 | 7.24 | 14.87 | 1.52 | 23.79 |

Sidney Martin reports the existence of a proteose (hemialbumose) in the juice of the papaw or melon tree (*Carica papaya*) where it is associated with the ferment papain, which is very similar to that of the pancreatic secretion of animals.

**Ferments** are substances which produce or excite chemical changes in a manner as yet mostly unexplained, the ferments themselves not appreciably contributing of their own substance to the products of the processes which they set in operation.

The ferments that figure in agricultural chemistry are closely related to and apparently derived from the albuminoids, but in no case has their chemical composition been positively established. They are distinguished and characterized almost solely by the sources whence they are derived, and the effects which they produce. The

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*Kühne first distinguished the products of pepsin or trypsin digestion into hemialbumose and antialbumose, the former being converted by trypsin into amido-acids (see p. 114), the latter remaining unaltered by the digestive ferments. Kühne & Chittendon have more recently shown "hemialbumose" to be a mixture mainly of proto and dentero-albumose.

substances which the chemist can prepare, and to which he gives special designations, are doubtless mixtures, and in most cases contain but a small proportion of the real ferment, which, in a state of entire purity, is unknown.

*Leaven*, or *Yeast*, which has been employed in making bread, wine and beer for many centuries, contains, or mainly consists of, a microscopic plant of very simple structure (pp. 244-5), which, when placed in a solution of cane-sugar, is able in the first place to cause the "inversion" of that substance into the two sugars, dextrose and levulose, and, secondly, to transform both the latter into alcohol and carbon dioxide. The "inverting" effect of yeast upon cane-sugar has been traced to a substance which can be separated from the yeast and obtained as a dry, white powder. The alcoholic fermentation requires the living yeast plant for its accomplishment. Ferments are accordingly divided into the two classes, *unorganized* and *organized*. We shall here notice briefly a few unorganized ferments or *enzymes*, as they are also termed, that have been somewhat carefully studied.

*Invertin* is obtained from dry, pulverized yeast by heating it to 212° to coagulate albumin and then extracting with warm water. The invertin dissolves, and, by addition of alcohol, is precipitated. Barth thus obtained a substance containing 6 per cent of nitrogen which was able, in the course of 48 hours, to transform (invert) 760 times its weight of cane-sugar. Invertin has no effect on starch or dextrin.

*Diastase* is the name applied to a substance that may be obtained as a whitish powder from sprouted barley (malt) by extracting with dilute alcohol and precipitation with strong alcohol, which is capable of transforming 2,000 times its weight of starch, first into dextrin and finally into maltose and dextrose. The purest diastase prepared by Lintner contained 10.4 per cent. nitrogen and gave reactions for albuminoids, but it had properties besides its action on starch that strikingly distinguished it from the ordinary proteids.

*Pepsin* is that ferment of the so-called gastric juice of the animal stomach which enables this organ to dissolve and "peptonize" the albuminoids of the food. It may be extracted from the inner coating of the stomach by glycerine or very dilute hydrochloric acid, and is precipitable from these solutions by strong alcohol. Pepsin requires the presence of a free acid to dissolve the albuminoids; in neutral or alkaline solution it has no "digestive power."

*Trypsin* is a ferment formed in the pancreas and existing in the pancreatic juice which, in mammalian animals, during the digestion of food, is poured into the upper intestine, where it continues and completes the solution of albuminoids begun by the gastric juice. Trypsin acts in neutral but most effectively in alkaline solutions; its operation is arrested by free acids. The results of its action differ in some respects from those of pepsin.

*Papain.*—The milky juice of the Brazilian plant *Carica papaya,* or melon-tree, contains this ferment, which, like trypsin, is freely soluble in water, rapidly dissolves albuminoids, best in neutral or alkaline solutions, converting them into proteoses and peptones. Papain itself, as obtained by Wurtz & Bouchut, has the properties and composition that characterize the proteoses.

Ferments appear to perform very important functions in the vegetable as well as in the animal organism, and have to be referred to frequently as occasioning the conversion of insoluble into soluble substances, and of complex into simpler bodies.

**Composition of the Albuminoids.**—There are various reasons why the exact composition of some of the bodies just described is still a subject of uncertainty. They are, in the first place, naturally mixed or 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, salt-solutions, alcohol and ether, and there is reason to believe that in many cases these reagents essentially modify the properties and composition of the proteids. These bodies, in fact, as a class, are extremely susceptible to change and alter in respect to appearance, solubility, and other qualities that serve to distinguish them, without any corresponding change in chemical composition being discoverable by our methods of analysis. On the other hand, the substances that have been prepared by different experimenters from the same sources, and by substantially the same methods, often show decided differences of composition.

Finally, the methods of analysis used in determining their composition are liable to considerable error, and, if applied to the pure substances, are scarcely delicate enough to indicate their differences with entire accuracy.

In the accompanying table (p. 106) are given the most recent and trustworthy analyses of the various vegetable albuminoids, and of the corresponding substances of animal origin.

Referring to the analyses of Albumins we observe that the egg-albumin differs from serum-albumin in containing about one per cent more of oxygen and one less of carbon, while hydrogen, nitrogen and sulphur are practically the same. These two albumins have been very thoroughly studied, their difference of composition is well established, and they have positive differences in their properties, so that there can be little doubt that they are specifically distinct substances. Of the Vegetable Albumins none offer any reasonable guarantee of purity. The composition of barley-albumin is near that of the animal albumins, but it contains one-third less sulphur. So far, then, as present data indicate, the veg-

COMPOSITION OF ALBUMINOIDS.

| ALBUMINS. | *Carbon.* | *Hydrogen.* | *Nitrogen.* | *Sulphur.* | *Oxygen.* | *Analysts.* |
|---|---|---|---|---|---|---|
| Egg | 52.2 | 6.9 | 15.8 | 1.9 | 23.2 | Chittenden & Polton. |
| Blood serum | 53.1 | 6.9 | 16.0 | 1.8 | 22.2 | Hammarsten. |
| Wheat | 53.1 | 7.2 | 17.6 | 1.6 | 20.5 | Ritthausen. |
| Barley | 52.8 | 7.2 | 15.8 | 1.2 | 23.0 | |
| FIBRINS. | | | | | | |
| Blood | 52.7 | 6.8 | 16.9 | 1.1 | 22.5 | Hammarsten. |
| Gluten-fibrin, wheat | 54.3 | 7.2 | 16.9 | 1.0 | 20.6 | Ritthausen. |
| " " maize | 54.6 | 7.5 | 15.5 | 0.7 | 21.7 | |
| CASEINS. | | | | | | |
| Milk casein * | 53.3 | 7.1 | 15.9 | 0.8 | 22.0 | Chittenden & Painter. |
| Gluten-casein, wheat | 52.9 | 7.0 | 17.1 | 1.0 | 22.0 | Ritthausen. |
| " " " | 52.8 | 7.0 | 15.8 | 1.1 | 23.3 | Chittenden & Smith. |
| Gluten-casein, buckwheat*. | 50.2 | 6.8 | 17.4 | 1.5 | 24.1 | Ritthausen. |
| Legumin, lupins | 51.4 | 7.0 | 17.5 | 0.6 | 23.5 | |
| GLOBULINS. | | | | | | |
| Paraglobulin | 52.7 | 7.0 | 15.8 | 1.1 | 23.4 | Hammarsten. |
| Fibrinogen, blood | 52.9 | 6.9 | 16.7 | 1.3 | 22.2 | |
| Myosin, beef | 52.8 | 7.1 | 16.8 | 1.3 | 21.9 | Chittenden & Cummins. |
| Conglutin, lupin | 50.1 | 7.0 | 18.7 | 1.1 | 23.0 | Ritthausen. |
| " hazel-nut | 51.2 | 7.1 | 18.6 | 0.6 | 22.5 | |
| Vitellin, squash | 51.3 | 7.5 | 18.1 | 0.6 | 22.5 | |
| " hemp (crystals) | 51.0 | 7.0 | 18.7 | 0.8 | 22.5 | |
| " Brazil-nut | 52.4 | 7.1 | 18.1 | 0.5 | 21.9 | Weyl. |
| GLIADIN, wheat | 52.7 | 7.1 | 18.0 | 0.9 | 21.3 | Ritthausen. |
| MUCEDIN, wheat | 54.1 | 6.9 | 16.6 | 0.9 | 21.5 | Ritthausen. |

See pp. 101 and 102 for analyses of Proteoses and Peptone.

etable albumins are not identical with those derived from the animal.

As respects the Fibrins we have already seen that there is no similarity in properties between that of blood and those obtained from gluten. The analyses of the two gluten-fibrins show either that these substances are quite distinct or that they have not yet been obtained in the pure state.

The Vegetable Caseins, as analyzed by Ritthausen, are

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* The analysis of milk casein should include 0.9 phosphorus. The buckwheat casein contained 0.9 phosphorus, which is not included in the analysis. Whether phosphorus is an ingredient of casein, or an "impurity," is not perhaps positively established.

observed to contain more nitrogen by 1.2 to 1.6 per cent than exists in animal casein. Furthermore, they differ from each other so widely in carbon content (2.7 per cent) as to make it highly probable that their true composition was not in all cases correctly determined.

This conclusion is justified by the results of Chittenden & Smith, who have recently analyzed five different preparations of gluten-casein, made from wheat by Ritthausen's method. The average of their accordant analyses is given above.* Since nitrogen was determined by two methods (those of Dumas and Kjeldahl) these analyses would appear to establish the composition of gluten-casein, which accordingly closely agrees with that found by Ritthausen for "albumin" from barley, and with that of paraglobulin, and has the same nitrogen content as the casein of milk.

The Animal Globulins agree in composition with each other as well as with animal fibrin which is formed from globulin (fibrinogen). The Vegetable Globulins are strikingly different in composition, containing 1.5 to 2 per cent more nitrogen and mostly but half as much sulphur. The hazel-nut conglutin and the hemp-seed vitellin have the same composition.

It is evident that the vegetable albuminoids, on the whole, are distinct from those of the animal, but their true composition and relations to each other, to a great extent, remain to be established.

*Some Mutual Relations of the Albuminoids.*—It was formerly supposed that these bodies are identical in composition, the differences among the analytical results being due to foreign matters, and that they differ from each other in the same way that cellulose and starch differ, viz.: on account of different arrangement of the atoms. Afterwards, Mulder advanced the notion that the albuminoids are compounds of various proportions

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* Kindly communicated by the authors.

of hypothetical sulphur and phosphorus radicles with a common ingredient, which he termed *protein* (from the Greek signifying "to take the first place," because of the great physiological importance of such a body). Hence the designations protein-bodies and proteids. 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 in the juices of the digestive organs, and pass into the blood, where they form blood albumin and globulin. As the blood nourishes the muscles, they are modified into the flesh-albuminoids; on entering the mammary system they are converted into casein, while in the appropriate part of the circulation they are formed into the albumin of the egg, or embryo.

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

*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 share of the healthy animal organism, and especially characterize 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 albumin, or fibrin, or casein except by the transformation of similar bodies presented to it from external sources. They are hence indispensable ingredients of the food of animals, and were therefore designated by Liebig as the *plastic elements of nutrition*. They have also been termed the blood-building or muscle-forming elements. 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 in blood, etc. 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.

*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. Kept in the dissolved or moist state, exposed to warm air, they speedily decompose or putrefy, yielding a large variety of products. Heated with acids, alkalies, and oxidizing agents, they mostly give origin to the same or to analogous products, among which no less than twenty different compounds have been distinguished.

The numbers of atoms that are associated in the molecules of the proteids are very great, though not in most cases even approximately known. The *Haemoglobin* of blood, which forms red crystals that admit of preparing in a state of great purity, contains in 100 parts—

| C | H | N | O | S | Fe |
|---|---|---|---|---|---|
| 54.2 | 7.2 | 16.1 | 21.6 | 0.5 | 0.4 |

The iron (Fe) is a constant and essential ingredient, and if one atom only of this metal exist in the haemoglobin molecule, its empirical formula must be something like $C_{640}H_{1000}N_{164}FeS_2O_{190}$, and its molecular weight over 14,000. Haemoglobin readily breaks up into a proteid and a much simpler red crystalline substance, *Haemaeetin*, yielding about 96 per cent of the former and 4 per cent of the latter. Haematin has approximately the formula $C_{82}H_{34}N_4FeO_5$, so that the proteid, though simpler than haemoglobin, must have an extremely complicated molecule, and it is, accordingly, difficult to decide whether a few thousandths of the acids, bases or salts which may be associated with these bodies, as they exist in plants or pass through the hands of the chemist, are accidental or essential to their constitution.

*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 often deposited in an organized form, chiefly in grains similar to those of starch, and mostly insoluble in water.

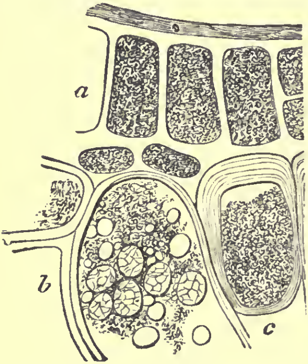

Fig. 18.

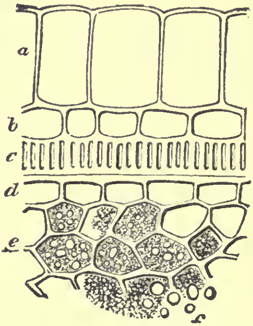

Fig. 19.

These grains of albuminoid matter are not, in many cases at least, pure albuminoids. 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 the *organized granules* found in the plant, of which the albuminoids are chief or characteristic ingredients.

In Fig. 18 is represented a magnified slice through the outer cells (bran) of a husked oat kernel. The cavities of these outer cells, *a*, *c*, are chiefly occupied with very fine grains of aleurone. In one cell, *b*, are seen the much larger starch grains. In the interior of the oat kernel, and other cereal seeds, the cells are chiefly occupied with starch, but throughout grains of aleurone are more or less intermingled.

Fig. 19 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 of aleurone, among which droplets of oil, *f*, are distributed.

In Fig. 20 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 bayberry (*Myrica cerifera*) and *e* from mace (an appendage to the nutmeg, or fruit of the *Myristica moschata*).

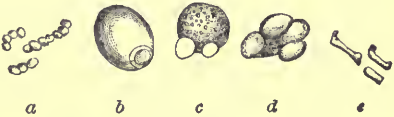

Fig. 20.

*Crystalloid aleurone.*—It has been already remarked that crystallized albuminoids exist in plants. This was first observed by Hartig (*Entwickelungsgeschichte des*

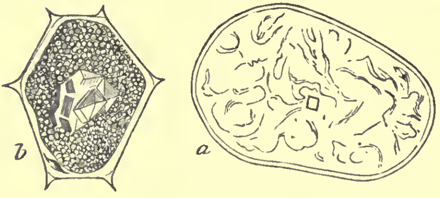

Fig. 21.

*Pflanzenkeims*, p. 104). In form they sometimes imitate crystals quite perfectly, Fig. 21, *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 not the constancy peculiar to ordinary crystals. Therefore the term *crystalloids*, i.e., having the likeness of crystals, has been applied to them.

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. 21, *a* represents a cell from a boiled potato, in the center 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 center is a comparatively large mass of aleurone, having crystalloid facets.

As already stated, the proteids in the crystalloid aleurones of hemp, castor-bean and squash have the chemical characters of globulin. The aleurone of the Brazil-nut (*Bertholletia*) and that of the yellow lupin contain, according to Hartig and Kubel, 9.4% of nitrogen which corresponds to some 50 or 60% of proteids.

Weyl obtained from the Brazil-nut a very pure amorphous vitellin with 18.1% of nitrogen. The vitellin of Brazil-nut, castor-bean, and of hemp and squash seeds has been recrystalized from salt solutions by Schmiedeberg, Drechsel, Grübler and Ritthausen. According to Vines, seeds of lupin and peony yield a myosin to salt-solution, and sunflower seeds, after treatment with ether to remove oil, yield a globulin with the properties of myosin, but if alcohol is used, the proteid has the character of vitellin.

Vines, who has examined the aleurone of many plants, finds it in all cases more or less soluble in water. The globulin doubtless goes into solution by help of the salts present. Vines also states that a body soluble in water, having the properties of a proteose (*hemialbumose*), is universally present in aleurone.

*Estimation of the Albuminoids.*—The quantitative separation of these bodies, as they occur in plants, is mostly impossible in the present state of science. In many cases their collective quantity in an organic substance may be calculated with approximate accuracy from its content of nitrogen.

In calculating the nutritive value of a cattle-food the albuminoids are currently reckoned as equal to its nitrogen multiplied by 6.25. This factor is the quotient obtained by dividing 100 by 16, which, some 25 years ago, when cattle-feeding science began to assume its present form, there was good reason to assume was the average per cent of nitrogen in the albuminoids. As Ritthausen has insisted, this factor is too small, since the albuminoids of the cereals and of most leguminous seeds, as well as of the various oil-cakes, contain nearer 17 than 16 per cent of nitrogen, if our analyses rightly represent their composition, and the factor 6 ($= 100 \div 16.66$) would be more nearly correct.

This mode of calculation only applies with strictness where all the nitrogen exists in albuminoid form. This appears to be substantially true in most seeds, but in case of young grass and roots there is usually a considerable proportion of non-albuminoid nitrogen, for which due allowance must be made. (See *Amides.*) [*]

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[*] *Ammonia*, $NH_3$, *and Nitric acid*, $NHO_3$. These bodies are mineral, not organic substances, and are not, on the whole, considerable ingredients of plants. They are however the principal sources of the nitrogen of vegetation, and, serving as plant-food, enter plants through their roots, chiefly from the soil, and exist within them in small quantity, and for a time, pending the conversion of their nitrogen into that of the amides and albuminoids, to whose production they are probably essential. In seeds and fruits, and in mature plants, growing in soils

AVERAGE QUANTITY OF ALBUMINOIDS IN VARIOUS VEGETABLE PRODUCTS.—ALBUMINOIDS = $N \times 6.25$.

| | American, *Jenkins*. | German, *Wolff*. |
|---|---|---|
| Maize fodder, green | 1.8 | 1.9 |
| Beet tops, " | 2.7 | 3.0 |
| Carrot tops, " | 4.3 | 5.1 |
| Meadow grass, in bloom | 3.1 | 4.8 |
| Red clover, " | 3.7 | 4.8 |
| White clover, " | 4.0 | 5.6 |
| Turnips, fresh | 1.1 | 1.8 |
| Carrots, " | 1.1 | 2.2 |
| Potatoes, " | 2.2 | 3.4 |
| Corn cobs, air-dry | 2.3 | 2.3 |
| Straw, " | 3.5 | 4.0 |
| Pea straw, " | 7.3 | 10.4 |
| Bean straw, " | 10.2 | 16.3 |
| Meadow hay, in bloom | 7.0 | 15.5 |
| Red-clover hay, " | 12.5 | 19.7 |
| White-clover hay, " | 14.6 | 23.2 |
| Buckwheat kernel, air-dry | 10.0 | 14.4 |
| Barley " " | 12.4 | 16.0 |
| Maize " " | 10.6 | 16.0 |
| Rye " " | 10.6 | 17.6 |
| Oat " " | 11.4 | 17.6 |
| Wheat " " | 11.8 | 20.8 |
| Pea " " | 22.4 | 35.8 |
| Bean " " | 24.1 | 40.8 |

THE AMIDES, AMIDOACIDS, IMIDES, AND AMINES. —Ammonia and the ammonium salts, so important as food to plants, and as ingredients of the atmosphere, of soils, and of manures, occur in so small proportions in living vegetation as to scarcely require notice in this work occupied with the composition of Plants. They are, however, important in connection with the amides now to be briefly described. Ammonia, an invisible gas of pungent odor which dissolves abundantly in water to form the *aqua ammonia* of spirits of hartshorn of the apothecary, is a compound of one atom of nitrogen with three atoms of hydrogen. It unites to acids, forming the ammonium salts :

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of moderate fertility, both ammonia and nitric acid, or strictly speaking, ammonia-salts and nitrates, commonly occur in very small proportions. In roots, stems, and foliage of plants situated in soils rich in these substances, they may be present in notable quantity. The dry leaves and stems of tobacco and beets sometimes contain several per cent of nitrates. When these substances are presented to plants in abundance, especially in dry weather, they may accumulate in the roots and lower parts of the plant more rapidly than they can be assimilated. On the other hand, when their supply in the soil is relatively small they are so completely and rapidly assimilated as to be scarcely detectable. Their possible presence should be taken into account when it is undertaken to calculate the albuminoids of the plant from the amount of nitrogen found in its analysis.

$$\underset{\textit{Acetic acid.}}{CH_3COOH} + \underset{\textit{Ammonia.}}{NH_3} = \underset{\textit{Ammonium acetate.}}{CH_3COONH_4}$$

*Amides.*—This term is often used as a general designation for all the bodies of this section which result from the substitution of the hydrogen of ammonia by any atom or group of atoms. In a narrower sense amides are those ammonia-derivatives containing *"acid-radicals"* which are indicated in their systematic names.

**Acetamide,** $CH_3CONH_2$. Many ammonium salts, when somewhat strongly heated, suffer decomposition into amides and water.

$$\underset{\textit{Ammonium acetate.}}{CH_3COONH_4} = \underset{\textit{Acetamide.}}{CH_3CONH_2} + \underset{\textit{Water.}}{H_2O}$$

The above equation shows that acetamide is ammonia, $NH_3$, or $HNH_2$, one of whose hydrogens has been replaced by the group of atoms, $CH_3CO$, the acetic acid radical, so called. Acetamide is a white crystalline body. The simple amides, like acetamide, are as yet not known to exist in plants. They readily unite with water to produce ammonium salts.

**Carbamide, or Urea** $CO(NH_2)_2$. This substance—the amide of carbonic acid $CO(OH)_2$—naturally occurs in considerable proportion in the urine of man and mammalian animals. It is a white, crystalline body, with a cooling, slightly salty taste, which readily takes up the elements of water and passes into ammonium carbonate. Urea has not been found in plants, but derivatives of it in which acid radicals replace a part of its hydrogen are of common occurrence. (Guanin, allantoin.)

*Amidoacids* are acids containing the $NH_2$ group as a part of the acid radical.

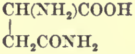
**Amidoacetic Acid,** $C_2H_5NO_2$, or $CH_2(NH_2)COOH$, is derived from acetic acid, $CH_3COOH$, by the replacement of H in $CH_3$ by $NH_2$. The amidoacids have not a sour, but usually a sweetish taste, and, like the amides, act both as weak acids and weak bases. Amidoacetic acid, also called *glycocoll*, has not as yet been found in plants, but exists in the scallop and probably in other shell-fish, and a compound of it, benzoylglycocoll or hippuric acid, is a nearly constant ingredient of the urine of the horse and other domestic herbivorous animals.

**Betain**, or trimethylglycocoll, $C_5H_{11}NO_2$, a crystallizable substance found in beet-juice, stands in close chemical relations to amidoacetic acid.

**Amidovaleric acid**, $C_5H_{11}NO_2$, occurs in ox-pancreas and in young lupin plants. **Amidocaproic acid**, or **Leucin**, $C_6H_{13}NO_2$, first observed in animals, has lately been discovered in various plants. The same is true of **Tyrosin**, or **oxyphenyl-amidopropionic acid**, $C_9H_{11}NO_3$, and of **phenyl-amidopropionic acid**, $C_9H_{11}NO_2$.

The above amidoacids are readily obtained as products of decomposition of animal and vegetable albuminoids by the action of hot acids. Amidoacetic acid was thus first obtained from gelatin. Leucin and Tyrosin are commonly prepared by boiling horn shavings with dilute sulphuric acid; they are also formed from vegetable albuminoids by similar treatment and are final results of the digestion of proto- and deutero-proteoses (hemialbumose) under the action of trypsin and papain.

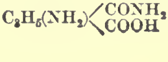
**Asparagin and Glutamin.**—These bodies, which are found only in plants, are amides of amidoacids, being derived from dibasic acids. Asparagin, the amide of amidosuccinic acid,



$$\begin{array}{l}CH(NH_2)COOH\\ |\\ CH_2CONH_2\end{array}$$

has been found in very many plants, especially in those just sprouted, as in asparagus, peas, beans, etc. Asparagin forms white, rhombic crystals, and is very soluble in water.

Glutamin, the amide of amidoglutaric acid,



$$C_3H_5(NH_2)\langle\begin{matrix}CONH_2\\ COOH\end{matrix}$$

has been found, together with asparagin, in beet-juice and in squash seedlings.

The amides, when heated with water alone, and more easily in presence of strong acids and alkalies, are converted into ammonia and the acids from which they are derived. Thus, asparagin yields ammonia and amidosuccinic acid at the boiling heat under the influence of hydrochloric acid, or of potassium hydroxide, and glutamin is broken up by the last-named reagent at common temperatures, and by water alone at the boiling point, with formation of ammonia and amidoglutaric acid.

The amidoacids are not decomposed by hot water or acids with separation of ammonia. Amidosuccinic and amidoglutaric acids result from albuminoids by boiling with dilute sulphuric acid, and by the action of bromine. The latter acid as yet has been obtained from vegetable albuminoids only, and is prepared most abundantly from gluten, and especially from mucedin.

*Imides*, closely related to the amides, are a series of very interesting substances, into whose chemical constitution we cannot enter here further than to say that they contain several NH* groups, i. e., ammonia, $NH_3$, in which two hydrogens are replaced by hydro-carbon, or oxycarbon groups or carbon atoms.

These bodies are *Uric acid*, $C_5H_4N_4O_3$, *Adenin*, $C_5H_5N_5$, *Guanin*, $C_5H_5N_5O$, *Allantoin*, $C_4H_6N_4O_3$, *Xanthin*, *Hypoxanthin*, $C_5H_4N_4O$, *Theobromin*, $C_7H_8O_4O_2$, *Caffein*, $C_8H_{10}N_4O_2$, and *Vernin*, $C_{16}H_{20}N_8O_8$. Of these the first, so far as now known, occurs exclusively in the animal. Adenin, Guanin, Allantoin, Xanthin, and Hypoxanthin, are common to animals and plants; the last three are exclusively vegetable.

Caffein 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

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* Or its hydro-carbon derivatives.

the extent of one-half per cent; in tea it occurs in much larger quantity, sometimes as high as 6 per cent.

**Theobromin** resembles caffein in its characters. It is found in the cacao-bean, from which chocolate is manufactured.

**Vernin**, discovered recently in various plants, young clover, vetches, squash-seedlings, etc., yields guanin by the action of hydrochloric acid. All these bodies stand in close chemical relations to each other, being complex imide derivatives of dioxymalonic (mesoxalic) acid.

The amides and amidoacids, like ammonia, are able to combine directly with acids, are accordingly bases, but they are weak bases, because the basic quality of their ammonia is largely neutralized by the acid radicals already present in them. On the other hand, amides and amidoacids often act as weak acids, for a portion of the hydrogen of the $NH_2$ group is easily displaced by metals.

The amides thus in fact possess in a degree the qualities of both the acid and of the base (ammonia) from which they are derived. They also are commonly "neutral" in the sense of having no sharp acid or alkaline taste or corrosive character.

In vegetation amides appear as intermediate stages between ammonium salts and albuminoids. They are, on the one hand, formed in growing plants from ammonium salts by a constructive process, and from them or by their aid, probably, the albuminoids are built up. On the other hand, in animal nutrition they are stages through which the elements of the albuminoids pass in their reversion to purely mineral matters. In germinating seeds and developing buds they probably combine both these offices, being first formed in the germ from the albuminoids of the seed, entering the young plant or shoot, and in it being reconstructed into albuminoids. Their free solubility in water and ability to penetrate moist membranes adapt them for this movement. They temporarily accumulate in seedlings and buds, but disappear again as growth takes place, being converted into albuminoids, in which transformation they require the conjunction of carbhydrates. Their ability to unite with acid as well as bases further qualifies them to take part in these physiological processes.

The imides are also at once weak bases and weak acids. Uric acid and allantoin, relatively rich in oxygen, have the acid qualities best developed. Guanin and caffein, with less oxygen and more hydrogen, are commonly classed among the organic bases, as in them the basic characters are most evident.

**Amines.**—When the hydrogen of ammonia is replaced by hydrocarbon groups (radicals) such as Methyl, $CH_3$, Ethyl, $C_2H_5$, Phenyl, $C_6H_5$, etc., *compound ammonias* or *amines* result which often resemble ammonia in physical and chemical characters, and some of them appear to be stronger bases than ammonia, being able to displace the latter from its combinations.

*Trimethylamine*, $N(CH_3)_3$, may be regarded as ammonia whose hydrogens are all substituted by the methyl group, $CH_3$, and is a very volatile liquid having a rank, fishy odor, which may be obtained from herring pickle, and exhales from some plants, as from the foliage of *Chenopodium vulvaria*, and the flowers of *Crataegus oxycantha.* It is produced from *betain* (trimethylamidoacetic acid), by heating with potash solution, just as ammonia is formed from many amides under similar treatment.

*Cholin*, $C_5H_{15}NO_2$, and *Neurin*, $C_5H_{13}NO$, are organic bases related to trimethylamine, which were first obtained from the animal. Cholin is an ingredient of the bile, and is found also in the brain and yolk of eggs, where it exists as a component of lecithin. It has latterly been discovered in the hop, lupin and pumpkin plants, and in cotton seed; by oxidation it yields betain. *Neurin* is readily formed from cholin by the action of alkalies and in the process of putrefaction. It is a violent poison, and is perhaps one of the ingredients which, in the seeds of the vetch and of cotton, prove injurious, or even fatal, when these seeds are too largely eaten by animals. Cholin and Neurin are syrupy, highly alkaline liquids.

7. ALKALOIDS is the general designation that has been applied to the organic bases found in many plants, which are characterized in general by their poisonous and medicinal qualities. Caffein and Theobromin, already noticed, were formerly ranked as alkaloids. We may mention the following :

*Nicotin*, $C_{10}H_{14}N_2$, is the narcotic and intensely poisonous principle in tobacco, where it exists in combination with malic and citric acids. In the pure state it is a colorless, oily liquid, having the odor 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 Havana, about 2 per cent of nicotin. Nicotin contains 17.3 per cent of nitrogen, but no oxygen.

*Lupinidin*, $C_8H_{15}N$, *Lupanin*, $C_{15}H_{25}N_2O$, and *Lupinin*, $C_{21}H_{40}N_2O_2$, are bases existing in the seeds of the lupin. The first two are liquids ; the last is a crystalline solid. They are poisonous and are believed to occasion the sickness which usually follows the use of lupin-seeds in cattle food.

*Sinapin*, $C_{16}H_{23}NO_5$, occurs in white mustard. When boiled with an alkali it is decomposed, yielding *neurin* as one product.

*Vicin*, $C_{28}H_{51}N_{11}O_{21}$, and *Convicin*, $C_{10}H_{14}N_3O_7$, are crystalline bases that occur in the seeds of the vetch, with regard to whose nature and properties little is known.

*Avenin*, $C_{56}H_{21}NO_{18}$, according to Sanson, is a substance of alkaloidal character, existing in oats. It is said to be more abundant in dark than in light-colored oats, and, when present to the extent of more than nine-tenths of one per cent, to act as a decided nerve-excitant on animals fed mainly on oats. Avenin is described as a granular, brown, non-crystallizable substance, but neither Osborne (at the Connecticut Experiment Station) nor Wrampelmeyer (*Vs. St.*, XXXVI, p. 299) have been able to find any evidence of the presence of such a body in oats.

*Morphin*, $C_{17}H_{19}NO_3$, occurs, together with several other alkaloids, in opium, the dried milky juice of the seed-vessels of the poppy cultivated in India. Its use in allaying pain and obtaining sleep and its abuse in the "opium habit" are well known.

*Piperin*, $C_{17}H_{19}NO_3$, the active principle of white and black pepper, is a white crystalline body isomeric with morphin.

*Quinin*, $C_{20}H_{24}N_2O_2$, is the most important of several bases used as anti-malarial remedies obtained from the bark of various species of cinchona growing in the forests of tropical South America, and cultivated in India.

*Strychnin*, $C_{21}H_{22}N_2O_2$, and *Brucin*, $C_{23}H_{26}N_2OH$, is the intensely poisonous alkaloid of nux vomica (dog button).

*Atropin*, $C_{17}H_{23}NO_3$, is the chief poisonous principle of the "Nightshade" or belladonna, and of stramonium or "Jamestown weed."

*Veratrin*, $C_{32}H_{49}NO_9$, is the chief toxic ingredient of the common White Hellebore, so much used as an insecticide.

*Solanin*, $C_{42}H_{87}NO_{15}$ (?), is a poisonous crystalline alkaloid found in many species of Solanum, especially in the black nightshade (*Solanum nigrum*). It occurs in the sprouted tubers and green fruit of the potato (*Solanum tuberosum*) and in the stems and leaves of the tomato (*Solanum lycopersicum*).

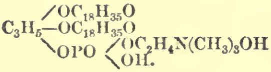
The alkaloids, so far as investigated, appear to be more or less complex derivatives of the bases ***Pyridin,*** $C_5H_5N$, and *Quinolin,* $C_9H_7N$, which are colorless, volatile liquids with sharp, unpleasant odor, produced from albuminoids at high temperatures, and existing in smoke, bone-oil and tar. The alkaloids bear to these bases similar relations to those subsisting between the amines and ammonia.

8. Phosphorized Substances.—This class of bodies are important because of their obvious relations to the nutrition of the brain and nerve tissues of the animal, which have long been known to contain phosphorus as an essential ingredient. All our knowledge goes to show that phosphorus invariably exists in both plants and animals as phosphoric acid or some derivative of this acid, or, in other words, that their phosphorus is always united to oxygen as in the phosphates, and is not directly combined to carbon, hydrogen, or nitrogen.

**Nuclein.**—This term is currently employed to designate various imperfectly-studied bodies that resemble the albuminoids in many respects, but contain several per cent of phosphorus. They are easily decomposable, boiling water being able to remove from them phosphoric acid, and under the action of dilute acids they mostly yield phosphoric acid, albuminoids and hypoxanthin, $C_5H_4N_4O$, or similar imide bases. They are very difficult of digestion by the gastric juice. The nucleins are found in the protoplasm and especially in the cell-nuclei (see p. 245), of both plants and animals, and have been obtained from yeast, eggs, milk, etc., by a process based on their indigestibility by pepsin. Chemists are far from agreed as to the nature or composition of the nucleins.

**Lecithin,** $C_{44}H_{90}NPO_9$.—This name applies to a number of substances that have been obtained from the brain and nerve tissue of animals, eggs and milk, as well as from yeast, and the seeds of maize, peas, and wheat. The lecithins are described as white, wax-like substances, imperfectly crystallizable, similar to protagon in their deportment toward water, and readily decomposed into cholin, glycerophosphoric acid, and one or more fatty acids. Three lecithins appear to have been identified, yielding respectively, on decomposition, stearic, palmitic, and oleic acids.

The formula $C_{44}H_{90}NPO_9$ is that of distearic lecithin, which is composed of glyceryl, $C_3H_5$, united to two stearic acid radicals, and also to phosphoric acid, which again is joined to cholin, as represented by the formula—



$$C_3H_5\begin{cases}OC_{18}H_{35}O\\OC_{18}H_{35}O\\OPO\begin{cases}OC_2H_4N(CH_3)_3OH\\OH.\end{cases}\end{cases}$$

Lecithin is believed to be a constant and essential ingredient of plants and animals.

**Protagon**, $C_{160}H_{308}N_5PO_{35}$, discovered by Liebreich in the brain of animals, has been further studied by Gamgee & Blankenhorn. It is a white substance that swells up with water to a gelatinous mass and finally forms an opake solution. From solution in ether or alcohol it can be easily obtained in needle-shaped crystals, whose composition is given below. Alkalies decompose protagon into glycero-phosphoric acid, stearic and other fatty acids, and cholin or neurin. Protagon was formerly confounded with lecithin and thought to exist in plants, but its presence in the latter has not been established.

| | *Protagon.* | *Lecithin.* |
|---|---|---|
| Carbon | 66.39 | 65.43 |
| Hydrogen | 10.69 | 11.16 |
| Nitrogen | 2.39 | 1.73 |
| Phosphorus | 1.07 | 3.84 |
| Oxygen | 19.46 | 17.84 |
| | 100.00 | 100.00 |

Knop was the first to show that the crude fat which is extracted from plants by ether contains an admixture of some substance of which phosphorus is an ingredient. In the oil obtained from the sugar-pea he found 1.25 per cent. of phosphorus. Töpler afterwards 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.* |
|---|---|---|---|
| Lupin | 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 | 0.40 | Oat | 0.44 |
| Chocolate-bean | none | Flax | none |
| Millet | " | Colza | " |
| Poppy | " | Mustard | " |

It is probable that the phosphorus in these oils existed in the seeds as lecithin, or as glycerophosphoric acid, which is produced in the decomposition of lecithin. Maxwell (Constitution of the Legumes), reckoning from the phosphoric acid found in the ether-extract, estimates the pea kernel to contain 0.368 per cent, the horse-bean (*Faba vulgaris*) 0.600 per cent, and the vetch 0.532 per cent of lecithin. Lecithin is thus calculated to make up 19.63 per cent of the crude fat of the pea, 31.54 per cent of the crude fat of the horse-bean, and 35.24 per cent of that of the vetch.

**Chlorophyl**, i. e., *leaf-green*, is the name applied to the substance which occasions the green color in vegetation. It is found in all those parts of most annual plants and of the annually renewed parts of perennial plants which are exposed to light. The green parts of plants usually contain chlorophyl only near their surface, and in quantity not greater than one or two per cent of the fresh vegetable substance.

Chlorophyl, being soluble in ether, accompanies fat or wax when these are removed from green vegetable matters by this solvent. It is soluble in alcohol and hydrochloric and sulphuric acids, imparting to these liquids an intense green color, but it suffers alteration and decomposition so readily that it is doubtful if the composition of chlorophyl, as it exists in the living leaf, is accurately known, especially since it is there mixed with other substances, separation from which is difficult or impracticable.

**Chlorophyllan**, obtained by Hoppe-Seyler from grass, separates from its solution in hot alcohol in characteristic acicular crystals which are brown to transmitted light, and in reflected light are blackish green, with a velvety, somewhat metallic lustre. This substance has the consistence of beeswax, adheres firmly to glass, and at about 230° melts to a brilliant black liquid. The crystallized chlorophyllan has a composition as follows :

| CHLOROPHYLLAN. | |
|---|---|
| Carbon | 73.36 |
| Hydrogen | 9.72 |
| Nitrogen | 5.68 |
| Phosphorus | 1.38 |
| Magnesium | 0.34 |
| Oxygen | 9.52 |
| | 100.00 |

Chlorophyllan is chemically distinct from chlorophyl, as proved by its optical properties, but in what the difference consists is not understood. Boiling alkali decomposes it with formation of chlorophyllanic acid that may be obtained in blue-black crystals, and at the same time glycerophosphoric acid and cholin, the decomposition-products of lecithin, are produced. Tschirch found that chlorophyllan, by treatment with zinc oxide, yields a substance whose optical properties lead to the belief that it is identical with the chlorophyl that occurs in the living plant. It was obtained as a dark-green powder, but its exact chemical composition is not known.

The special interest of chlorophyl lies in the fact that it is to all appearance directly concerned in those constructive processes by which the plant composes starch and other carbhydrates out of the mineral substances which form its food.

**Xanthophyl** is the yellow coloring matter of leaves and of many flowers. It occurs, together with chlorophyl, in green leaves, and after disappearance of chlorophyl remains as the principal pigment of autumn foliage.

# CHAPTER II.

## THE ASH OF PLANTS.

### § 1.

### THE INGREDIENTS OF THE ASH.

As has been stated, the volatile or destructible part of plants, i. e., the part which is converted into gases or vapors under the ordinary conditions of burning, consists chiefly of Carbon, Hydrogen, Oxygen and Nitrogen, together with small 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 eight other elements, whose common compounds are permanent at the ordinary heat of burning.

In the subjoined table, the names of the 12 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. |

If to the above be added

Hydrogen and Nitrogen

the list includes all the elementary substances that belong to agricultural vegetation.

Hydrogen is never an ingredient of the perfectly burned and dry ash of any plant.

Nitrogen may remain in the ash under certain conditions in the form of a *Cyanide* (compound of Carbon and Nitrogen), as will be noticed hereafter.

Besides the above, certain other elements are found, either occasionally in common plants, or in some particular kind of vegetation; these are Iodine, Bromine, Fluorine, Titanium, Boron, Arsenic, Lithium, Rubidium, Barium, Aluminum, Zinc, Copper. These elements, however, so far as known, have no special importance in agricultural chemistry, and mostly require no further notice.

We may now complete our study of the Composition of the Plant by attending to a description of those elements that are peculiar to the ash, and of those compounds which may occur in it.

It will be convenient also to describe in this section some substances, which, although not ingredients of the ash, may exist in the plant, or are otherwise important to be considered.

**The Non-metallic Elements**, which we shall first notice, though differing more or less widely among themselves, have one point of resemblance, viz., they and their compounds with each other have *acid* properties, i. e., they either are acids in the ordinary sense of being sour to the taste, or enact the part of acids by uniting to metals or metallic oxides to form salts. We may, therefore, designate them as the *acid elements*. They are Oxygen, Sulphur, Phosphorus, Carbon, Silicon, and Chlorine.

With the exception of Silicon, and the denser forms of Carbon, these elements by themselves are readily volatile. Their compounds with each other, which may occur in vegetation, are also volatile, with two exceptions, viz., 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*.

**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 acid bodies; 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**, *Sym.* C, *at. wt.* 12, has been noticed already with sufficient fullness (p. 14). 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.

**Carbon Dioxide**, commonly termed **Carbonic acid**, *Sym.* $CO_2$, *molecular weight* 44, is the colorless 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 calcium 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 carbon dioxide is set free with effervescence.

**Carbonic Acid**, $H_2CO_3$, or $CO(OH)_2$, *mo. wt.* 62. This, the carbonic acid of modern chemistry, is not known as a distinct substance, since, when set free from carbonates by the action of a stronger acid, it falls into carbon dioxide and water:

$$CaCO_3 + 2\ HCl = CaCl_2 + H_2CO_3 \text{ and } H_2CO_3 = H_2O + CO_2.$$

Carbon dioxide is also termed anhydrous carbonic acid, or again, carbonic anhydride.

CYANOGEN, *Sym.* $C_2N_2$.—This important compound of Carbon and Nitrogen is a gas which has an odor like that of peach-pits, and which burns on contact with a lighted taper with a fine purple flame. In its union with oxygen by combustion, carbon dioxide is formed, and nitrogen set free:

$$C_2N_2 + 4\ O = 2\ CO_2 + N_2.$$

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 amygdalin, 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 a normal ingredient of one common plant. The oil of mustard is *allylsulphocyanate*, $C_3H_5CNS$.

### SULPHUR AND ITS COMPOUNDS.

Sulphur, *Sym.* S, *at. wt.* 32.—The properties of this element have been already described (p. 25). Some of its compounds have also been briefly alluded to, but require more detailed notice.

HYDROGEN SULPHIDE, *Sym.* $H_2S$, *mo. wt.* 34. This substance, familiarly known as sulphuretted hydrogen, occurs dissolved in the water of numerous so-called sulphur springs, as those of Avon and Sharon, N. Y., 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 odor of which, when rotten, is largely due to this gas. It is evolved from manure heaps, from salt marshes, and even from the soil of moist meadows.

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.

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

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

SULPHUR DIOXIDE, commonly called SULPHUROUS ACID, *Sym.* $SO_2$, *mo. wt.* 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).

Sulphur dioxide is characterized by its power of discharging, for a time at least, most of the red and blue vegetable colors. It has, however, no action on many yellow colors. Straw and wool are bleached by it in the arts.

Sulphur dioxide 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 (sulphides) which are wrought in mining regions.

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

**Sulphur-Trioxide,** *Sym.* $SO_3$, *mo. wt.* 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 sulphuric acid. Sulphur trioxide was formerly termed sulphuric acid or anhydrous sulphuric acid, and now it is common in statements of analysis to follow this usage.

**Sulphuric Acid,** *Sym.* $H_2SO_4$, *mo. wt.* 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 colorless, heavy liquid, of an oily consistency, and sharp, sour taste.

It is manufactured on the large scale by mingling sulphur dioxide gas, nitric acid gas, and steam, in large lead-lined chambers, the floors of which are covered with water. The sulphur dioxide 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 glass vessels.

The chief agricultural application of sulphuric acid is in the preparation of "superphosphate of lime," which is consumed as a fertilizer in immense quantities. This is made by mixing together sulphuric acid, somewhat diluted with water, with bone-dust, bone-ash, or some mineral phosphate. Commercial oil of vitriol is a mixture of sulphuric acid with more or less water. The strongest oil of vitriol commonly made, or "66° acid," contains 93.5% of $H_2SO_4$. The so-called "60° acid" contains 77.6% $H_2SO_4$ or 83% of 66° acid. Chamber acid or "51° acid" contains 63.6% $H_2SO_4$, or 67% of 66° acid.

Sulphuric acid occurs in the free state, though extremely dilute, in certain natural waters, as in the Oak Orchard Acid Spring of Orleans, N. Y., where it is produced by the oxidation of sulphide of iron.

Sulphuric acid is very corrosive and destructive to most vegetable and animal matters.

EXP. 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 color 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 for making superphosphate.

EXP. 54.—Place in a *thin* glass vessel, as a beaker glass, 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.

Sulphuric acid forms with the bases an important class of salts—the *sulphates*, to be presently noticed—some of which exist in the ash, as well as in the sap of plants.

When organic matters containing sulphur—as hair, albumin, etc.—are burned with full access of air, this element remains in the ash as sulphates, or is partially dissipated as sulphur dioxide.

### PHOSPHORUS AND ITS COMPOUNDS.

**Phosphorus,** *Sym.* P, *at. wt.* 31, has been sufficiently described (p. 27). Of its numerous compounds but two require additional notice.

**Phosphorus Pentoxide,** *Sym.* $P_2O_5$, *mo. wt.* 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). The term "phosphoric acid," as now encountered in fertilizer analyses, has reference to "anhydrous phosphoric acid," as phosphorus pentoxide was formerly designated. Phosphorus pentoxide 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—

**Phosphoric Acid,** *Sym.* $H_3PO_4$, 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 organic bodies containing phosphorus, as lecithin (p. 122), and, perhaps, some of the albuminoids, are decomposed by heat or decay, the phosphorus appears in the ashes or residue, in the condition of phosphoric acid or phosphates.

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

### CHLORINE AND ITS COMPOUNDS.

**Chlorine,** *Sym.* Cl., *at. wt.* 35.5.—This element exists in the free state as a greenish-yellow, suffocating gas, which has a peculiar odor, and the property of bleaching vegetable colors. It is endowed with the most vigorous affinities for many other elements, and hence is never met with, naturally, in the free state.

EXP. 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.

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, *Sym.* $HCl$, *mo. wt.* 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 hydrogen chloride 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 black oxide of manganese. In this reaction hydrogen of the hydrochloric acid unites with oxygen of the oxide of manganese, producing water, while chloride of manganese and free chlorine are separated.

$$4\,HCl + MnO_2 = MnCl_2 + 2\,H_2\,O + 2\,Cl.$$

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.

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

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

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 purpose of the chemist.

IODINE, *Sym.* I, *at. wt.* 127.—This interesting body is a black solid at ordinary temperatures, having an odor resembling that of chlorine. Gently heated, it is converted into a violet vapor. It occurs in sea-weeds, 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-bogs, and in the produce of soils which are manured with sea-weed.

BROMINE and FLUORINE may also exist in very small quantity in plants, but these elements require no further notice in this treatise.

### SILICON AND ITS COMPOUNDS.

**Silicon,** *Sym.* Si, *at. wt.* 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 plumbago, and a third, that occurs in crystals, having the form and nearly the hardness of the diamond.

**Silicon Dioxide,** *Sym.* $SiO_2$, *mo. wt.* 60.—This compound, known also as *Silica,* 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.*—Silica is extremely insoluble in pure water and in most acids. It has, therefore, 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 the alkali metals.

EXP. 56.—*Formation of potassium silicate.* Heat a piece of quartz or flint, as large as a chestnut, as hot as possible in the fire, and quench 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 potassium silicate, 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 sodium silicate.

When silica is strongly heated with potash or soda, or with lime, magnesia, or oxide of iron, it readily melts together and unites with these bodies, though nearly infusible by itself, and 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 sodium, calcium, and aluminum, with a large proportion of silica, is nearly or altogether insoluble, not only in water, but in most acids—constitutes, in fact, ordinary glass.

A multitude of silicates exist in nature as rocks and minerals. Ordinary clay, common slate, soapstone, mica, or mineral isinglass, feldspar, hornblende, garnet, and other compounds of frequent and abundant occurrence, are silicates. The natural silicates may be roughly distinguished as belonging to 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 carbon dioxide acid. Many native silicates are *anhydrous*, or destitute of water ; others are *hydrous*, i. e., they contain water as a large and essential ingredient.

**The Silicic Acids.**—Various silicic acids—compounds of silica with water—are known to the chemist, or are represented by the silicates found in nature. The silicic acids themselves have little stability and are readily resolved into water and silica.

*Soluble Silica,* $Si(OH)_4$?—This body is known only in solution. It is formed when the solution of an alkali-silicate is decomposed by means of a large excess of some strong acid, like the hydrochloric or sulphuric.

EXP. 57.—Dilute half the solution of potassium silicate obtained in Exp. 56 with ten times its volume of water, and add diluted hydrochloric acid gradually until the liquid tastes sour. In this Exp. the hydrochloric acid decomposes and destroys the potassium silicate, uniting itself to 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.

By appropriate methods Doveri and Graham have 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, colorless, 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 $H_2SiO_3$. 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 as much as possible 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 carbon dioxide 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.*—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, has a composition nearly corresponding to the formula $H_4Si_3O_8$, or to a compound of 3 $SiO_2$ with 2 $H_2O$. At the temperature of 212° F., 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.

The hydrates of silica which have been subjected to a heat of 212°, or more, appear to be totally insoluble in pure water.

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

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

EXP. 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, 3 $SiO_2$ $H_2O$, as a gritty powder.

In the ash of plants, silica is usually found in combination with alkali-metals or calcium, 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 many 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, was found by Davy in turnips which had been manured with a fertilizer (superphosphate), in whose preparation arsenical oil of vitriol was employed.

When arsenic, in the form of *Paris green* or *London purple*, is applied to land the arsenic soon becomes converted into highly insoluble iron compounds and is not taken up by plants in appreciable quantity.

**The Metallic Elements** which remain to be noticed, viz.: Potassium, Sodium, Calcium, Magnesium, Iron, Manganese, Aluminium, Zinc, and Copper, are basic in their character, i. e., they unite with 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 and Sodium are termed *alkali-metals.* Their oxides dissolve in and chemically unite to water, forming hydroxides that are called *alkalies.* The metals themselves do not occur 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 moisture, and are rapidly converted into the corresponding alkalies. Thrown upon water, they mostly inflame and burn with great violence, decomposing the liquid. Exp. 11.

Of the alkali-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 sometimes present in them in but small quantity.

## POTASSIUM AND ITS COMPOUNDS.

**Potassium,** *Sym.* K ;* *at. wt.* 39.—When heated in the air, this metal burns with a beautiful violet light, and forms potassium oxide.

**Potassium Oxide, or Potash,** $K_2O$, 94, is the so-called "actual potash" that figures in the analyses of plants and valuation of fertilizers. It is, however, scarcely known as a substance, because it energetically unites with water and forms hydroxide.

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* From the Latin name *Kalium.*

**Potassium Hydroxide,** $KOH$, 56, is the *caustic potash* of the apothecary and chemist. It may be procured in white, opaque masses or sticks, which rapidly absorb moisture and carbonic acid from the air, and readily dissolve in water, forming *potash-lye.* It strongly corrodes many vegetable and most animal matters, and dissolves fats, forming *potash-soaps.* Both the oxide and hydroxide of potassium unite to acids forming salts.

### SODIUM AND ITS COMPOUNDS.

**Sodium,** $Na$,* 23.—Burns with a brilliant, orange-yellow flame, yielding sodium oxide.

**Sodium Oxide, or Soda,** $Na_2O$, 62, is practically little known, though constantly referred to as the base of the sodium salts. It unites to water, producing the hydroxide.

**Sodium Hydroxide, or Caustic Soda,** $NaOH$, 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.

ALKALI-EARTH METALS.—The two metallic elements next to be noticed, viz., Calcium and Magnesium, give, with oxygen, the *alkali-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 a 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 color. In moist air it rapidly tarnishes and acquires a coating of lime.

**Calcium Oxide, or Lime,** $CaO$, 56, is the result

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* From the Latin name *Natrium.*

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 *quick lime,* 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.

**Calcium Hydroxide,** $Ca\ (OH)_2$, 74.—Quick-lime, when exposed to the air, gradually absorbs water and falls to a fine powder. It is then said to be *air-slacked.* When water is poured upon quick-lime 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 quick-lime becoming 74 lbs. by *water-slacking.* On heating slacked lime to redness, water is expelled, and calcium oxide remains.

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 acid. Lime-water has the alkaline taste in a marked degree.

### MAGNESIUM AND ITS COMPOUNDS.

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

**Magnesium Oxide, or Magnesia,** MgO, 40, is found in the drug-stores in the shape of a bulky white powder, under the name of *calcined magnesia.* It is prepared by subjecting either magnesium hydroxide, carbonate, or nitrate, to a strong heat. It occurs in the ashes of plants.

**Magnesium Hydroxide,** $Mg(OH)_2$, is produced slowly and without heat, when magnesia is mixed with water. It occurs rarely as a transparent, glassy mineral (Brucite) at Texas, Pa., Hoboken, N. J., and a few other places. It readily absorbs carbon dioxide and passes into carbonate of magnesium. Magnesium hydroxide is so slightly soluble in water as to be tasteless. It requires 55,000 times its weight of water for solution (Fresenius).

HEAVY METALS.—The two metals remaining to notice are Iron and Manganese. These again considerably resemble each other, though they differ exceedingly from the metals of the alkalies and alkali-earths. They are about eight times heavier than water. Each of these metals forms two basic oxides, which are commonly 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.

**Ferrous Oxide, or Protoxide of Iron,** 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 ferrous sulphate, the salt known commonly 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 ferrous hydroxide, $Fe(OH)^2$.

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* From the Latin name *Ferrum*.

This precipitate rapidly absorbs oxygen from the air, becoming black and finally brown. The anhydrous protoxide of iron is black. Carbonate of protoxide of iron is of frequent occurrence as a mineral (spathic iron), and exists dissolved in many mineral waters, especially in the so-called chalybeates. The ferrous salts are mostly white or green.

**Ferric Oxide, or Peroxide of Iron,** $Fe_2O_3$, 160.—When ferrous hydroxide is exposed to the air, it acquires a brown color from union with more oxygen, and becomes ferric hydroxide $Fe(OH)_3$. The yellow or brown rust which forms on surfaces of metallic iron when exposed to moist air is the same body. 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 color.

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 are analogous to those of iron just noticed.

**Manganous Oxide, or Protoxide of Manganese,** MnO, 71, has an olive-green color. It is the base of all the usually occurring salts of manganese. Its hydroxide, 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 manganous salts are mostly pale rose-red in color.

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

RED OXIDE OF MANGANESE, $Mn_3O_4$, or $MnO . Mn_2O_3$.—This oxide remains when manganese or any of its other oxides are subjected to a high temperature with access of air. The metal and the protoxide gain oxygen by this treatment, the higher oxides lose oxygen until this compound oxide is formed, which, as its symbol 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 (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, $Al_2O_3$, the oxide of the metal Aluminium, is found in considerable quantity (20 to 50 per cent) in the ashes of the ground pine (*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 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 about the zinc mines of Aix-la-Chapelle.

COPPER is frequently present in minute quantity in the ash of plants, especially of such as grow in the vicinity of manufacturing establishments, where dilute solutions containing copper are thrown to waste.

**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.

THE CARBONATES which occur in the ashes of plants are those of Potassium, Sodium, and Calcium. The Carbonates of Magnesium, Iron, and Manganese are decomposed by the heat at which ashes are prepared.

**Potassium Carbonate, or Carbonate of Potash,** $K_2CO_3$, 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 this carbonate a brisk effervescence immediately takes place, owing to the escape of carbon dioxide gas, and potassium chloride and water are formed, which remain behind.

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

**Potassium Bicarbonate,** $KHCO_3$.—A solution of potassium carbonate, when exposed to carbon dioxide, absorbs the latter, and the potassium bicarbonate is produced, so called because to a given amount of potassium it contains twice as much carbonic acid as the carbonate. *Potash-salæratus* consists essentially of this salt. It probably exists in the juices of various plants.

**Sodium Carbonate, or Carbonate of Soda,** $Na_2CO_3$, 106.—This substance, 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 somewhat complicated processes. It occurs in commerce in an impure state under the name of *Soda-ash.* United to water, it forms *sal-soda,* which usually exists in transparent crystals or crystallized masses. These contain 63 per cent of water, which partly escapes when the salt is exposed to the air, leaving a white, opaque powder.

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

**Sodium Bicarbonate,** $NaHCO_3$.—The *supercarbonate of soda* of the apothecary is this salt in a nearly pure state. The cooking-soda of commerce is a mixture of this with some simple carbonate. It is prepared in the same way as potassium bicarbonate. The bicarbonates, both of potassium and sodium, 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 carbon dioxide.

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

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

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 calcium salts (oxalate, tartrate, malate, etc.), which exist in the juices of the vegetable, or are abundantly deposited in its tissues in the solid form. Carbonate of lime 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. Sulphate of Magnesium is well known as Epsom salts, and Sulphate of Iron is copperas or green vitriol.

**Potassium Sulphate, or Sulphate of Potash,** $K_2SO_4$, 174.—This salt may be procured by dissolving potash or carbonate of potash 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 cent of this salt.

**Sodium Sulphate, or Sulphate of Soda,** $Na_2SO_4$, 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, or Sulphate of Lime,** $CaSO_4$, 136.—The burned *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.

In nature, sulphate of lime is usually combined with two molecules of water, and thus constitutes *Gypsum*, $CaSO_4 . 2\ H_2O$, 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 400 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.

Land plaster is ground gypsum, that from Nova Scotia being white, that from Onondaga and other localities in New York State gray in color.

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

Numerous phosphates of each of these bases exist, or may be prepared artificially. But three classes of phosphates have any immediate interest to the agriculturist. As has been stated (p 132), phosphoric acid, prepared by boiling phosphorus pentoxide with water, is represented by the symbol $H_3PO_4$. The phosphates may be regarded as phosphoric acid in which one, two, or all the atoms of hydrogen are substituted by one or several metals.

**Potassium Phosphates or Phosphates of Potash.** —There are three of these phosphates formed by replacing one, two, or three hydrogen atoms of phosphoric acid by potassium, viz.: $KH_2PO_4$, *primary* or monopotassic phosphate; $K_2HPO_4$, *secondary* or dipotassic phosphate, and $K_3PO_4$, *tertiary* or tripotassic phosphate.* Of these salts, the secondary and tertiary phosphates exist largely (to the extent of 40 to 50 per cent) in the ash of the kernels of wheat, rye, maize, and other bread grains. The potassium phosphates do not occur in commerce; they closely resemble the corresponding sodium-salts in their external characters.

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*The primary phosphates are often designated *acid* or *super-phosphates*, the secondary *neutral phosphates*, and the tertiary *basic phosphates*.

**Sodium Phosphates, or Phosphates of Soda.**—Of these the *disodic phosphate*, $Na_2HPO_4$, alone needs notice. It is found in the drug-stores in the form of glassy crystals, which contain 12 molecules (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.

**Calcium Phosphates, or Phosphates of Lime.**—Since one atom of calcium replaces two of hydrogen, the formulæ of the calcium phosphates are written as follows: *monocalcic* or *primary phosphate* $CaH_4P_2O_8$; *dicalcic* or *secondary phosphate*, $CaHPO_4$; *tricalcic* or *tertiary phosphate*, $Ca_3P_2O_8$.* Both the secondary and tertiary phosphates probably occur in plants. The secondary is a white crystalline powder, nearly insoluble in water, but easily soluble in acids. In nature it is found as a urinary concretion in the sturgeon of the Caspian Sea. It is also an ingredient of guanos, and probably of animal excrements in general.

The *tricalcic phosphate*, or, as it is sometimes termed, *bone-phosphate*, is a chief ingredient of the bones of animals, and constitutes 90 to 95 per cent of the ash or earth of bones. It may be formed by adding a solution of lime to one of sodium phosphate, and appears as a white precipitate. It is insoluble in pure water, but dissolves in acids and in solutions of many salts. In the mineral kingdom tricalcic phosphate is the chief ingredient of *apatite* and *phosphorite*. These minerals are employed in the preparation of the commercial *superphosphates* now consumed to an enormous extent as a fertilizer. Plain superphosphate is essentially a mixture of sulphate of lime with the three phosphates above noticed and with free phosphoric acid.

**The Phosphates of Magnesium, Iron, Aluminium and Manganese,** are bodies insoluble in water,

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*These formulæ correspond to 2 molecules of phosphoric acid, $=H_6P_2O_8$, with 2 and 4 H-atoms replaced by Ca.

that occur in very small proportion in the ashes of plants and in soils, but are important ingredients of some fertilizers.

THE CHLORIDES are all characterized by their ready solubility in water. The Chlorides of 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, or Muriate of Potash,** 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 $KHO + HCl = KCl + H^2O$.

Potassium chloride closely resembles common salt in appearance, solubility in water, taste, etc. It is now an important article of commerce and largely consumed as a fertilizer. It is also often present in the ash and in the juices of plants, especially of sea-weeds, and is likewise found in most fertile soils.

**Chloride of Sodium,** 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 connectedly in this place.

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

NITRATES.—*Nitric acid* (the compound by which nitrogen is chiefly 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 (niter, saltpeter), $KNO_3$.

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 niter and dried. The leaves of the sugar-beet, sunflower, tobacco, and some other plants, frequently contain this salt, and, when 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 are noticed at length in "How Crops Feed." See also p .

OXALATES, 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.

**Ammonium Salts** exist in minute amount in some plants. What particular salts thus occur is uncertain, and special notice of them is 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 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 while most or all of them may exist in the plant 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 always assert positively that in a given plant potassium exists as phosphate, or sulphate, or carbonate. We judge, indeed, from the predominance of potassium and phosphoric acid in the ash of wheat, that potassium phosphate is a large constituent of this grain, but of this we are scarcely certain, though in the absence of evidence to the contrary we are warranted in assuming these two ingredients to be united. On the other hand, calcium carbonate and calcium sulphate have been discovered by the microscope in the cells of various plants, in crystals whose characters are unmistakable.

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 choice in the manner of representing the composition of a plant as regards its ash-ingredients.

We do not indeed so commonly speak of the calcium or the silicon in the plant as of lime and silica, because these rarely-seen elements are much less familiar than their oxides.

Again, we do not speak of the sulphates or chlorides, when we desire to make statements which may be compared together, because, as has just been remarked, we cannot always, nor often, say what sulphates or what chlorides are present.

In the paragraphs that follow, which are devoted to a more particular statement of the *mode of occurrence, relative abundance, special functions,* and *indispensability* of the fixed ingredients of plants, will be indicated the customary methods of defining them.

## § 2.

## QUANTITY, DISTRIBUTION, AND VARIATIONS OF THE ASH-INGREDIENTS.

**The Ash** of plants consists of the various acids, oxides, and salts, that have been noticed in § 1, which are fixed or non-volatile at a heat near redness.

Ash-ingredients are always present in each cell of every plant.

The ash-ingredients exist partly in the cell-wall, incrusted or imbedded in the cellulose, and partly in the plasma or contents of the cell (see p 249).

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 alkali-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 calcium phosphates 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, alkalies, 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 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 manifest 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 most cases is given an *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.

### 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 " | 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 |

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*These figures are copied unchanged from the old edition, and may differ from later averages, but are approximately correct.

### ROOTS AND TUBERS.

| | | | |
|---|---|---|---|
| Potatoes, 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 |

### STRAW AND STEMS.

| | | | |
|---|---|---|---|
| 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 | Cauto tree | 34.4 |

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 kernel 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 ash-ingredients. 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 kernels 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. (*Am. Jour. Science*, Vol. III, 1847.)

From the table it is seen that wood (0.3 to 2.7 per cent) and seeds (1.5 to 3.7 per cent)—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).

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 | | | |
| June 11............. | 10.7 | 9.8 | | | |
| June 18............. | 9.0 | 9.3 | | | |
| June 25............. | 10.9 | 9.1 | | | |
| July 2............. | 11.3 | 7.8 | | | 4.9 |
| July 9............. | 12.2 | 7.8 | | | 4.3 |
| July 16............. | 12.6 | 7.9 | | 6.0 | 3.3 |
| July 23............. | 16.4 | 7.9 | 10.0 | 9.1 | 3.6 |
| July 30............. | 16.4 | 7.4 | 9.6 | 12.2 | 4.2 |
| Aug. 6............ | 16.0 | 7.6 | 10.4 | 13.7 | 4.3 |
| Aug. 13............ | 20.4 | 6.6 | 10.4 | 18.6 | 4.0 |
| Aug. 20............ | 21.1 | 6.6 | 11.7 | 21.0 | 3.6 |
| Aug. 27............ | 22.1 | 7.7 | 11.2 | 22.4 | 3.5 |
| Sept. 3............ | 20.9 | 8.3 | 10.7 | 27.4 | 3.6 |

Here, in case of the 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 |
| June 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 |
| July 21 | 4.4 | 5.0 | 5.5 | 10.1 | 9.7 | 2.8 | 5.2 |
| July 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 per cent of ash, both in tops and roots.

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.

5. The influence of the *soil* and *season* 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 |

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 (*Qu. Jour. Chem., Soc.* II, p. 20) found the percentages of ash in dry matter of the tuber as follows:

| | VARIETY OF POTATO. | | | | |
|---|---|---|---|---|---|
| | *White Apple.* | *Prince's Beauty.* | *Axbridge Kidney.* | *Magpie.* | *Forty-fold.* |
| Ash per cent | 4.8 | 3.6 | 4.3 | 3.4 | 3.9 |

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 vigor 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.

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, having 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 (*Journal Roy. Ag. Soc. Eng.* Vol. 22, 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 kernels, while the pedigree wheat has shown beardless ears of 8¾ inches in length, closely packed with large kernels 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, would, no doubt in time become as prolific of grain as the latter, 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.

9. *Of all the parts of plants, the seeds are the least liable to vary in composition.* Two varieties or two individuals may differ enormously in their relative proportions of foliage, stem, chaff, and seed; but the seeds themselves nearly agree. Thus, in the analysis of 67 specimens of the wheat kernel, 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 much 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 range from 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.

Wolff (*Die Naturgesetzlichen Grundlagen des Ackerbaus*, 3 Aufl., p. 117) has deduced from a large number of analyses the following averages for three important classes of agricultural plants, viz. :

| | *Grain.* | *Straw.* |
|---|---|---|
| Cereal crops | 2 per cent. | 5.25 per cent. |
| Leguminous crops | 3 " " | 5 " " |
| Oil-plants | 4 " " | 4.5 " " |

More general averages are as follows (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.

1. Ash-ingredients are indispensable to the life and growth of all plants. In mold, yeast, and other plants of the simplest kind, as well as in those of the higher orders, analysis never fails to recognize a proportion of fixed matters. We must hence conclude that these are necessary to the primary acts of vegetation, that atmospheric food cannot be assimilated, that vegetable matter cannot be organized, except with the coöperation of those substances which are invariably found in the ashes of the plant. This proposition is demonstrated 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 & 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, connection 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 26 days, reaching a height of two or 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. This experiment demonstrates most conclusively that a plant cannot grow in the absence of those substances found in its ash. The development of the cresses ceased so 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.

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 & Polstorf, above described.

III. We have reason to believe that each part or organ (each cell) of the plant contains a certain, nearly invariable, 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 COMPOSITION OF THE ASH OF AGRICULTURAL PLANTS.

The result of the extended inquiries which have been made into the subject of this section may be conveniently presented and discussed under a series of propositions, viz.:

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.:

Bases
- Potash, $K_2O$.
- Soda, $Na_2O$.
- Lime, $CaO$.
- Magnesia, $MgO$.
- Oxide of iron, $Fe_2O_3$.

Acids
- Chlorine, $Cl$.
- Sulphuric acid, $SO_3$.
- Phosphoric acid, $P_2O_5$.
- Silicic acid, $SiO_2$.
- Carbonic acid, $CO_2$.

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-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 especially true of the seeds of plants, which attain nearly the same development under all ordinary circumstances. It is less true of foliage and roots, whose dimensions and character vary to a great extent. In the following tables (p. 164–170) 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 means of several single analyses. In this way, it is believed, the real variations of composition are pretty truly exhibited, independently of the errors of analysis.

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 analyzed. 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 doubtless 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.

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* At the time of preparing the first edition of this book, in 1868. More recent analyses are comparatively few in number, excepting those of wheat (grain and straw) by Lawes & Gilbert, and do not differ essentially from those given. The numerous very incorrect ash-analyses, published by Dr. E. Emmons and Dr. J. H. Salisbury, in the Natural History of New York, and in the Trans. of the New York State Agricultural Society, are not included.

The following table includes both the kernel 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.

For the average composition of other plants and vegetable products, the reader is referred to a table in the appendix, p. 409, compiled by Prof. Wolff, of the Royal Agricultural Academy of Würtemberg. That table includes also the averages obtained by Prof. Wolff for most of the substances, cotton excepted, whose composition is represented in the pages immediately following.

In both tables the *carbonic acid*, $CO^2$, which occurs in most ashes, is excluded, from the fact that its quantity varies according to the temperature at which the ash is prepared.

The following is a statement of the various Names and Symbols that are or have been currently applied to the Ash-Ingredients in Chemical Literature. The changes that have been made from time to time, both in symbols and in names, are the results of progress in knowledge or of attempts to improve nomenclature :

| *Older Symbols.* | *Newer Symbols.* | *Synonyms.* |
|---|---|---|
| KO | $K_2O$ | Potash, Potassa, Potassium Oxide, Potassic Oxide. |
| NaO | $Na_2O$ | Soda, Sodium Oxide, Sodic Oxide. |
| MgO | MgO | Magnesia, Magnesium Oxide, Magnesic Oxide. |
| CaO | CaO | Lime, Calcium Oxide, Calcic Oxide. |
| $Fe_2O_3$ | $Fe_2O_3$ | Iron Oxide, Peroxide of Iron, Sesquioxide of Iron, Ferric Oxide. |
| $PO_5$ | $P_2O_5$ | Phosphoric Acid, Anhydrous Phosphoric Acid, Phosphoric Anhydide, Phosphorus Pentoxide, Phosphoric Oxide. |
| $SO_3$ | $SO_3$ | Sulphuric Acid, Anhydrous Sulphuric Acid, Sulphuric Anhydride, Sulphur Trioxide, Sulphuric Oxide. |
| $SiO_3$ | $SiO_2$ | Silicic Acid, Anhydrous Silicic Acid, Silicic Anhydride, Silicon Dioxide, Silicic Oxide, Silica Silex. |
| $CO_2$ | $CO_2$ | Carbonic Acid, Anhydrous Carbonic Acid, Carbonic Anhydride, Carbon Dioxide, Carbonic Dioxide. |

### COMPOSITION OF THE ASH OF SOME AGRICULTURAL PLANTS AND PRODUCTS.

*Arranged to exhibit the Extent of Variations.*

| Pr Ct of Ash | Pot-ash | Soda | Mag-nesia | Lime | Oxide Iron | Phos-phoric Acid | Sul-phuric Acid | Silica | Chlo-rine | |
|---|---|---|---|---|---|---|---|---|---|---|
| **WHEAT KERNEL.** | | | | | | | | | | |
| | 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 & 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 “ |
| | 32.7 | 0.6 | 10.7 | 3.0 | 0.9 | 49.6 | 1.4 | 1.0 | 0.1 | Average of 48 later Analyses by Lawes & Gilbert. |
| **RYE KERNEL.** | | | | | | | | | | |
| 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 KERNEL 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 & 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 | 3.0 | 16.8 | 10.1 | 2.4 | 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. |

* Viz.: Schmidt, Thon, Will & Fresenius, Boussingault, Weber, Petzholdt, Baer, Fr. Schulze. † Viz.: Herapath, Way & Ogston, Fr. Schulze, Will & Fresenius, Bichon, Geradewohl, Schulz-Fleeth. ‡ Viz.: John, Schmidt, Koechlin, Thomson.

| Pr Ct of Ash | Pot-ash | Soda | Mag-nesia | Lime | Oxide Iron | Phos-phoric Acid | Sul-phuric Acid | Silica | Chlo-rine | |
|---|---|---|---|---|---|---|---|---|---|---|
| OAT KERNEL 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 & 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 percentage in 21 Analyses. |
| 4.0 | 24.3 | 8.2 | 9.7 | 8.4 | 2.1 | 32.3 | 4.0 | 56.0 | 1.6 | Highest " 21 " |
| MAIZE KERNEL. | | | | | | | | | | |
| | 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 & Ogston. |
| | 26.6 | 7.5 | 15.4 | 1.6 | 0.6 | 39.6 | 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 | undt | 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 | " | " |
| | 30.7 | | 14.7 | 3.1 | 0.8 | 44.5 | 4.1 | 1.8 | 0.5 | Campbell. [and Lehmann.‡ |
| 1.7 | 23.7 | 0.0 | 11.3 | ? | 1.4 | 35.0 | ? | ? | 3.6 | Lowest per cent in 3 Analyses by Sachse, Schreber, |
| 1.9 | 29.6 | 0.0 | 16.0 | ? | 9.6 | 40.4 | ? | ? | 4.5 | Highest " 3 " by Sachse, Schreber, |
| 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. [and Lehmann. |
| 2.1 | 30.8 | 13.2 | 17.0 | 6.3 | 9.6 | 53.7 | 5.5 | 3.9 | 4.5 | Highest " " " |
| RICE KERNEL 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 | | 63.3 | | 3.4 | | Highest " 5 " |

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*Viz: Herapath, Boussingault, Porter, Fr. Schulze, Knop & Schnederman, Bretschneider, Bibra. †Maize Meal.
‡Detailed Analyses not accessible.

COMPOSITION OF THE ASH OF SOME AGRICULTURAL PLANTS AND PRODUCTS, ETC.—[*Continued.*]

| Pr Ct of Ash | Pot-ash | Soda | Mag-nesia | Lime | Oxide Iron | Phos-phoric Acid | Sul-phuric Acid | Silica | Chlo-rine | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | RICE KERNEL 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 KERNEL. | | | | | |
| **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 | " " |
| | | | | | PEA KERNEL. | | | | | |
| | 40.9 | 3.1 | 7.6 | 5.4 | 0.8 | 35.3 | 4.3 | 0.8 | 1.4 | Average of 31 Analyses. [mie Collegium. |
| | 42.3 | 0.9 | 8.0 | 4.8 | 1.0 | 37.6 | 2.7 | 0.6 | 1.8 | " 14 " for Prussian Landes Oecono- |
| | 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 & 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 " |
| | | | | | BEAN KERNEL. | | | | | |
| | 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 & 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 percentage 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 " [above. |
| | 43.1 | 0.2 | | 6.3 | | 32.7 | 3.3 | | | Analysis by Henneberg & Stohmann, not included |
| | | | | | 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 & 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 percentage in 15 Analyses. |
| 6.9 | 16.7 | 7.8 | 5.2 | 8.8 | 1.8 | 8.9 | 5.6 | 73.6 | 9.4 | Highest " 15 " |
| 6.1 | 16.4 | 0.7 | 1.8 | 4.7 | 0.7 | 3.6 | 3.0 | 66.6 | 2.6 | Average of 48 later Analyses by Lawes & Gilbert. |

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* Viz.: Will & Fresenius, Bichon, Thon, Boussingault, Baer. † Viz.: Herapath, Bichon, Boussingault, Buchner, Thon, Levi. ‡ Viz.: Chaff included. § Viz.: Petzholdt, Baer, Weber, Boussingault, Zoeller, Henneberg & Stohmann; whether or not Chaff is included is uncertain.

| Pr Ct of Ash | Pot-ash | Soda | Mag-nesia | Lime | Oxide Iron | Phos-phoric Acid | Sul-phuric Acid | Silica | Chlo-rine | |
|---|---|---|---|---|---|---|---|---|---|---|
| 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 | | 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 & Ogston. |
| | 30.6 | 4.3 | 1.9 | 7.1 | | 4.0 | 4.9 | 47.6 | | “ 8 “ “ Wolff. |
| 8.2 | 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 & 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 | 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 | 28.8 | | Way & 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 & 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 | 16.9 | 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.§ |

* By Will & Fresenius, Schulz-Fleeth, Zoeller, Rautenberg. † By Rammelsberg, Nitzsch, Liebig, Marchand, Steinberg, Schulze, Kroeker, Weber, Heintz, Erdmann, Städeler. ‡ 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, ETC.—[*Continued.*]

| Pr Ct of Ash | Potash | Soda | Magnesia | Lime | Oxide Iron | Phosphoric Acid | Sulphuric Acid | Silica | Chlorine | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 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 & Knop. |
| 6.1 | 31.3 | 12.1 | 5.7 | 27.2 | 1.1 | 7.7 | 3.7 | 4.6 | 7.8 | “ 5 “ “ Way & 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 Analyses 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 “ “ Metzdorff. |
| | 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 & 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 & 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 | 2.0 | 5.1 | 4.5 | 3.9 | 0.3 | 10.2 | 2.1 | 1.6 | 0.5 | Lowest percentage in 40 Analyses. |
| 6.0 | 8.9 | 29.8 | 13.8 | 23.3 | 2.2 | 18.5 | 8.9 | 9.0 | 10.8 | Highest “ 40 “ |

* Viz.: Moser, Fromberg, Boussingault, Cameron, John, Griepenkerl.

| Pr Ct of Ash | Pot-ash | Soda | Mag-nesia | Lime | Oxide Iron | Phos-phoric Acid | Sul-phuric Acid | Silica | Chlo-rine | |
|---|---|---|---|---|---|---|---|---|---|---|
| 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 & 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 & 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 & 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 in 19 Anal. 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 & Ogston. |
| 21.8 | 32.7 | 13.1 | 13.9 | 11.3 | 1.6 | 5.0 | 10.1 | 6.8 | 5.1 | Analysis 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 " |

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* Etti, Griepenkerl, Herapath, Boussingault. † Bretschneider, Richardson, Fromberg (2), Herapath. ‡ Herapath, Stammer.

COMPOSITION OF THE ASH OF SOME AGRICULTURAL PLANTS AND PRODUCTS, ETC.—[*Continued.*]

| Pr Ct of Ash | Pot-ash | Soda | Mag-nesia | Lime | Oxide Iron | Phos-phoric Acid | Sul-phuric Acid | Silica | Chlo-rine | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 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 by * |
| 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 & 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 & 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 Anal. exclusive of Campbell's. |
| 19.7 | 37.2 | 19.9 | 16.1 | 39.6 | 5.5 | 15.1 | 16.3 | 9.5 | 18.9 | Highest " 12 " " " |
| | | | | | COTTON STALKS. | | | | | |
| 3.1 | 33.7 | | 8.1 | 42.1 | 0.6 | 12.6 | 1.8 | | 1.1 | J. Lawrence Smith. Report to Black Oak Ag'l Soc. 1846. |
| | 29.6 | | 3.7 | 24.3 | | 34.9 | 3.5 | 3.2 | 0.7 | O. Judd. Proceedings Am. Asso. 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 Phila. 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 | 1.1 | 14.2 | 6.2 | 0.6 | 37.2 | 4.1 | trace | 0.5 | Higgins & Bickell. Turner's Cotton Plant. Man. p. 207. |
| | | | | | COTTON FIBER. | | | | | |
| 1.3 | 41.8 | 6.1 | 11.2 | 19.8 | 2.4 | 6.4 | 4.2 | 0.3 | 7.8 | Higgins & Bickell (*loc. cit.*) |

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* Hoffmann, Eylerts, Bretschneider (2). † Fromberg (2), Bretschneider. ‡ Namur, Anderson.

The composition of the ash of a number of ordinary crops is concisely exhibited in the subjoined general statement.

| | *Alkalies.* | *Magnesia.* | *Lime.* | *Phosphoric Acid.* | *Silica.* | *Sulphuric Acid.* | *Chlorine.* |
|---|---|---|---|---|---|---|---|
| CEREALS— | | | | | | | |
| Grain* | 30 | 12 | 3 | 46 | 2 | 2.5 | 1 |
| Straw | 13—27 | 3 | 7 | 5 | 50—70 | 2.5 | 2 |
| LEGUMES— | | | | | | | |
| Kernel | 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 |

3. Different parts of any 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 Stem.* | 3 *Upper Stem.* | 4 *Lower Leaves.* | 5 *Upper Leaves.* | 6 *Ears.* | 7 *Chaff.* | 8 *Husk.* | 9 *Kernel husked.* |
|---|---|---|---|---|---|---|---|---|---|
| Potash | 81.2 | 68.3 | 55.9 | 36.9 | 24.8 | 13.0 | 10.06 | 12.4 | 31-7 |
| Soda | 0.4 | 1.5 | 1.0 | 0.9 | 0.4 | 0.1 | | | |
| Magnesia | 2.1 | 3.6 | 3.9 | 3.8 | 3.9 | 8.9 | 11.2 | 2.3 | 8.6 |
| Lime | 3.6 | 5.3 | 8.6 | 16.7 | 17.2 | 7.3 | | 4.3 | 5.3 |
| Oxide of Iron | 1.0 | 0.0 | 0.2 | 2.7 | 0.5 | trace | | 0.3 | 0.8 |
| Phosphoric acid. | 2.7 | 1.4 | 2.7 | 1.7 | 1.5 | 36.5 | | 0.6 | 49.1 |
| Sulphuric acid | 0.0 | 1.3 | 1.1 | 3.2 | 7.5 | 4.9 | 5.3 | 4.3 | 0.0 |
| Silica | 4.1 | 9.3 | 20.4 | 34.0 | 41.8 | 26.0 | 68.0 | 74.1 | 1.8 |
| Chlorine | 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%). This alkali is predominant throughout the stem, but in the upper parts, 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 acid appears as the char-

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*Exclusive of husk.

acteristic ingredient, existing there in connection with a large amount of potash (32%) and considerable magnesia. Chlorine acquires its maximum (11.7%) in the middle stem, but in the kernel is present in small quantity, while sulphuric acid is totally wanting in the lower stem, and most abundant in the upper leaves.

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 6 sugar-beets into 5 series or circles, proceeding from the outer and older leaves inward. He examined each series separately with the following results:

| | I. | II. | III. | IV. | V. |
|---|---|---|---|---|---|
| Potash | 18.7 | 25.9 | 32.8 | 37.4 | 50.3 |
| Soda | 15.2 | 14.4 | 15.8 | 15.0 | 11.1 |
| Chloride of Sodium | 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 |
| Oxide of Iron | 1.4 | 0.5 | 0.6 | 0.6 | 0.5 |
| Phosphoric acid | 3.3 | 4.8 | 5.8 | 8.4 | 12.7 |
| Sulphuric acid | 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 acid 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, oxide of iron, sulphuric acid, and silica, remains nearly invariable throughout.

Another illustration is furnished by the following analyes of the ashes of the various parts of the horse-chestnut tree made by Wolff (*Ackerbau,* 2. *Auf.*, 134):

| | *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 acid | trace | trace | 3.8 | 9.1 | 3.5 | trace |
| Phosphoric acid | 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 |

| | | | | *Ripe Fruit.* | | |
|---|---|---|---|---|---|---|
| | *Stamens.* | *Petals.* | *Green Fruit.* | *Kernel.* | *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 acid | trace | trace | 3.7 | 1.7 | 1.0 | 3.6 |
| Phosphoric acid | 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.

The three plants, wheat, rye, and maize, belong, botanically speaking, to the same natural order, *gramineæ,* and the ripe kernels 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 wheat, rye, and maize-kernel, the grains of barley and oats are closely invested with a husk, which forms a part of the kernel as ordinarily seen. This husk yields an ash which is rich in silica, and we can only properly compare barley and oats 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 kernel—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 table on page 174.

By reference to the table (p. 166), it will be observed that the pea and bean kernel, together with the allied vetch and lentil (p. 171), also nearly agree in ash-composition.

So, too, the ashes of the root-crops, turnips, carrots, and beets, exhibit a general similarity of composition, as may be seen in the table (p. 168-9).

| | *Wheat. Average of seventy-nine Analyses.* | *Rye. Average of twenty-one Analyses.* | *Maize. Average of seven Analyses.* | *Skinless oats. Analysis by Fr. Schulze.* | *Skinles barleys. Analysis by Fr. Schulze.* |
|---|---|---|---|---|---|
| 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 |
| Oxide of Iron | 0.7 | 0.8 | 1.0 | 0.8 | 0.7 |
| Phosphoric acid | 46.1 | 45.6 | 47.1 | 46.9 | 45.0 |
| Sulphuric acid | 1.2 | 1.9 | 1.7 | — | — |
| Silica | 1.9 | 2.6 | 2.1 | 2.4 | 0.7 |
| Chlorine | 0.2 | 0.7 | 0.1 | — | — |

The seeds of the oil-bearing plants likewise constitute a group whose members agree in this respect (p. 170).

5. The ash of the same species of plant is more or less variable in composition, according to circumstances.

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 vigor of its development.

*c.* The variety of the plant or the relative development of its parts, and

*d.* The soil or the supplies of food.

*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. 241).

*b. Vigor 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 analyzed the ashes of each parcel, with results as below :

| | 1 | 2 | 3 |
|---|---|---|---|
| Silica | 27.0 | 39.9 | 42.0 |
| Sulphuric acid | 4.8 | 4.1 | 5.6 |
| Phosphoric acid | 8.2 | 8.5 | 8.8 |
| Chlorine | 6.7 | 5.8 | 4.7 |
| Oxide of Iron | 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 |

*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 (*Qu. Jour. Chem. Soc.*, II, p. 20) analyzed the ashes of the tubers of five varieties of potatoes, raised on the same soil and under precisely similar circumstances. His results are as follows :

| | *White Apple.* | *Prince's Beauty.* | *Axbridge Kidney.* | *Magpie.* | *Forty-fold.* |
|---|---|---|---|---|---|
| Potash | 69.7 | 65.2 | 70.6 | 70.0 | 62.1 |
| Chloride of Sodium | — | — | — | — | 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 acid | 17.2 | 20.8 | 14.9 | 14.4 | 20.7 |
| Sulphuric acid | 3.6 | 6.0 | 4.3 | 7.5 | 7.9 |
| Silica | — | — | 0.2 | — | — |

*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 vigor 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 Ag. Soc.*, 1857-9, 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. Ag. Society*, 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 follows:

| | *Light oats.* | *Heavy oats.* |
|---|---|---|
| Potash................ | 9.8 | 13.1 |
| Soda.................. | 4.6 | 7.2 |
| Lime.................. | 6.8 | 4.2 |
| Phosphoric acid...... | 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

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* Thickly covering with sediment from muddy tide-water.

on the unmanured soil, and on the same, after application of the substances specified below :

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| | *Unmanured.* | *Chloride of sodium.* | *Nitrate of potash.* | *Carbonate of potash.* | *Sulphate of magnesia.* | *Carbonate of lime.* |
| Potash | 31.7 | 21.6 | 39.6 | 40.5 | 28.2 | 23.9 |
| Chloride of potassium | 7.4 | 26.9 | 0.8 | 3.1 | 6.9 | 9.7 |
| Chloride of sodium | 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 acid | 4.7 | 2.8 | 2.7 | 4.3 | 7.1 | 3.5 |
| Phosphoric acid | 10.3 | 9.5 | 6.5 | 8.9 | 10.9 | 10.0 |
| Carbonic acid | 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 |

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 acid and magnesia, and in 6, lime, are present in larger proportion than in the ash from the unmanured soil.

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, endeavored 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 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. 163) are here "corrected" in this manner, by the subtraction of a certain per cent 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 the previous page.

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| *After deduction of* | *Nothing.* | 20 *p. c.* *Chloride of potassium.* | 20 *p. c.* *Carbonate of potassium.* | 25 *p. c.* *Carbonate of potassium.* | 8.5 *p. c.* *Sulphate of magnesium.* | 16.6 *p. c.* *Carbonates of calc'm and magnesium.* |
| Potash | 31.7 | 27.0 | 32.5 | 33.5 | 30.6 | 28.0 |
| Chloride of potassium. | 7.4 | 9.1 | 1.0 | 3.9 | 7.4 | 11.3 |
| Chloride of sodium | 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 acid | 4.7 | 3.5 | 3.4 | 5.4 | 2.1 | 4.1 |
| Phosphoric acid | 10.3 | 11.7 | 8.1 | 11.2 | 11.8 | 11.7 |
| Carbonic acid | 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 potassium chloride, potassium carbonate, etc., 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 truly assimilated nitrogen as albuminoids, amido-acids, etc. 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 acts is present, and no more.

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 a very different result.

In 1859, Metzdorf (*Wilda's Centralblatt,* 1862, II, p. 367) analysed the ashes of eight samples of the red-onion potato, grown on the same field in Silesia, but differently manured.

Without copying 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 50 pounds of this substance, but from a parcel to which had been applied a poudrette containing less than three 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 chemical analysis had arrived at much perfection, it was believed that the ashes of the plant were either unessential to growth, or else were the products of growth—were generated by 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, and with highly valuable results.

**Experiments in Artificial Soils.**—The Prince Salm-Horstmar, of Germany, was one of the first and most laborious students 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, and all the usual external conditions of growth (light, warmth, moisture, etc.), were supplied.

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 described, the most important of which will shortly be given.

**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.

*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 blotting-paper, 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.

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. 22. Cut a vertical notch in the cork to its center, 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

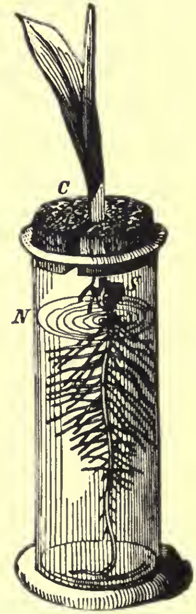

Fig. 22.

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 skillful management of conservatory or house-plants.

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 experience of Nobbe and Siegert, Knop, Wolff, and others,* supplies valuable information on this point. Wolff has obtained striking results with a variety of plants in using a solution made essentially as follows:

Place 20 grams of the fine powder of well-burned bones with a half 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 boiling liquid a solution of pure potassium carbonate until a slight permanent turbidity is produced; then add 11 grams of potassium nitrate, 7 grams of crystallized magnesium sulphate, and 3 grams of potassium chloride, with water enough to make the solution up to the bulk of one liter.

Wolff's solution, thus prepared, contains in 1000 parts as follows, exclusive of iron:

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* See especially Tollens (*Henneberg's Jour. für Landwirthschaft*, 1882, p. 537) for full and concise instructions.

| | | |
|---|---|---|
| Phosphoric acid | 8.2 | |
| Lime | 10.5 | |
| Potash | 9.1 | |
| Magnesia | 1.4 | |
| Sulphuric acid | 2.2 | |
| Chlorine | 0.9 | |
| Nitric acid | 29.7 | |
| Solid Matters | | 62 |
| Water | | 938 |
| | | 1000 |

For use, dilute 15 or 20 c. c. of the above solution with water to the bulk of a liter and add one or two drops of strong solution of ferric chloride.

The solution should be changed at first 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, and the latter changed every 5 or 3 days.

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 calcium sulphate before the last dilution, as well as from the precipitation of phosphate of iron 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 five and three quarters 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 1535 well-developed seeds. (*Vs. St.*, VIII, pp.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, p. 72.)

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 odor of hydrogen sulphide, and black iron 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 acids 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*, if needful, by 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 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's earliest experiments were made with well-water.

Birner and Lucanus, in 1864 (*Vs. St.*, VIII, 154), raised oat-plants in well-water, which 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 but $\frac{1}{3000}$ of dissolved matters, or in 100,000 parts:

| | | |
|---|---|---|
| Potash | 2.10 | |
| Lime | 15.10 | |
| Magnesia | 1.50 | |
| Phosphoric acid | 0.16 | |
| Sulphuric acid | 7.50 | |
| Nitric acid | 6.00 | |
| Silica, Chlorine, Oxide of iron | traces | |
| Solid Matters | | 32.36 |
| Water | | 99,967.64 |
| | | 100,000 |

On the other hand, too great dilution is fatal to growth. Nobbe (*Vs. St.*, VIII, 337) found that in a solution containing but $\frac{1}{10000}$ 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 for the growth of land plants—the soil having important functions that cannot be enacted 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.

**Potassium, Calcium, and Magnesium as soluble Salts, Phosphorus as Phosphates and Sulphur as Sulphates, are absolutely necessary for the life of Agricultural Plants,** as is demonstrated by all the experiments hitherto made for studying their influence.

It is impossible to recount here in detail the evidence to this effect that is furnished by the investigations of Salm-Horstmar, Sachs, Knop, Nobbe, Birner and Lucanus, and others (*Vs. St.*, VIII, p. 128–161).

Some of the experimental proof of this statement is strikingly exhibited by the figures on Plate I, copied from Nobbe, showing results of the water-culture of buckwheat in normal nutritive solutions and in solutions variously deficient.

**Is Sodium Essential for Agricultural Plants?** This question has occasioned much discussion. A glance at the table of ash-analyses (pp. 164–170) will show that the range of variation is very great as regards this alkali-metal. The older analysts often reported a considerable proportion of sodium oxide, even 20% or more, in the ash of seeds and grains. In most of the analyses, however, sodium oxide is given 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.*

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 sodium by the processes customarily employed is liable to great inaccuracy, especially with the inexperienced analyst. On the one hand, it is not or was not easy to detect, much less to estimate, minute traces of sodium when mixed with much potassium; while, on the other hand, sodium, 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, 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 sodium from a material which properly should contain it, and we may hence be in doubt whether the older analyses, in which sodium is not mentioned, are to be altogether depended upon.

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 sodium oxide in the ash of several field crops, according to the newest analyses:

SODIUM OXIDE (SODA) IN LATER ASH-ANALYSES.

| | | | | | |
|---|---|---|---|---|---|
| Ash of Wheat kernel, | none, | Bibra, | to | 5% | Bibra. |
| " " " " | 0.28% | Lawes & Gilbert, | " | 1.18% | |
| " " Potato tuber, | none, | Cameron,<br>Metzdorff, | " | 4% | Wolff. |
| " " Barley kernel, | 1%<br>2% | Bibra,<br>Zoeller, | " | 6% | Bibra.<br>Veltmann. |
| " " " " | | " | | 7% | Zoeller. |
| " " Sugar beet, | 4% | Ritthausen, | " | 29.8% | Ritthausen. |
| | 7% | Bretschneider, | " | 16.6% | Bretschneider. |
| " " Turnip root, | 7.7% | Anderson, | " | 17.1% | Anderson. |

Although, as just indicated, sodium in some instances has been found wanting in the wheat kernel and in potato tubers, it is not certain that it was absent from other parts of the same plants, nor has it been proved that sodium is wanting in any *entire plant* which has grown on a natural soil.

Weinhold found in the ash of the stem and leaves of the common live-for-ever (*Sedum telephium*) no trace of sodium detectable by ordinary means; while in the ash of the roots of the same plant there occurred 1.8 per cent of its oxide (*Vs. St.*, IV, p. 190).

It is possible then that, in the above instances, sodium really existed in the plants, though not in those parts which were subjected to analysis. It should be added that in ordinary analyses, where sodium is stated to be absent, it is simply implied that it is present, if at all, in too small a quantity to admit of determining by the usual method, while in reality a minute amount may be present in all such cases.*

The final result of all the analytical investigations hitherto made, with regard to cultivated agricultural plants, then, is that sodium 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, and Nobbe & Siegert have contributed experimental evidence bearing on this question.

The investigations of Salm-Horstmar were made with great 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, Sodium, while advantageous, is not essential, but that for the perfection of fruit an appreciable though minute quantity of this element is indispensable. (*Versuche und Resultate über die Nahrung der Pflanzen*, pp. 12, 27, 29, 36.)

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*The methods of spectral analysis, by which $\frac{1}{2000000000}$ of a grain of sodium oxide may be detected, demonstrate this element to be so universally distributed that it is next to impossible to find or to prepare anything that is free from it.

Stohmann's single experiment led to the similar conclusion, that maize may dispense with sodium 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 sodium. (*Vs. St.*, III, p. 301.) Nobbe & Siegert came to the same results in similar trials with buckwheat. *Vs. St.*, IV, p. 339.)

Later trials by Nobbe, Schröder and Erdmann, and by others, confirm the conclusion that sodium may be nearly or altogether dispensed with by plants.

The buckwheat represented in Plate I vegetated for 3 months in solutions as free as possible from sodium, with the exception of VI, in which sodium was substituted for potassium.

The experiments of Knop, Nobbe, Siegert and others, while they prove that much sodium is not needful to maize and buckwheat, do not, however, satisfactorily demonstrate that *a little sodium* 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 sodium 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 sodium to supply this substance to the plants in appreciable quantity.

To sum up, it appears from all the facts before us:

1. That sodium is never *totally* absent from plants, and 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 sodium that is not necessary to the plant; that is, in other words, accidental.

**Can Sodium replace Potassium?**—The close similarity of potassium and sodium, and the variable quantities in which the latter especially is met with in plants, have led to the assumption that one of these alkali-metals can take the place of the other.

Salm-Horstmar and Knop & Schreber first demonstrated that sodium cannot *entirely* take the place of potassium—that, in other words, potassium is indispensable to plant life. Plate I, VI, shows the development of buckwheat during 3 months, in Nobbe, Schröder & Erdmann's water-cultures, when, in a normal nutritive solution, potassium is substituted by sodium, as completely as is practicable.

Cameron concluded, from a series of experiments which it is unnecessary to describe, that, under natural conditions, sodium may *partially* replace potassium. 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 sodium, the latter almost destitute of this substance, but contained correspondingly more potassium. Two analyses of the ash of the beet, one by Wolff (1), the other by Way (2), exhibit similar differences:

| | *Asparagus.* | | *Field Beet.* | |
|---|---|---|---|---|
| | *Wild.* | *Cultivated.* | 1. | 2. |
| Potassium oxide | 18.8 | 50.5 | 57.0 | 25.1 |
| Sodium oxide | 16.2 | trace | 7.3 | 34.1 |
| Calcium oxide | 28.1 | 21.3 | 5.8 | 2.2 |
| Magnesium oxide | 1.5 | | 4.0 | 2.1 |
| Chlorine | 16.5 | 8.3 | 4.9 | 34.8 |
| Sulphur trioxide | 9.2 | 4.5 | 3.5 | 3.6 |
| Phosphorus 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 sodium, if any, is absolutely necessary to plant-life—that the sodium which appears to replace potassium is accidental, and that the replaced potassium 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.

**Alkalies in Strand and Marine Plants.**—The above conclusions apply also to plants which most commonly grow 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 comparative absence of sodium compounds.

The common saltworts, *Salsola,* and the samphire, *Salicornia,* are plants which, unlike those just mentioned, seldom stray inland. Göbel, who has analyzed 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 potassium oxide, and 30.3 per cent of sodium oxide, and in the *Salicornia herbacea* 2.6 per cent of potassium oxide and 36.4 per cent of sodium oxide, the sodium oxide 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.* Potassium 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 contained both sodium and potassium; from the seeds of this, sown also in garden soil, grew plants in which only potassium-salts with traces of sodium could be found. These strand-plants are occasionally found at a distance from salt-shores, and their growth as strand-plants appears to be due to their capacity for flourishing in spite of salt, and not from their requiring it. (*Hoffmann, Vs. St.*, XIII, p. 295.)

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 potassium in sea-water is but $\frac{1}{30}$ that of the sodium, it is yet a fact, as shown by the analyses of Forchhammer (*Jour. für Prakt. Chem.*, 36, p. 391) and Anderson (*Trans. High. and Ag. Soc.*, 1855–7, p. 349) that the ash of sea-weeds is, in general, as rich, or even richer, in potassium than in sodium. In 14 analyses, by Forchhammer, the average amount of sodium in the dry weed was 3.1 per cent; that of potassium 2.5 per cent. In Anderson's results the percentage of potassium is invariably higher than that of sodium.*

Analogy with land-plants would lead to the inference that the sodium of the sea-weeds is in a great degree accidental. In fact, *Fucus vesiculosis* and *Zygogonium salinum* have been observed to flourish in fresh water. (*Vs. St.*, XIII, p. 295.)

**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. According to Salm-Horstmar, *ferrous oxide*, FeO, is indispensable to the colza plant. (*Versuche, etc.*, p. 35.) Knop asserts that maize, which refuses to grow in entire absence of iron, flourishes when 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 ferric oxide 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

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*Doubtless due to the fact that the material used by Anderson was freed by washing from adhering common salt.

the analyses of the seeds of cereals, ferric oxide ranges from an unweighable trace to 2 and even 3%. In root crops it has been found as high as 5%. Kekule found in the ash of gluten from wheat 7.1% of ferric oxide. (*Jahresbericht der Chem.*, 1851, p. 715.) Schulz-Fleeth found 17.5% in the ash of the albumin from the juice of the potato tuber. The proportion of *ash* is, however, so small that in case of potato-albumin the ferric oxide amounts to but 0.12 per cent of the dry substance. (*Der Rationelle Ackerbau*, p. 82.)

In the ash of wood, and especially in that of bark, ferric oxide often exists to the extent of 5 to 10%. The largest percentages have been found in aquatic plants. In the ash of the duckweed (*Lemna trisulca*) Liebig found 7.4%. Gorup-Besanez found in the ash of the leaves of the *Trapa natans* 29.6%, and in the ash of the fruit-envelope of the same plant 68.6%. (*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 iron to be essential, because the larger share of it exists in the tissues as a brown powdery oxide which may be extracted by acids, and has the appearance of having accumulated there mechanically.

Doubtless a portion of the iron encountered in analyses of agricultural vegetation has never once existed within the vegetable tissues, but comes from the soil, which adheres with great tenacity to all parts of plants.

**Manganese is Unessential to Agricultural Plants.** Manganese is commonly much less abundant than iron, and is often, if not usually, as good as wanting in agricultural plants. It generally accompanies iron where the latter occurs in considerable quantity. Thus, in the ash of *Trapa*, the oxide $Mn_3O_4$ was found to the extent of 7.5–14.7%. Sometimes it is found in much larger quantity than oxide of iron ; e. g., C. Fresenius found

11.2% of oxide of manganese in ash of leaves of the red beech (*Fagus sylvatica*) that contained but 1% 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%.

In ash of the wood of the larch (*Larix Europæa*), Böttinger found 13.5% $Mn_3O_4$ and 4.2% $Fe_2O_3$, and in ash of wood of *Pinus sylvestris* 18.2% $Mn_3O_4$, and 3.5% $Fe_2O_3$. In ash of the seed of colza, Nitzsch found 16.1% $Mn_3O_4$, 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 analyzed, 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. Birner & Lucanus have demonstrated that manganese is not needful to the oat-plant, and cannot take the place of iron. (*Vs. St.*, VIII, p. 43.)

**Is Chlorine Indispensable to Crops?**—What has been written of the occurrence of sodium in plants appears to apply in most respects equally well to chlorine. In nature, 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 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 phosphates or silica, on prolonged exposure to a high temperature. In some of 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 leached 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 26 analyses of wheat by Way and Ogston, p. 150, is but 0.08%, it not being found at all in the ash of 21 samples. In Zoeller's later analyses chlorine is found in every instance, and averages 0.7%. In Lawes and Gilbert's numerous analyses of wheat-grain ash chlorine ranges from 0 to 1.14%, the average being 0.1%. In wheat-straw ash they found from 1.08 to 2.06%. The ash was in all cases prepared by burning at a low red heat.

Like sodium, 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 content of chlorine of any plant may be largely increased or diminished by supplying it to or withholding it from the roots.

As to the indispensableness of chlorine, we have somewhat conflicting data. Salm-Horstmar believed that a trace of it is needful to the wheat plant, though many of his experiments in reference to this element were unsatisfactory to himself. 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), presence of chlorine is essential to the perfection of the fruit.

Leydhecker came to the same conclusions as Nobbe and Siegert regarding the indispensableness of chlorine to the perfection of buckwheat. (*Vs. St.*, VIII, p. 177.)

On the other hand, Knop excludes chlorine from the list of necessary ingredients of maize, buckwheat, cress, and *Psamma arenaria*, having obtained a maize plant 3 feet high, bearing 4 ripe seeds, harvested 23 "chlorine-free seeds" from 5 buckwheat-plants, and raised 40 to 50 ripe seeds from more than one cress-plant, all grown without chlorine. (*Vs. St.*, XIII, p. 219.)

Wagner also obtained, in absence of chlorine, maize-plants 40 inches high, of 20 grams dry-weight. One of these ripened 5 small seeds, of which two were proved capable of germination; but none of these plants produced any pollen and they were fertilized with pollen from garden-plants. (*Vs. St.*, XIII, pp. 218–222.)

From a series of experiments in water-culture, Birner and Lucanus (*Vs. St.*, VIII, p. 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, pp. 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 (*Vs. St.*, VIII, p. 187) has produced normally developed vetch and pea plants, but only in solutions containing chlorine. Beyer (*Vs. St.*, XI, p. 262) found exclusion of chlorine in water-culture to prevent formation of seed in case of peas; the plants, after a month's healthy growth, produced new shoots only at the expense of the older leaves. In similar trials oats gave a small crop of ripe seeds when chlorine was not supplied. When, however, the seeds thus obtained nearly free from chlorine were vegetated in a solution destitute of this element they failed to produce seed again, though their growth and reproduction were normal when chlorine was furnished them in the nutritive solution.

In Plate I, X shows the extent to which, in Nobbe's cultures, buckwheat developed when vegetating for 3 months in a solution destitute of chlorine, but otherwise fully adapted to nourish plants.

In view of all the evidence, then, it would appear probable that chlorine is needful for the cereals, and that when the seed and nutritive media (soil or solution and air) are entirely destitute of this element fruit cannot be perfected. It is probable that in the cases where fruit was produced in supposed absence of chlorine this substance in some way gained access to the plants.

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.:

1. Chlorine is never *totally* absent.

2. If indispensable, but a minute amount is requisite for a very considerable vegetative development.

3. Some plants, as vetches and peas, require a not inconsiderable amount of chlorine for full development, especially of seed.

4. The foliage and succulent parts may include a large quantity of chlorine that is not indispensable to the life of the plant.

**Silica is not indispensable to Plants.**—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 1–3%, but is often found to the extent of 10–20%, or even 30%, especially in the pine. In leaves, it is usually more abundant than in stems. The ash of turnip leaves contains 3–10% ; of tobacco leaves, 5–18% ; of the oat, 11–58%. (Arendt, Norton.) In ash of lettuce, 20% ; of beech leaves, 26% ; in those of oak, 31% have been observed. (Wicke, *Henneberg's Jour.*, 1862, p. 156.)

The bark or cuticle of many plants contains an extraordinary amount of silica. The cauto tree of South America (*Hirtella silicea*) is most remarkable in this respect. Its bark is very firm and harsh, and is difficult to cut, having the texture of soft sandstone. It yields 34% of ash, and of this 96% is silica. (Wicke, *loc. cit.*, p. 143.)

Another plant, remarkable for its content of silica, is the bamboo. The ash of the rind contains 70%, and in the joints of the stem are often found concretions of hydrated silica, the so-called *Tabashir.*

The ash of the common scouring rush (*Equisetum hyemale*) has been found to contain 97.5% of silica. The straw of the cereal grains, and the stems and leaves of grasses, both belonging to the botanical family *Graminacœ*, are specially characterized by a large content of silica, ranging from 40–70% of the ash. The sedge and rush families likewise contain much of this substance.

The *position* of silica in the plant would thus appear to be, in general, at the surface. Although it is present in other parts of the plant, yet the *cuticle* is usually richest, especially where the content of silica is large. Davy, in 1799, drew attention to the deposition of silica in the cuticle of the grasses and cereals, and advanced the idea that it serves these plants an office of support similar to that enacted in animals by the bones.

In case of the pine (*Pinus sylvestris*), Wittstein has obtained results which indicate that the *age* of wood or bark greatly influences the content of silica. He found in ash of the—

| | | | | |
|---|---|---|---|---|
| Wood | of a tree, | 220 | years old, | 32.5% |
| " | " | 170 | " | 24.1 |
| " | " | 135 | " | 15.1 |

And in—

| | | | | |
|---|---|---|---|---|
| Bark | " | 220 | " | 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 plant, 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 deposited in or upon the cell-wall in such abundance 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 peculiar roughnesses of the stems or leaves are fully incrusted or interpenetrated by silica, and the ashes of the cuticle present the same appearance under the microscope as the cuticle itself.

The hairs of nettles, hemp, hops, and other rough-leaved plants, are highly silicious.

According to Wicke, the beech owes the smooth and undecayed surface which its trunk presents, to the silica of the bark. The best textile materials, which are bast-fibers of various plants, viz., common hemp, Manila hemp (*Musa textilis*), aloe-hemp (*Agave Americana*), common flax, and New Zealand flax (*Phormium tenax*) are incrusted with silica. In jute (*Corchorus textilis*) some cells are partially incrusted. The cotton fiber is free from silica. Wicke (*loc. cit.*) suggests that the durability of textile fibers is to a degree dependent on their content of silica.

Sachs, in 1862, was the first to publish evidence 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% of silica. Shortly afterwards, Knop produced a maize plant with 140 ripe seeds, and a dry-weight of 50 grammes (nearly 2 oz. av.) 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 15 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 & Ogston had found in the ash of field-grown maize, leaf and stem together, 27.98 per cent of silica.

In the numerous experiments that have been made more recently upon the growth of plants in aqueous solutions, by Sachs, Knop, Nobbe & Siegert, Stohmann, Rautenberg & Kühn, Birner & 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 & 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.

Wolff (*Vs. St.*, VIII, p. 200) obtained in the ash of maize thus cultivated, 2 to 3% of silica, while the same two varieties from the field contained in their ash 11½ to 13%. The proportion of ash was essentially the same in both cases, viz., about 6%. Wolff's results with the oat plant were entirely similar.

Birner & Lucanus (*Vs. St.*, VIII, p. 141) found that the supply of soluble silicates to the oat made its ash very rich in silica (40%) but diminished the growth of straw, without affecting that of the seed, as compared with plants nearly destitute of silica.

It is thus made certain that plants ordinarily rich in silica may attain a high development in absence of this substance. We shall see later, however (p. ), that silica is probably not altogether useless to plants when they grow under ordinary conditions.

Jodin reports having bred maize by water-culture, with the utmost practicable exclusion of silica, for four generations—whereby this substance was reduced to the merest traces—without interference with the normal development of the plant. (*Ann. Agron.*, IX, p. 385.)

**The Ash-Ingredients, which are Indispensable to Crops, may be taken up in Larger Quantity than is Essential.**—More than eighty 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 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. 164), 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. 192 and 194 in regard to potassium and iron.)

As further striking instances of the influence of the nourishing medium on the quantity of ash-ingredients in the plant, the following are adduced, which may serve to put in still stronger light the fact that a plant does not always require what it contains.

Nobbe & 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, phosphate and nitrate of potassium, with phosphate of iron, which together constituted 0.316% 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 but $\frac{1}{6}$ as much dry matter. The *seeds,* however, are scarcely different in composition.

Similar results were obtained by Councler with the leaves of *Acer negundo* (*Vs. St.*, XXIX, p. 242), 1,000 parts of the perfectly dry leaves contained :

| | *Water-plant.* | *Soil-plant.* |
|---|---|---|
| Silica, $SiO_2$, | 8.51 | 23.72 |
| Sulphuric oxide, $SO_3$, | 38.97 | 9.69 |
| Phosphoric oxide, $P_2O_5$, | 26.00 | 4.56 |
| Iron oxide, $Fe_2O_3$, | 1.94 | 1.22 |
| Magnesium oxide, MgO, | 7.56 | 6.25 |
| Calcium oxide, CaO, | 31.77 | 36.17 |
| Sodium oxide, $Na_2O$, | 1.23 | 0.88 |
| Potassium oxide, $K_2O$, | 96.92 | 45.05 |
| | 212.90 | 127.54 |

Leaves of the water-plant are much richer in ash-ingredients, especially in sulphate and phosphate of potassium. Those of the soil-plant contain more silica and lime.

**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 alkali chlorides, sulphates, carbonates, and phosphates, the chlorides of calcium and magnesium, 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, 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 Veg.*, p. 265.)

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 15 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 oxide of iron. (*Recherches*, p. 287.)

Ritthausen has shown that clover which lies exposed to rain after being cut may lose by washing more than one-half 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 vegetation.

3. The 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.

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, phosphate of magnesium exists in comparatively large quantity. In the dense teak wood, concretions of calcium phosphate have been noticed. Of a certain species of cactus (*Cactus senilis*) 80% of the dry matter consists of crystals of calcium oxalate and phosphate.

That the quantity of matters thus segregated is in some degree proportionate to the excess of them in the nourishing medium in which the plant grows has been observed by Nobbe & Siegert, who remark that the two portions of buckwheat, cultivated by them in solutions and in garden-soil respectively (p. 203), both contained crystals and globular crystalline masses, consisting probably of calcium and magnesium oxalates, and phosphates, deposited in the rind and pith; *but that these were by far most abundant in the water-plants whose ash-percentage was twice as great as that of the garden-plants.*

These insoluble substances may be either entirely unessential, 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 in reality 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.

Fig. 23.

The occurrence of crystallized salts thus segregated in the cells of plants is illustrated by the following cuts. Fig. 23 represents a crystallized concretion of calcium oxalate, having a basis or skeleton of cellulose, from a leaf of the walnut. (Payen, *Chimie Industrielle, Pl.* XII.) Fig. 24 shows a mass of crystals of the same salt, from the leaf stem of rhubarb. Fig. 25 illustrates similar crystals from the beet root. In the root of the young bean, Sachs found a ring of cells, containing crystals of sulphate of lime. (*Sitzungsberichte der Wien. Akad.*, 37, p. 106.) Bailey observed in certain parts of the inner bark of the locust a series of cells, each of which contained a crystal. In the onion-bulb, and many other plants, crystals are abundant. (*Gray's Botanical Text-Book*, 6th ed., Vol. II, p. 52.)

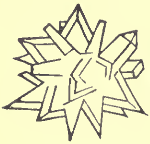

Fig. 24.

Fig. 25.

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 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 *Saxifraga crustata*, a low European plant, which is found in lime soils. The leaves of this saxifrage are entirely coated with a scaly incrustation of calcium and magnesium carbonates. At the edges of the leaf this incrustation acquires a considerable thickness, as is illustrated by figure 26, *a*. In an analysis made by Unger, to whom these facts are due, the fresh (undried) leaves yielded to a dilute acid 4.14% of calcium carbonate, and 0.82% of magnesium carbonate.

Unger learned by microscopic investigation that this excretion of carbonates proceeds mostly from a series of granular expansions at the margin of the leaf, which are directly connected with the sap-ducts of the plant. (*Sitzungsberichte der Wien. Akad.*, 43, p. 519.)

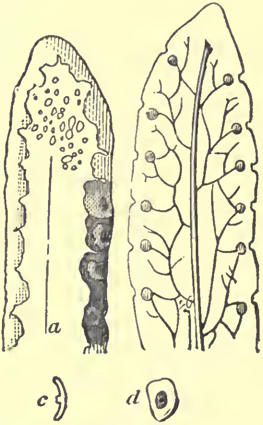

Fig. 26.

In figure 26, *a* represents the appearance of a leaf, magnified 4½ diameters. Around the borders are seen the scales of carbonates; some of these have been detached, leaving round pits on the surface of the leaf: *c*, *d* exhibit the scales themselves, *e* 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 carbonates chiefly take, in their passage through the plant.

**Further as to the state of ash-ingredients.**—It is by no means true that the ash-ingredients always exist in plants in the forms under which they are otherwise familiar to us.

Arendt and Hellriegel have studied 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 in water.* He found that all the sulphuric acid and all the chlorine were soluble. Nearly all the phosphoric acid was removed by water. The larger share of the calcium, magnesium, sodium and potassium compounds was soluble, though portions of each escaped solution. Iron was found in both the soluble and insoluble state. In the leaves, iron was found among the insoluble matters after all phosphoric acid had been removed. Finally, 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. See, also, table on p. 171).

Weiss and Wiesner discovered by microchemical investigation that iron exists as insoluble ferrous and ferric compounds both in the cell-membrane and in the cell-contents. (*Sitzungsberichte der Wiener Akad.*, 40, 278.)

Hellriegel found that in young clover a larger proportion of the various bases was soluble than in the mature plant. As a rule, the leaves gave most soluble matters, the leaf stalks less, and the stems least. He obtained,

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* To extract the soluble parts of the grain in this way was impossible.

among others, the following results (*Vs. St.*, IV, p. 59):

Of 100 parts of the following fixed ingredients of clover, were dissolved in the sap, and not dissolved—

| | | *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 oxide, $P_2O_5$ | 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—bodies, all of whose commonly-occurring compounds, silicates excepted, are readily soluble in water—enter into insoluble combinations in the plant; while phosphoric acid, which forms insoluble salts with calcium, magnesium, and iron, is freely soluble in connection with these bases in the sap.

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 oxide ($SO_3$) formed nearly 7% 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 to 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 oxide, would have amounted to 14%

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 oxide, would have made 13.7% of the fixed ingredients, or one per cent of the dry leaf itself.*

**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 *Titanium* is a necessary ingredient of plants. The later results of water-culture would appear to demonstrate that these conclusions are erroneous.

The rare alkali-metal, *Rubidium*, has been found in the sugar-beet, in tobacco, coffee, tea, and the grape. It doubtless occurs, perhaps together with the similar *Caesium* in many other plants, though always in very minute quantity. Birner and Lucanus found that these bodies, in the absence of potassium, acted as poisons to the oat. (*Vs. St.*, VIII, p. 147.)

According to Nobbe, Schroeder and Erdmann, *Lithium* is very injurious to buckwheat, even in presence of potassium. When lithium was substituted for two-thirds of the potassium of a normal nutritive solution, buckwheat vegetated indeed for 3 months, the stem reaching a length of 18 inches, but the plant was small and unhealthy, the leaves were pale and the older ones dropped away, as shown by VIII, plate I. (*Vs. St.*, XIII, p. 356).

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* *Arendt* was the first to estimate sulphuric oxide ($SO_3$) in vegetable matters with accuracy, and to discriminate it from the sulphur of organic compounds. This chemist separated 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 sulphuric oxide from the total he obtained as a difference that portion of sulphur which belonged to the albuminoids, etc. In his analysis 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 sulphuric oxide.

The investigations of A. Braun and of Risse (Sachs, *Exp. Physiologie,* 153) show that *Zinc* is a usual ingredient 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 produced by, such soils, viz., a violet (*Viola tricolor, var. calaminaris*), and a shepherd's purse (*Thlaspi alpestre, var. calaminaris*). In the ash of the leaves of the latter plant, Risse found 13% of oxide of zinc; in other plants he found from 0.3 to 3.3%. These plants, however, grow equally well in absence of zinc, which may slightly modify their appearance, but is unessential to their nutrition.

*Boron* as boric acid has recently been found in many wines of California and Europe.

*Copper* is often or commonly found in the ashes of plants; and other elements, viz., *Arsenic, Barium* and *Lead,* have been discovered therein, but as yet we are not warranted in assuming that any of these substances are of importance to agricultural vegetation. The soluble compounds of copper, arsenic and lead are in fact very injurious to plant life, unless very highly diluted.

*Iodine,* an invariable and probably a necessary constituent of many algæ, is not known to exist to any considerable extent or to be essential in any cultivated plants.

## § 4.

### FUNCTIONS OF THE ASH-INGREDIENTS.

Although much has been written, little is certainly known, with reference to the subject of this section.

**Sulphates.**—The albuminoids, which contain sulphur as an essential ingredient, obviously cannot be produced in absence of sulphates, which, so far as we know, are the exclusive source of sulphur to plants. The sulphurized oils of the onion, mustard, horse-radish, turnip, etc., likewise require sulphates for their organization.

**Phosphates.**—The phosphorized substances (*protagon, lecithin, chlorophyl*) require to their elaboration that phosphates be at the disposal of the plant. Knop has shown that hypophosphites cannot take the place of phosphates. The albuminoids which are probably 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. The di- and tri-potassic phosphates dissolve or form water-soluble compounds with many albuminoids, and, according to Schumacher (*Physik der Pflanze*, p. 128), considerably increase the diffusive rate of these bodies, and thus facilitate their translocation in the plant.

**Potassium.**—The organic acids, viz., oxalic, malic, tartaric, citric, etc., require potassium to form the salts of this metal, which exist abundantly in plants, e. g., potassium oxalate in sorrel, potassium bitartrate in the grape, potassium malate in garden rhubarb; and without potassium it is in most cases probably impossible for the acids to accumulate or to be formed. Mercadante cultivated sorrel (*Oxalis acetosella* and *Rumex acetosa*), in absence of potassium-salts; sodium, calcium, and magnesium being supplied. The plants failed to fructify, and their juices contained but one-eighth as much free acid (or acid salts?) as exists in the sap of the same kind of plants vegetating under normal conditions. The acids—oxalic, with a little tartaric—were united to calcium (*Berichte*, 1875, II, p. 1200). The organic acids may result from the decomposition of carbhydrates (starch or sugar), or they may be preliminary stages in the production of the carbhydrates. In either case their formation is an index to the constructive processes by which the plant originates new vegetable substance and increases in dry weight. Mercadante's observations are therefore in accord with the results of the investigations next to be considered.

In 1869, Nobbe, Schröder, and Erdmann employed the method of water-culture to make an elaborate study of the influence of potassium on the vegetative processes, and found that, all other needful conditions of growth being supplied, in absence of potassium buckwheat plants vegetated for three months without any increase in weight—that is to say, without producing new vegetable matter. Examination of these miniature plants demonstrated that (in absence of potassium) the first evident stage in the production of vegetable substance, viz., *the appearance of starch in the chlorophyl granules* of the leaf, could not be attained. The experimenters therefore drew the conclusion that potassium is an essential factor in the assimilation of carbon and the formation of starch. They found that the plants were able to *produce* starch when potassium was supplied either as chloride, nitrate, phosphate or sulphate. The *transfer* of the starch from the leaves to the fruit, or its conversion into a soluble form, appeared to require the presence of chlorine; accordingly, potassium chloride gave the best developed plants, especially at the period of fructification. This conclusion was greatly strengthened by the observation, repeatedly made, that the miniature plants which had vegetated for three or four weeks without increase of weight, or growth other than that which the seedling can make at the expense of the seed, began at once, on suitable addition of potassium chloride to the nutritive solution, to form starch, discoverable in all the chlorophyl granules, and thenceforward developed new stems and leaves and grew in quite the normal manner. In Plate I the appearance of some of the plants produced in these trials is shown. Ia represents the average plant raised in the normal solution containing abundance of potas-

PLATE I.

EXPLANATION. (See p. 212.)

Water-cultures of Japanese Buckwheat, supplied with the ingredients of a *Normal Solution*, viz.: Sulphates, Nitrates, Phosphates and Chlorides of Potassium, Magnesium, Calcium and Iron, except as stated below.

I and Ia. Solution normal. Potassium as Chloride.
II. Solution without Potassium.
$\text{II}_3$. Without Potassium for 4 weeks, thereafter Potassium Chloride.
III. Potassium as Nitrate. Chlorine as in Normal.
IV. Potassium as Sulphate. Chlorine one-fourth of Normal.
V. Potassium as Phosphate. Chlorine one-fifth of Normal.
VI. Sodium but not Potassium.
VIII. Lithium.
IX. Without Calcium.
X. Without Chlorine.
XI. Without Nitrogen.

The meter-scale (39⅜ inches) serves to measure the dimensions of the plants.

PLATE II.

EXPLANATION. (See p. 213.)

Water-cultures of Flowering Bean after vegetating 38 days.

a. In normal solution, seed with cotyledons.

b. In normal solution, seed without cotyledons.

c. In potassium-free solution, seed with cotyledons.

d. In potassium-free solution, seed without cotyledons.

sium chloride. II was deprived of potassium save that contained in the seed. In IV and V, respectively, the chlorine of the solution was reduced to one-fourth and one-fifth the amounts contained in the normal solution and replaced by sulphuric acid in IV and by phosphoric acid in V. In case of $II_3$, the plant vegetated without potassium for four weeks with a result similar to II, and then for two months was supplied with potassium chloride. For numerous interesting details reference must be made to the original paper (*Vs. St.*, XIII, pp. 321–424).

Lüpke, from water-cultures with the flowering bean *Phaseolus multiflorus*, and common bean *P. vulgaris*, has recently arrived at different conclusions. He finds that these plants are able, under the utmost possible exclusion of potassium, to assimilate carbon and produce starch, in fact to grow and to carry on all the vegetative functions that belong to the fully-nourished plant, though on a diminished scale. In order to limit the supply of potassium to the utmost, the cotyledons of some of the plants were cut away when the plumule began to appear above them. In this way 90% of the potassium of the seed was removed* and while the plants were thereby reduced in dimensions, their power to vegetate in a healthy manner was not suppressed. After 65 days of vegetation one of these plants yielded a crop of dry-substance 4.8 times as much as was contained in the newly sprouted seedling after excision of the cotyledons.

Some results of these cultures are shown in Plate II. The stem of the unmutilated flowering bean in normal solution I, a, reached a final length of 80 inches, that deprived of potassium grew to 40 inches.

Nobbe's conclusion that potassium is specifically essential or concerned in starch-production is accordingly erro-

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* Lüpke found that one seed of *P. multiflorus* contained 23 milligrams of potassium oxide; the seedling, after cutting off the cotyledons, contains 2.3 mm.

neous. As Lüpke remarks, potassium is rather like nitrogen, phosphorus, sulphur, etc., one of the elements of which probably a certain quantity is indispensable to the formation of every vegetable cell. Nobbe's results perhaps indicate that buckwheat requires relatively more potassium than the bean for its processes of growth. (*Land. Jahrbücher*, 1888, pp. 887–913.)

**Calcium.**—Böhm (*Jahresbericht über Ag. Chemie*, 1875–6, Bd. I, p. 255) and Von Raumer (*Vs. St.*, XXIX, 251) have furnished evidence that calcium (lime) is directly necessary to the formation of cell-tissue, that is to say, of cellulose.

This evidence rests upon observations made with seedlings of the flowering bean (scarlet-runner), *Phaseolus multiflorus*. When a seed sprouts, the young plant at first is nourished exclusively by the nutritive matters contained in the seed. When its roots enter the soil it begins to derive water, nitrogen, and ash-ingredients from the earth. When its leaves unfold in the *light* it begins to gather carbon from the air and to increase in weight. If its roots are placed in pure water it can acquire no ash-ingredients; if its leaves are kept in darkness it can gain nothing from the air. Thus circumstanced, it may live and vegetate for a time, but constantly loses in total dry weight, and its apparent growth is only the formation of new parts at the expense of the old. For some days the young stem shoots upward without green color, but perfectly formed, and then (in case of the flowering bean) suddenly, at a little space below the terminal bud, a discoloration appears, the stem wilts, withers, and dies away. The growth of stem that thus occurs is accompanied by and depends upon the solution of starch in the seed-lobes and its transfer to the points of growth where it is made over into cellulose—the frame-work of the stem. In absence of any external source of ash-ingredients the young stem dies long before the starch of the cotyledons is consumed. But if the roots be placed in a nutritive solution suited to water-culture, the stem grows on without injury until the cotyledons are completely emptied of starch, and afterwards continues to develop at the expense of the lower leaves.

The arrest of growth in the stem evidently is due to the absence of some one or more ash-ingredients, and Böhm found in fact that, by withholding lime-salts from the roots, this characteristic malady was invariably produced. Hence he concludes that calcium compounds are immediately concerned in the conversion of starch into cellulose.

**Magnesium.**—Von Raumer, in the paper just referred to (*Vs. St.*, XXIX, pp. 263 and 273), gives his observations on the relations of the magnesium salts to the vegetative processes. He states that, all other conditions being favorable, the exclusion of magnesium from a nutritive solution in which the scarlet-runner vegetates is followed by cessation of chlorophyl-production and of that enlargement of the new-formed cells wherein the act of growth largely consists. Accordingly, in absence of magnesium-supply, the plants, which at first grew normally, after reaching a height of forty inches, began to show signs of disturbed nutrition. The uppermost internodes (joints) of the stems almost ceased to lengthen and became exceptionally thick and hard, their leaves failed to open, and both joints and leaves were white in color with but the faintest tint of green. Soon new upward growth ceased altogether, the terminal bud and unfolded leaves dried away, and, while the lower, first-formed and green leaves remained fresh for weeks and the lower stem threw out new shoots, healthy growth was at a stand-still, and the plants gradually withered and perished. The normal growth of the bean plants for a month or more in nutritive solutions containing no magnesium is accounted for by the supply of this element existing in the seed,* which evidently was enough for the necessities of growth until the stem was forty inches high. From that point on the plants almost ceased to grow, and gradually died from want of food and inability to assimilate.

We have already seen that, according to Hoppe-Seyler, magnesium is a constant and presumably an essential ingredient of chlorophyllan, a crystallized derivative of chlorophyl. This makes evident that magnesium is directly concerned in and needful to the formation of the chlorophyl granules which, so far as observation as yet has gone, are the seat of those operations which first construct organic substance from inorganic matter.

Magnesium and calcium occur in the aleurone of seeds and, according to Grübler, form soluble, crystallizable compounds with certain albuminoids, so that these elements, like potassium, may be concerned in the transport of protein-bodies.

**Silica.**—Humphrey Davy was the first to suggest that the function of silica might be, in case of the grasses, sedges, and equisètums, to give rigidity to the slender stems of these plants, and enable them to sustain the often heavy weight of the fruit.

The results of the many experiments in water-culture by Sachs, Knop, Wolff, and others (see p. 200), 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, prove in the most conclusive manner, however, 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.

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*Common beans contain about one-fourth of one per cent of magnesia.

The "lodging" of cereal crops is demonstrated to result from too close a stand and too little light, which occasion a slender and delicate growth, and is not perceptibly influenced by presence or absence of silica. Silica, however, if not necessary to the life of the cereals, appears to have an important office in their perfect development under ordinary circumstances. Kreuzhage and Wolff have carefully studied the relations of silica to the oat plant, using the method of water-culture. In a series of nine trials in 1880, where, other things being equal, much silica, little silica, and no silica were supplied, the numbers of seeds produced were 1,423, 1,039, and 715 respectively, the corresponding weights being 46, 34, and 23 grams. The total crops weighed 196, 172, and 168 grams respectively, so that while the yield of seed was doubled in presence of abundant silica, the total crop (dry) was increased in weight but one-sixth. The supply of silica was accompanied with an absolutely diminished root-formation as well as by a relatively increased seed-production. Similar trials in 1881 and 1882 gave like results (*Vs. St.*, XXX, p. 161). Wolff concludes that silica ensures the timely and uniform ripening of the crop as well as favors the maximum development of seed.

The natural supply of silica appears to be always sufficient. Application of this substance in fertilizers has never proved remunerative. In those water-cultures where large seed-production has been obtained in absence of silica, it is probable that lime-salts, phosphates, or other ash-ingredients, which are commonly taken up more abundantly than in field culture, have brought about the same result that silica usually effects. This action of the ash-ingredients is apparently due to a clogging of the cell-tissues and consequent check of the processes of growth and would seem to be caused either by the otherwise unessential silica or by an excess of the ingredients essential to growth. The hard, dense coat of the seed of the common weed "stone-crop" (*Lithospermum*) usually contains some 13 to 20 per cent of silica and twice that amount of calcium carbonate. Höhnel produced these seeds in water-culture from well-grown plants deprived of silica and found them quite normally developed. The seed-coat was permeated with calcium carbonate, which appears to have fully replaced silica without detriment to the plant (*Haberlandt, Untersuchungen,* II, p. 160).

**Chlorine.**—As has been mentioned, both Nobbe and Leydhecker found that buckwheat grew quite well up to the time of blossom without chlorides. From that period on, in absence of chlorides, 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 much extent, but is transferred to the newer organs, and especially to the fruit, where it often accumulates in large quantities. In absence of chlorides in 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. 196). Knop (*Chem. Centralblatt*, 1869, p. 189) obtained some ripe, well-developed buckwheat seeds in chlorine-free water-cultures, while in the same solutions, with addition of chlorides, other buckwheat plants remained sterile, the flowers withering without setting seed. Knop states that in other trials maize and bean plants grew better without than with chlorides. In either case starch did not accumulate in the stem or leaves of maize, while all the organs of the bean were overloaded with starch both in presence and absence of chlorides.

The experiments of Nobbe and Leydhecker are very circumstantially described and have been confirmed by the later work of Nobbe, Schröder, and Erdmann (*Vs. St.*, XIII, pp. 392–6). See p. 196.

**Iron.**—We are in possession of some interesting facts, which throw light upon the function of this metal in the plant. In case of the deficiency of iron, foliage loses its natural green color, 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 showed (1849) that plants which grow in soils or media destitute of iron are very pale in color, 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 afterward perfectly white leaves unfolded. On adding a few drops of sulphate or chloride of iron 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 color 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 color where it was previously wanting. By microscopic studies he found that, in the absence of iron, the protoplasm of the leaf-cells remains a colorless or yellow mass, destitute of visible organization. Under the influence of iron, grains of *chlorophyl* begin at once to appear, and pass through the various stages of normal development. We know that the power of the leaf to decompose carbon dioxide and assimilate carbon resides in the cells that contain chlorophyl, or, we may say, in the chlorophyl-grains themselves. We understand at once, then, that in the absence of iron, which is essential to the formation of chlorophyl, there can be no proper growth, no increase at the expense of the external atmospheric food of vegetation.

Risse, under Sachs's direction (*Exp. Physiologie*, p. 143), demonstrated that *manganese* cannot take the place of iron in the office just described.

## CHAPTER III.

### § 1.

### QUANTITATIVE RELATIONS AMONG THE INGREDIENTS OF PLANTS.

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 or basic metals might displace each other in equivalent quantities, i. e., in the ratio of their molecular or atomic 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, carbonate of magnesium was present; in that of Mont La Salle, it was absent. In the former existed but half as much carbonate of potassium as in the latter. In both, however, the same total percentage of carbonates was found, and the amount of oxygen in the 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 oxides, in the case in question, really replaced each other in equivalent proportions. The same was true for the ash 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 analyses.

**Relation of Phosphates to Albuminoids.**—Liebig likewise considered that a definite relation exists between the phosphoric acid and the albuminoids of the ripe grains. That this relation is not constant is evident from the following statement of data bearing on the question. In the table, the amount of nitrogen (N), representing the albuminoids (see p. 113), found in various analyses of rye and wheat grain, is compared with that of phosphoric acid ($P_2O_5$), the latter being taken as unity. The ratios of $P_2O_5$ to N were found to range as follows:

| | | | | | | $P_2O_5$. N. |
|---|---|---|---|---|---|---|
| In | 7 | Samples | of | Rye-kernel by | Fehling & Faiszt | 1 : 1.97—3.06 |
| " | 11 | " | " | " | Mayer | 1 : 2.04—2.38 |
| " | 5 | " | " | " | Bibra | 1 : 1.68—2.81 |
| " | 6 | " | " | " | Siegert | 1 : 2.35—2.96 |
| " | 28 | " | " | " | the extreme range was from | 1 : 1.68—3.06 |
| " | 2 | " | " | Wheat-kernel by | Fehling & Faiszt | 1 : 2.71—2.86 |
| " | 11 | " | " | " | Mayer | 1 : 1.83- -2.19 |
| " | 2 | " | " | " | Zoeller | 1 : 2.02—2.16 |
| " | 30 | " | " | " | Bibra. | 1 : 1.87—3.55 |
| " | 6 | " | " | " | Siegert | 1 : 2.30—3.33 |
| " | 51 | " | " | " | the extreme range was from | 1 : 1.83—3.55 |

Siegert, who collected these data (*Vs. St.*, III, p. 147), and who experimented on the influence of phosphatic and nitrogenous fertilizers upon the composition of wheat and rye, gives as the general result 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, etc., have proved fruitless.

It is much rather demonstrated that the proportion of the constituents is 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 genetic relations between phosphates and albuminoids, or between starch and alkalies, as Liebig first suggested and as various observers have labored 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.

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 chemistry 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) 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 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 Prof. John Pitkin Norton, of Yale College. His laborious research published in 1846 (*Trans. Highland and Ag. Soc.*, 1845–7, also *Am. Jour. of Sci. and Arts*, Vol. 3, 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 analytic 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 labors the subjoined figures and conclusions are due.

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. |
| 2d Period | June 30, | (12 days), Arendt—Shortly before full heading. |
| | “ 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— “ “ |
| 5th Period | July 31, | (10 days), Arendt—Fully ripe. |
| | Aug. 6, | ( 9 days), Bretschneider—Fully ripe. |

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 analyze a uniform material (see p. 171), 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.

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* *Das Wachsthum der Haferpflanze, Leipzig*, 1859.

† *Wachsthumsverhältnisse der Haferpflanze, Jour. für Prakt. Chem.*, 76, 193.

**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 | " | 16,623 " | " |
| 4th | " | 14,981 " | " |
| 5th | " | 10,622 " | " |

**The Total Weights of Water and Dry Matter** for all but the 2d Period—the material of which was accidentally lost—were:

TABLE II.—*Bretschneider.*

| | *Dry Matter,* lbs. av. per acre. | *Water,* lbs. av. per acre. |
|---|---|---|
| 1st Period, | 1,284 | 5,074 |
| 2d & 3d " | 4,383 | 12,240 |
| 4th " | 5,427 | 9,554 |
| 5th " | 6,886 | 3,736 |

1.—From Table I it is seen: That the weight of the live crop is greatest at or 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

3.—The loss after the 3d 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, | (58 days), | 1,284 Gain. | 5,074 Gain. |
| 2d & 3d " | (19 days), | 3,099 " | 7,166 " |
| 4th " | (20 days), | 1,044 " | 2,686 Loss. |
| 5th " | ( 8 days), | 1,459 " | 5,818 " |

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*In Arendt's Experiment, at the time of "heading out" 3d Period.

On dividing the above quantities by the number of days of the respective periods, there results:

**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. |
| 2d & 3d " | 163 " " | 377 " " |
| 4th " | 52 " " | 134 " Loss. |
| 5th " | 162 " " | 646 " " |

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 (Organic Matter), 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 |
| 2d & 3d " | 2,137 | 286 | 1,575 | 122 | 263 |
| 4th " | 2,600 | 343 | 2,043 | 150 | 291 |
| 5th " | 3,229 | 405 | 2,713 | 167 | 372 |

**Amounts of Carbon, Hydrogen, Oxygen, Nitrogen, and Ash-ingredients** assimilated by the oat-crop during the several periods. Water of vegetation is not included (*lbs. per acre*):

TABLE VI.—*Bretschneider.*

| | *Carbon.* | *Hydrogen.* | *Oxygen.* | *Nitrogen.* | *Ash-ingredients.* |
|---|---|---|---|---|---|
| 1st Period, | 593 | 80 | 455 | 46 | 110 |
| 2d & 3d " | 1,544 | 206 | 1,575 | 76 | 153 |
| 4th " | 453 | 57 | 468 | 28 | 28 |
| 5th " | 629 | 62 | 670 | 17 | 81 |

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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 unburned plant.

**Relative Quantities of Carbon, Hydrogen, Oxygen, Nitrogen (Organic Matter) and Ash** in the dry oat-crop, at the end of the several periods (*per cent*) :

TABLE VII.—*Bretschneider.*

| | *Carbon.* | *Hydrogen.* | *Oxygen.* | *Nitrogen.* | (*Organic Matter.*) | *Ash.* |
|---|---|---|---|---|---|---|
| 1st Period, | 46.22 | 6.23 | 35.39 | 3.59 | 91.43 | 8.57 |
| 2d & 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 |

**Relative Quantities of Carbon, Hydrogen, Oxygen, and Nitrogen,** in dry substance, after deducting the somewhat variable amount of ash (*per cent*) :

TABLE VIII.—*Bretschneider.*

| | *Carbon.* | *Hydrogen.* | *Oxygen.* | *Nitrogen.* |
|---|---|---|---|---|
| 1st Period, | 50.55 | 6.81 | 38.71 | 3.93 |
| 2d & 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, VII, and VIII, 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 carbhydrates and less albuminoids.

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 IX.—*Bretschneider.*

| | *Carbon.* | *Nitrogen.* | *Hydrogen.* | *Oxygen.* |
|---|---|---|---|---|
| 1st Period, | 100 | 7.8 | 13.4 | 73.6 |
| 2d & 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 IX 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 1st, 2d, and 3d Periods, but increases remarkably from the time 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 similar to that at which the fixed matters (ash) are absorbed. In the first period Nitrogen and Ash; in the 4th Period, Nitrogen and Oxygen; in the 5th Period, Oxygen and Ash are assimilated in largest proportion.

This is made evident by calculating for each period *the relative average 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 X.—*Bretschneider.*

| | *Carbon.* | *Hydrogen.* | *Oxygen.* | *Nitrogen.* | *Ash.* |
|---|---|---|---|---|---|
| **1st Period,** | **0.31** | **0.33** | **0.28** | **0.47** | **0.50** |
| **2d and 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 5th over the 4th 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 ($CO_2$, $H_2O$, $NH_3$, $N_2O_5$) is lost.

The following statement exhibits the *absolute average daily increase of Carbon, Hydrogen, Oxygen, Nitrogen, and Ash,* during the several periods (*lbs. per acre*):

TABLE XI.—*Bretschneider.*

| | *Carbon.* | *Hydrogen.* | *Oxygen.* | *Nitrogen.* | *Ash.* |
|---|---|---|---|---|---|
| 1st Period, | 10.0 | 1.4 | 7.8 | 0.8 | 1.9 |
| 2d and 3d " | 81.0 | 10.8 | 83.0 | 4.0 | 8.0 |
| 4th " | 22.6 | 2.9 | 23.4 | 1.4 | 1.4 |
| 5th " | 70.0 | 6.9 | 74.4 | 1.9 | 9.0 |

Turning now to Arendt's results, which are carried more into detail than those of Bretschneider, we will notice:

*A.*—**The Relative** (*percentage*) **Composition of the Entire Plant and of its Parts*** during the several periods of vegetation.

1. *Fiber* † is found in greatest proportion—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 fiber, the quantity of this substance regularly diminishes, not absolutely, but only relatively, as the plant becomes older, sinking from 27 per cent at heading to 12 per cent at maturity. In the leaves, which, as regards fiber, stand intermediate between the stem and ear, this

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*Arendt selected large and well-developed plants, divided them into six parts, and analyzed 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. 45.

substance ranges from 22 to 38 per cent. Previous to blossom, the upper leaves, afterwards the lower leaves, are the richest in fiber. 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 fiber is due in all cases to increased production of other ingredients.

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 during the latter stages of its growth. The range is from 0.2 to 3 per cent. In the ear the proportion increases from 2 to 3.7 per cent. In the leaves the quantity is much larger and is mostly wax with little fat. 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.

3. *Non-nitrogenous matters*, *other than fiber*, viz., *starch*, *sugars*, *gums*, etc.,* 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 |

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* What remains after deducting fat and wax, albuminoids, fiber and ash, from the dry substance, is here included.

† Calculated by multiplying the percentage of nitrogen by 6.33.

These differences may be variously accounted for. They are due, in part, to the fact that Arendt analyzed only 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.

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 fluctuations (relative) in the content 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.<br>3.74 | Lower leaves.<br>2.39 | Upper leaves.<br>2.27 | Ears.<br>2.85 | Ears.<br>3.04 |
| Lower leaves.<br>3.38 | Upper leaves.<br>2.19 | Lower leaves.<br>2.18 | Upper leaves.<br>1.91 | Upper leaves.<br>1.74 |
| Lower leaves.<br>2.15 | Ears.<br>2.06 | Ears.<br>1.85 | Lower leaves.<br>1.62 | Upper stem.<br>1.56 |
| | Middle stem.<br>1.52 | Upper stem.<br>1.34 | Upper stem.<br>1.60 | Lower leaves.<br>1.43 |
| | Upper stem.<br>0.87 | Middle stem.<br>0.98 | Middle stem.<br>1.20 | Middle stem.<br>1.17 |
| | Lower stem.<br>0.80 | Lower stem.<br>0.88 | Lower stem.<br>0.83 | Lower stem.<br>0.79 |

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 |

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

*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 alternate columns the *total weights of* 1,000 *plants at the end* of the several periods, and (by subtracting the first from the second, the second from the third, etc.) 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,

## 1,000 ENTIRE OAT PLANTS. (*Water Free.*)

| | Take up or produce during | Contain at end of | Absorb or produce during | Contain at end of | Absorb or produce during | Contain at end of | Absorb or produce during | Contain at end of | Absorb or produce during |
|---|---|---|---|---|---|---|---|---|---|
| | PERIOD I. | PERIOD II. | | PERIOD III. | | PERIOD IV. | | PERIOD V. | |
| | (3 leaves open.) | (Heading out.) | | (Blossomed.) | | (Beginning to ripen.) | | | |
| Fiber, | 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-nitro. 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 oxide, | 1.06 | 2.71 | 1.65 | 2.68 | 0 | 4.83 | 2.12 | 5.34 | 0.41 |
| Phosphoric oxide, | 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 |
| Total 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 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 2d Period.

2. *Fiber* is produced most largely at the time of heading out (2d Period). When the plant has finished blossoming (end of 3d Period), the formation of fiber entirely ceases. Afterward there appears to occur a slight diminution of this substance, more probably due to unavoidable loss of lower leaves than 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.

4. *Albuminoids* are very irregular in their formation. The greatest amount is organized during the 4th 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 1st Period is not much less than in the 4th, but in the 2d, 3d and 5th 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 1st Period as 100, the amounts gained during the subsequent periods are related as follows:

| | 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 2d and 3d Periods, and sinks rapidly during the time when in Arendt's plants it attained the maximum. Curiously enough, the gain in the 2d, 3d and 4th 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 much less completely, 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 favor of the weather, or other external conditions.

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 strikingly demonstrate that, in the act of organization, the nitrogenous principles have no close quantitative relations to the non-nitrogenous bodies (carbhydrates and fats).

The quantities of albuminoids gained during each period being represented by 10, the amounts of carbhydrates, etc., are seen from the subjoined ratios:

| | PERIODS. | | | | |
|---|---|---|---|---|---|
| | I. | II & III. | IV. | V. | *Ratio in Ripe Plant.* |
| Arendt.......... | 10 : 34 | 10 : 114 | 10 : 28 | 10 : 25 | 10 : 66 |
| Bretschneider.. | 10 : 30 | 10 : 50 | 10 : 46 | 10 : 120 | 10 : 51 |

5. The *Ash-ingredients* of the oat are absorbed throughout its entire growth, but in regularly diminishing quantity. The gain during the 1st Period being taken at 10, that in the 2d Period is 9, in the 3d, 8, in the 4th, 5½, in the 5th, 2 nearly.

The ratios of gain in ash-ingredients to that in entire dry substance, are as follows, 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.

*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 (*per cent*):

| | *Fiber.* | *Fat.* | *Carbhydrates.** | *Albuminoids.* | *Ash.* |
|---|---|---|---|---|---|
| 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 |

Taking the *total gain* as 100, the gain during each period was accordingly as follows (*per cent*):

| | *Fiber.* | *Fat.* | *Carbhydrates.** | *Albuminoids.* | *Ash.* |
|---|---|---|---|---|---|
| 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 |

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:

| | *Silica.* Per cent. | *Sulphuric Oxide* Per cent. | *Phosphoric Oxide* Per cent. | *Lime.* Per cent. | *Magnesia.* Per cent. | *Potash.* Per cent. |
|---|---|---|---|---|---|---|
| I. Period, | 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:

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* Exclusive of Fiber.

| | *Silica.* | | *Sulphuric Oxide.* | | *Phosphoric Oxide.* | | *Lime.* | | *Magnesia.* | | *Potash.* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Per cent. | | Per cent. | | Per cent. | | Per cent. | | Per cent. | | Per cent. | |
| I. Period, | 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) |

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 oxide.*† 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 4th Period in both cases.

*C.*—**Translocation of Substances in the Plant.**—The transfer of certain matters from one part of the plant to another during its growth 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 roots. It is also probable that a transfer of *carbhy-*

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* In these instances Bretschneider's later crops appear to contain less sulphuric oxide, 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.

† Phosphoric oxide is the "phosphoric acid," $P_2O_5$, of older and to a great degree of current usage. See p. 163.

*drates,* 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.

On the other hand, *phosphoric oxide* 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 oxide as follows:

| | 1*st* Period. | 2*d* Period. | 3*d* Period. | 4*th* Period. | 5*th* Period. |
|---|---|---|---|---|---|
| 3 lower joints of stem, | 0.47 | 0.20 | 0.21 | 0.20 | 0.19 |
| 2 middle " " | | 0.39 | 1.14 | 0.46 | 0.18 |
| Upper joint " | | 0.66 | 1.73 | 0.31 | 0.39 |
| 3 lower leaves " | 1.05 | 0.70 | 0.69 | 0.51 | 0.35 |
| 2 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 1st or 3d Period in all cases, and increase very rapidly in the ear.

Arendt found that *sulphuric oxide* 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 sulphates at all, though its total in the plant considerably increased. It is almost certain, then, that sulphuric oxide *originates,* either partially or wholly, by oxidation of sulphur or some sulphurized compound, in the upper organs of the oat.

*Magnesium* 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 *Calcium* 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 magnesium.

As to *potassium,* no transfer is fairly indicated, except from the ears. These contained at blossoming (Period III) a maximum of potassium. During their subsequent growth the amount of this element diminished, being probably displaced by magnesium.

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.

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 timbers, 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, what positions they occupy, what purposes they serve, and on what plan the edifice is constructed.

It is impossible for the builder to do his work until he has mastered the plans and specifications of the architect. So 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 have taught, a more definite and particular knowledge,—a 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 practiced in fruit- and flower-culture are only intelligible by the help of this knowledge.

ORGANISM OF THE PLANT.—We have at the outset spoken of organic matter, of organs and organization. It is in the world of life that these terms have their fittest application. 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* or *Organic 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, and, at the expense of atmospheric oxygen, is virtually burned up to air and ashes.

In the organic world a something, which we call *Vitality,* resists and overcomes or modifies the affinities of oxygen, and insures the existence of a continuous and perpetual succession of living forms.

An Organism or Organized Structure is characterized and distinguished from inorganic matter by two particulars:

1. It builds up and increases its own mass by appropriating external matter. It absorbs and assimilates food. It grows by the enlargement of all its parts.

2. It reproduces itself. It develops from a germ, and in turn gives origin to new germs.

ULTIMATE AND COMPLEX ORGANS.—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 *Vegetative Organs.* 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 *Reproductive Organs.*

## CHAPTER II.

## PRIMARY ELEMENTS OF ORGANIZED STRUCTURE.

### § 1.

### THE VEGETABLE CELL.

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—a mass of rounded or many-sided bags 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 vastly 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.

**Cellular Plants.**—In the simpler forms or lower orders * of vegetation, we find plants which, throughout all the stages of their life, consist entirely of similar cells, and indeed many are known which are but a single cell. The phenomenon of red snow, frequently observed in Alpine and Arctic regions, is due to a microscopic one-celled plant which propagates with great rapidity, and gives its color 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 sodium and magnesium, a flocculent mold, sometimes red, sometimes green, most often white, is formed, which, under the microscope, is seen to be a vegetation consisting of single cells. Brewers' yeast, Fig. 27, is nothing more than a mass of one or few-celled plants.

In sea-weeds, mushrooms, the molds that grow on damp walls, or upon bread, cheese, etc., and in the blights which infest many of the farmer's crops, we have examples of plants formed exclusively of cells.

Fig. 27.

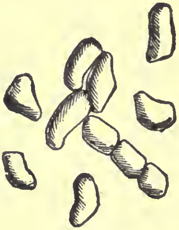

Fig. 28.

All the plants of higher orders we find likewise to consist chiefly of globular or angular cells. All the growing parts especially, as the tips of the roots, the leaves, flowers and fruit, are, for the most part, aggregations of such minute vesicles.

If we examine the pulp of fruits, as that of a ripe

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* Viz.: the *Cryptogams*, including Molds and Mushrooms (*Fungi*), Mosses, Ferns, Sea-Weeds (*Algæ*) and Bacteria (*Schizomycetes*).

apple or tomato, we are able, by means of a low magnifier, to distinguish the cells of which it almost entirely consists. Fig. 28 represents a bit of the flesh of a ripe pippin, magnified 50 diameters. The cells mostly cohere together, but readily admit of separation.

**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. 29 exhibits the appearance of a cell from the flesh of the Artichoke (*Helianthus*), 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, the sap or free water of vegetation. 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 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.

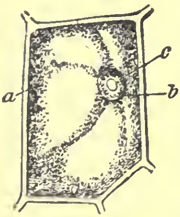

Fig. 29.

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 afterward with sulphuric acid, the outer membrane—the *cell-wall*—shortly becomes of a fine blue color. It is accordingly *cellulose*, the only vegetable substance yet known which is made blue by iodine *after*, and only after, the action of sulphuric acid. At the same time we observe that the interior, half-liquid, *protoplasm*, coagulates and shrinks together,—separates, therefore, from the cell-wall, and, including with it the nucleus and the smaller granules, lies in the center of the cell like a collapsed bladder. It also assumes a deep yellow or brown color. If we moisten one of these cells with nitric acid, the cell-wall is not affected, but the liquid penetrates it, coagulates the inner membrane, and colors it yellow. In the same way this membrane is tinged violet-blue by hydrochloric acid. These reactions leave no room to doubt that the slimy inner lining of the cell or protoplasm contains abundance of *albuminoids.* The protoplasm is not miscible with water and maintains itself distinct from the cell-sap. In young cells it is constantly in motion, the granules suspended in it circulating as in a liquid current.

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 isolated cells consist only of protoplasm and nucleus, being destitute of cell-walls during a portion or the whole of their existence.

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, etc., 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, so far as our observations extend, are always, at first, formed closely on the pattern that has been described.

**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. 30, 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*, air-filled cavities between the cells are seen, called *intercellular spaces*. A slice across the potato-tuber (see Fig, 52, p. 300) 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 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 evident trace of cell-structure ; however, upon soaking in sulphuric acid, the mass softens and swells, and the individual cells are revealed, their surfaces separating in six-sided outlines.

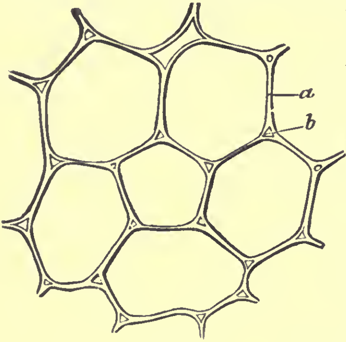

Fig. 30.

**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 honey-comb is an excellent illustration of the appearance of many forms of vegetable cell-tissue.

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 citric acid, sugar and albuminoids.

In the pith of the rush, star-shaped cells are found. In common mold the cells are long and thread-like. In the so-called frog-spittle (*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.

Cotton-fiber, flax, and hemp consist of long and slender cells, Fig. 31. Wood is mostly made up of elongated cells, tapered at the ends and adhering together by their sides. See also Fig. 49, *c*, *h*, p. 292.

Each cotton-fiber is a single cell which forms an external appendage to the seed-vessel of the cotton plant. When it has lost its sap and become air-dry, its sides collapse and it resembles a twisted strap. *A*, in Fig. 31, exhibits a portion of a cotton-fiber highly magnified. The flax-fiber, from the inner bark of the flax-stem, *b*, Fig. 31, is a tube of thicker walls and smaller bore than the cotton-fiber, 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-fiber closely resembles flax-fiber in appearance.

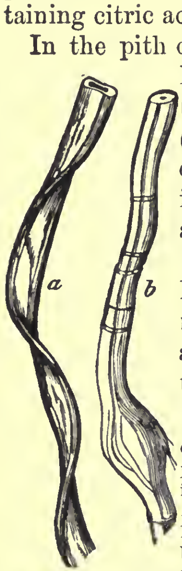

Fig. 31.

*Thickening of the Cell-Membrane.*—The growth of the cell, which, when young, has a very delicate outer membrane, often results in the thickening of its walls by the interior deposition of cellulose and woody matters. This thickening may take place regularly and uniformly, or interruptedly. The flax-fiber, *b*, Fig. 31, is an example of nearly uniform thickening. The irregular deposition of cellulose is shown in Fig. 32, 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

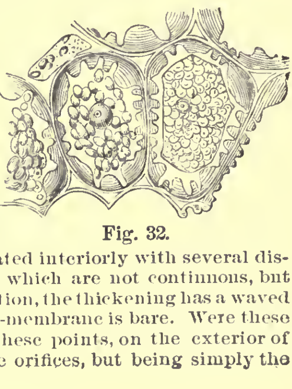
Fig. 32.

unthickened portions of the cell-wall. The cells in fig. 32 exhibit each a central nucleus surrounded by grains of aleurone.

**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 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.

All living or active cells are distended with liquid. This consists of water, which holds in solution gum, dextrin, inulin, the sugars, albuminoids, organic acids, and other vegetable principles, together with various salts, both of organic and mineral acids, and constitutes the sap of the plant. In oil-plants, droplets of oil occupy certain cells, Fig. 17, p. 83; while in numerous kinds of vegetation colored and milky juices are found in certain spaces or channels between the cells.

The water of the cell comes from the soil, or in some cases from the air. The matters, which are dissolved in the sap of the plant, together with the semi-solid protoplasm, undergo transformations resulting in the production of various solid substances. By observing the several 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 granular or crystalline bodies consisting chiefly of albuminoids, and of the various matters which give color 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 for the most part filled with starch.

In oats, wheat, and other cereals, we find, just within the skin or epidermis of the grain, 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. 18, p. 110.

**Transformations in Cell Contents.**—The same cell may exhibit a great variety of aspect and contents at different periods of growth. 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 interior of the cells are nearly devoid of recognizable 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 upon 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. Again, in a short time the grains lose their green color and assume, both as regards appearance and deportment with iodine, all the characters of starch. 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 inwardly—the starch having been converted into cellulose or bodies of similar properties. 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 converted from their surfaces inwardly into 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. The nucleus reappears, the aleurone dissolves, and even the cellulose* stratified upon the interior of the cell (Fig. 32) wastes away and is converted into soluble food (sugar ?) for the seedling plant.

Fig. 33.

**The Dimensions of Vegetable Cells** are very various. A creeping marine plant is known—the *Caulerpa prolifera* (Fig. 33)—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. The pulp of

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* Or more probably metarabin, paragalactin, xylin, or the like insoluble substances, which as yet have been but imperfectly distinguished from cellulose in the thickened cell-walls.

the orange consists of cells which are one-quarter of an inch or more in diameter. The fiber of cotton is a single cell, commonly from one to two inches long. 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 $\frac{1}{1200}$ to $\frac{1}{200}$ of an inch in diameter. The spores of Fungi are still smaller. The germs of many bacteria are so minute as to be undiscoverable by the highest powers of the microscope.

**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.**—The young and active cell always contains a *nucleus* (Fig. 34, *b*). 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, *a*, 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 inclosing each within its new cell, which is completed by a further external growth of cellulose.

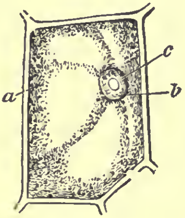

Fig 34.

Fig. 35.

In one-celled plants, like yeast (Fig. 35), 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.

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 resorption or death of the parent cell become independent.

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. Many will recollect having seen, on the morning of a June day, huge puff-balls, some as large as a peck measure, on the surface of a moist meadow, where the day before nothing of the kind was noticed. In such sudden growth it has been estimated that the cells are produced at the rate of three or four hundred millions per hour.

**Permeability of Cells to Liquids.**—Although the highest magnifying power that can be brought to bear upon the membranes of the vegetable cell fails to reveal any apertures in them,—they being, so far as the best-assisted vision is concerned, completely continuous and imperforate,—they are nevertheless readily permeable to liquids. This fact may be 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 colors them intensely purplish-blue. The particles of which the cell-walls and their contents are composed must be separated from each other by distances greater than the diameter of the particles of water or of other liquid matters which thus permeate the cells.

## § 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 distinctions being based either on peculiarities of form or of function. For our purposes it will be necessary to define but a few varieties, viz.: *Cellular Tissue, Wood-Tissue, Bast-Tissue* and *Vascular Tissue.*

**Cellular Tissue**, or *Parenchyma*, is the simplest of all, being a mere aggregation of globular or polyhedral cells whose walls are in close adhesion, and whose juices commingle more or less in virtue of this connection. Cellular tissue is the groundwork of all vegetable structure, being the only form of tissue in the simpler kinds of plants, and that out of which all the other tissues are developed.

*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-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 "break joints" by overlapping each other, in this way forming the tough fibers of wood. Wood-cells are often more or less thickened in their walls by depositions of cellulose and other matters, according to their age and position, and are sometimes dotted and perforated, as will be explained hereafter—Fig. 53, p. 301.

**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 of this tissue in the bast, or inner bark. Linen, hemp, and most textile materials of vegetable origin, cotton excepted, consist of bast-fibers. Bast-cells occupy a place in rind, corresponding to that held by wood-cells in the interior of the stem—Fig. 49, p. 293.

**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—Fig. 49, p. 293.

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 VEGETATIVE ORGANS OF PLANTS.

## § 1.

### THE ROOT.

The roots of plants, with few exceptions, from the first moment of their development, grow downward. In general, they require a moist medium. 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 unfavorable to their functions.

**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 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.

**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.**—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. 36 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.

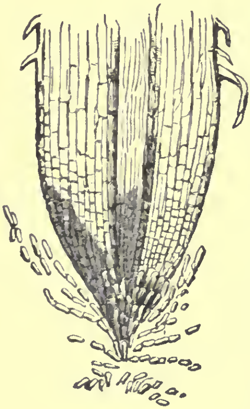
Fig. 36.

A striking illustration of the root-cap is furnished by the air-roots of the so-called Screw Pine (*Pandanus odoratissimus*), exhibited in natural dimensions, in Fig. 37. 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.

Fig. 37.

**Distinction between Root and Stem.**—Not all the subterranean parts of the plant are 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 and pepper-root, 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, e. g., 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 fibers 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. Roots of other plants, such as the plum, apple, and poplar, may produce buds when cut off from the parent plant during the growing season. The roots of the former perish if deprived of connection with the stem and leaves. The latter may strike out new stems and leaves for themselves. Plants like the plum are, therefore, capable of propagation by *root-cuttings*, i. e., by placing pieces of their roots in warm and moist earth.

**Tap-roots.**—All plants whose seeds divide into two seed-leaves or *Cotyledons*, and whose stems increase externally by addition of new rings of growth—the *Dicotyledonous 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 grapevine. 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 Canada thistle, 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.

**Crown Roots.**—*Monocotyledonous plants*, or *Endogens*, i. e., 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, palms, etc., have no single descending axis or tap-root, but produce *crown roots*, i. e., a number of roots issue at once from the base of the stem. 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.

THE OFFICES OF THE ROOT are threefold:

1. To fix the plant in the 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 case of many plants, especially of those whose terms of life extend through several or many years, to serve as a store-house for the future use of the plant.

**1. 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 or seedling apple tree, which has a tap-root, withstands the force of a wind that would prostrate a maize-plant or a poplar, 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 alfalfa, extend very deeply into the soil, and the latter acquire in some cases a length of 30 feet. The roots of the ash have been known as much as 95 feet long. (*Jour. Roy. Ag. Soc.*, VI, p. 342.)

**2. Root-absorption.—The Office of Absorbing Plant Food from the Soil** is one of the utmost importance, and one for which the root is most wisely adapted by the following particulars, viz.:

*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 shortly acquire a blue color 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. 270.) All other parts of the roots, which are still young and delicate in surface-texture, are constantly active 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-colored 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.

*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.

*The Medium in which Roots Grow* has a great influence on their extension. When they are situated in concentrated 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; moist 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, dry soils are very long and slender.

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 fibers. 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 fibers, 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 aerial 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.

*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 neighborhood. 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 Quantity of Roots actually belonging 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 extreme difficulty. Schubart was the first to make satisfactory observations 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 6 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 fibers, to a depth of about 4 feet from the surface of the ground. The roots of winter wheat he observed as deep as 7 feet, in a light subsoil, forty-seven days after sowing. The depth of the roots of winter wheat, winter rye, and winter colza, as well as of clover, was 3 to 4 feet. The roots of clover, one year old, were 3½ feet long, those of two-year-old clover but four inches longer. The quantity of roots in per cent of the entire plant in the dry state was found to be as follows. (*Chem. Ackersmann*, I, p. 193.)

| | |
|---|---|
| Winter wheat—examined last of April | 40% |
| " " " " " 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 20 to 30 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.

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 (4 + 4 + 2 in.) 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 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.

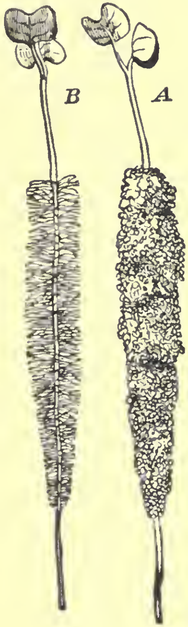

Fig. 38.

*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 fibers 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 fibers 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. 38 represents a young mustard seedling. *A* is

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* Rhenish, 34 = 35 English feet.

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. 39 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.

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.

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.

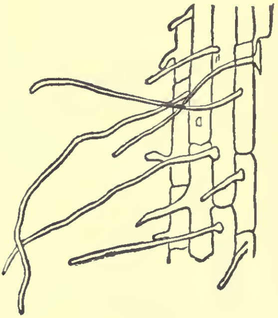

Fig. 39.

The Silver Fir (*Abies Picea*) has no root-hairs, but its rootlets are covered with a very delicate cuticle highly favorable 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.)

*Contact of Roots with the Soil.*—The root-hairs, as they extend into the soil, are naturally brought into close

Fig. 40.

Fig. 41.

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 either found to be broken, or in many places inseparably attached to the particles of earth.

Fig. 42.

Fig. 40 exhibits the appearance of a young wheat-plant as lifted from the soil and pretty strongly shaken. *S*, the seed; *b*, the blade; *e*, roots covered with hairs and enveloped in soil. Only the growing tips of the roots, *w*, which have not put forth hairs, come out clean of soil. Fig. 41 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, *e*, 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. 42, exhibits the appearance of root-hairs with adhering particles of earth, when magnified 800 diameters: *A*, root-hairs of wheat-seedling, like Fig. 40; *B*, of oat-plant, both from loamy soil. Here is plainly seen the intimate attachment of the soil and root-hairs. The latter, in forcing their way against considerable pressure, often expand around, and partially envelop, the particles of earth. (Sachs's *Exp. Phys. d. Pflanzen.*)

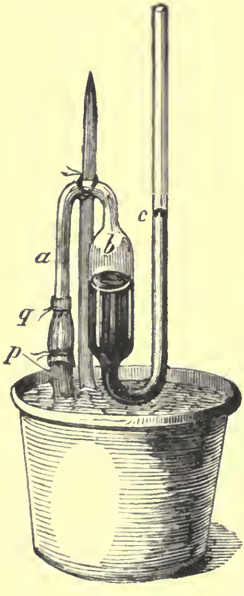

Fig. 43.

*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. 43, 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, *e*, until its pressure becomes sufficient to balance the absorptive power of the roots. Stephen Hales, who first experimented in this manner (1721) found in one instance that the pressure exerted on a gauge, 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 seat of absorption Dutrochet demonstrated to be 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 to 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 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,

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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.

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 vigor 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 case of 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. Sometimes water is absorbed at the roots so forcibly as not only to distend the plant to the utmost, but to cause the sap of the plant to exude 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 favorable conditions for rapid development.

The bleeding of the vine, when severed in the springtime, the abundant flow of sap from the sugar-maple and the water-elm, 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.

Of the *external circumstances* that affect this absorptive power, heat and light would appear to be influential. 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, in case of potted tobacco and squash plants, absorption was nearly or entirely suppressed by cooling the roots to 41° F., but was at once renewed by plunging the pots into warm water.

The external supplies of water,—in case a plant is stationed in the soil, the degree of moisture contained in this medium,—obviously must influence any manifestation of the imbibing force. But full investigation shows that this regular daily fluctuation is a habit of the plant which is independent of small changes of temperature and even of considerable variation in the amount of moisture of the soil.

*The rate of absorption* is subject to changes dependent on 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) when the soil was saturated with water and when the thermometer indicated a constant temperature. Hofmeister states that the formation of new roots and buds on the stump is accompanied by a sinking of the water in the pressure-gauge.

*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 which is 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 apparently, to a certain extent, a selective power. See p. 401.

**3. The Root as a Magazine.**—In *Fleshy Tap-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 their surface, and especially from their lower extremities, while the older fleshy part serves as a magazine in which large quantities of carbhydrates, etc., 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, put into the ground for a second year, has produced seed, it is found to be quite exhausted of the nutritive matters which it previously contained in so large quantity.

*Root Tubers*, like those of the dahlia and sweet potato, are fleshy enlargements of lateral or secondary roots filled with reserve material, from which buds and new stems may develop. Small tubers (*Tubercles*) are frequently formed on the roots of the garden bean (*Phaseolus*).

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 to feed himself and his cattle the substances that nature primarily designed to nourish the growth of flowers and seeds during another summer.

**Soil-Roots; Water-Roots; Air-Roots.**—We may 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 especially to the soil, and which perish by short exposure to dry air, or rot, if long immersed in water. Many aquatic plants, on the other hand, speedily die when their roots are removed from water, or from earth saturated with water, and exposed to the atmosphere or stationed in earth of the usual dryness.

Air-roots are not common except among tropical plants or under tropical conditions of heat and moisture. Indian corn, when thickly planted and of rank growth, often throws out roots from the lower joints of the stem, which extend through the air several inches before they reach the soil. The same may be observed of many common plants, as the oat, grape, potato, and buckwheat, when they long remain in hot, moist air. The Banyan-tree of India sends out from its branches, vertically, pendants several yards long which penetrate the earth and there become soil-roots.

On the other hand, various tropical plants, especially Orchids, emit roots which hang free in the air and never reach the earth. In the humid forest ravines of Madeira and Teneriffe, the *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. (Schacht, *Der Baum,* p. 172.)

A plant, known to botanists as the *Zamia spiralis,* not only throws out air-roots, *c c,* Fig. 44, 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 formation of air-roots may be very easily observed by placing water to the depth of half an inch in a tall vial, inserting a sprig of the common greenhouse-plant *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 discolored and decay; the others, however, remain for a long time fresh, and of a white color.

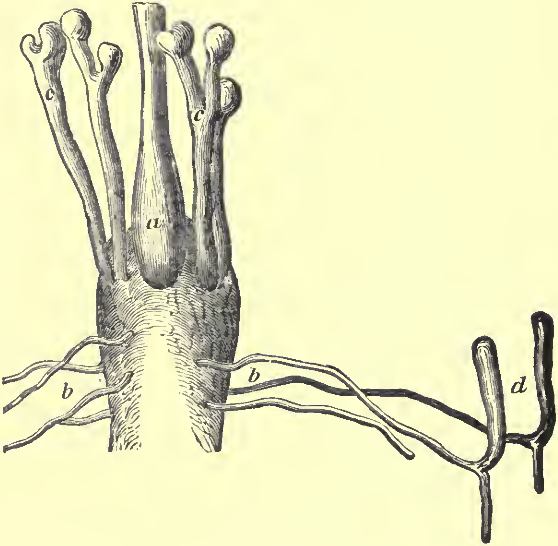

Fig. 44.

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 in point. 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 flowed 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, England, a drain was completely stopped by roots of horse-radish plants at a depth of 7 feet. At Thornsby Park, a drain 16 feet deep was stopped entirely by the roots of gorse, growing at a distance of 6 feet from the drain. (*Jour. Roy. Ag. Soc.*, I, p. 364.) In New Haven, Connecticut, certain wells are so obstructed by the aquatic roots of the 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 various grasses.

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. He devised the following experiment, which appears to prove 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 color, 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 fibers. In the dry earth of the funnel they were less extensively developed, yet exhibited some juicy 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. (*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. 263).

The seeds of many ordinary land plants—of plants, indeed, that customarily grow in a dry soil, such as the bean, squash, maize, etc.—will readily germinate in moist cotton or sawdust, 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 with due supplies of nutriment will run through all the customary stages of development, produce abundant foliage, blossoms, and perfect seeds, without a moment's contact of their roots with soil. (See Water Culture, p. 181.)

In plants thus growing with their roots in a liquid medium, after they have formed several large leaves, be carefully transplanted to the soil, they wilt 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 wilts, 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 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 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 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 above detailed admit of partial, if not complete, explanation, without recourse to the supposition that soil- and water-roots are essentially diverse in nature. 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 found by his later 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 wilts, and may easily perish unless profusely watered or shielded from evaporation.

The air-roots of Orchids, which never reach the soil, have a peculiar spongy texture and take up the water which exists as vapor in the air, as shown by the experiments of Unger, Chatin, and Sachs. Duchartre's investigations led him to deny their absorptive power. (*Elements de Botanique*, p. 216.) In his experiments made on entire plants, the air-roots failed to make good the loss by evaporation from the other parts of the plant.

It is evident from common observation that *moisture* is the condition that chiefly determines root-development. Not only do all seeds sprout and send forth roots when provided with abundant moisture at suitable temperatures, but generally older roots and stems, and fleshy leaves, or cuttings from these, will produce new rootlets when properly circumstanced as regards moisture, whether that moisture be supplied by aid of a covering of damp soil, wet sand or paper, by stationing in humid air, or by immersion in water itself.

**Root-Excretions.**—It was formerly 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 odors exhale from the roots of other plants. Numerous experiments have been instituted at various times for the purpose of testing this question. Noteworthy 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, etc., 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 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.

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 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 soluble salts or free acids may indeed *diffuse* out of the

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*From the wounded bark of the sugar-pine (*Pinus Lambertiana*) of California.

root-cells into the water of the soil. This is, however, no physiological action, but a purely physical process.

**Vitality of Roots.**—It appears that in case of most plants the roots cannot long continue their vitality if their connection 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, etc., 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.

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 ground, but extend beneath the surface of the soil, and are usually considered to be roots.

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 is the support of these organs, and, it would appear, only extends in length or thickness with the purpose of sustaining them mechanically or providing them with nutriment.

**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.

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. 45. The opening of the bud consists in the lengthening of this axis, which is the stem, and the consequent separation from each other as well as expansion of the leaves. 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 signified 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

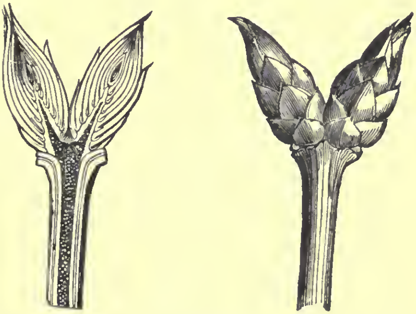

Fig. 45.

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. 45, 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.

**Nodes; Internodes.**—Nodes are those knots or parts of the stem where the leaves are attached. The portions of the stem between the nodes are termed *internodes.* It is from the nodes that roots most freely develop when stems (layers or cuttings) are surrounded by moist air or soil.

**Culms.**—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 rest upon a well-defined, thickened node.

**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 buds at the point where the base of the leaf or of the leaf-stalk unites with the stem. From these axillary buds, in case their growth is not checked, side-stems or branches issue, which again subdivide in the same manner into branchlets.

In perennial plants, when young, or in their young shoots, it is easy to trace the nodes and internodes, or the points where the leaves are attached and the intervening spaces, even 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, or short stumps of the limbs themselves, 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 also with some of the cone-bearing trees, especially the balsam-fir.

**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 off, 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 molds 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. Close pruning or breaking the young twigs causes abundant development of flower-buds on fruit trees that otherwise "run to wood."

**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.

**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.

**Runners** and **Layers** are stems that are sent 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 become layers. The runner is a somewhat peculiar stem. It issues horizontally, and usually bears but few or no 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 to them a ball or pot of earth. The striking out of roots from the layer is in many cases facilitated by cutting half through, twisting, or otherwise wounding the stem at the point 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 50 or 60 grain-bearing culms. (Hallet, *Jour. Roy. Soc. of Eng.*, 22, p. 372.)

**Suckers.**—When branches arise from the stem below the surface of the soil, so that they are partly subterranean and partly aerial, 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.

**Subterranean Stems.**—Of these there are three forms. They are usually taken to be roots, from the fact of existing below the surface of the soil. This circumstance is, however, quite accidental. The pods of the peanut (*Arachis hypogæa*) ripen beneath the ground—the flower-stems lengthening and penetrating the earth as soon as the blossom falls; but these stems are not by any means to be confounded with roots.

**Root-stocks, or Rhizomes.**—True roots are destitute of leaves. This fact easily distinguishes them from the *rhizome,* which is a stem that extends below the surface of the ground. At the nodes of these *root-stocks,* as they are appropriately named, scales or rudimentary leaves are seen, and thence roots proper are emitted. In the axils of the scales may be traced the buds from which aerial and fruit-bearing stems proceed. Examples of the root-stock are very common. Among them we may mention the blood-root and pepper-root as abundant in the woods of the Northern and Middle States, various mints, asparagus, and the quack-grass (*Agropyrum** *repens*) represented in Fig. 46, 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 quack-grass becomes especially troublesome, for the more the fields where it has obtained a footing are tilled the more does it commonly spread and multiply; only oft-repeated harrowing in a season of prolonged dryness suffices for its extirpation.

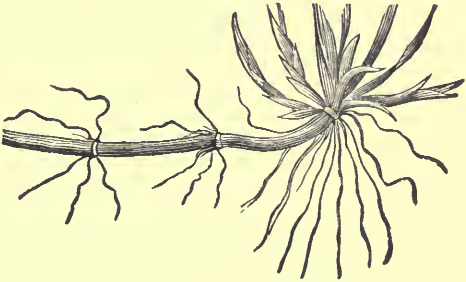

Fig. 46.

**Corms** are enlargements of the base of the stem, bearing leaf-buds either at the summit or side, and may be regarded as much-shortened rhizomes, with only a few slightly-developed internodes. Externally they resemble bulbs. The garden crocus furnishes an example.

**Tubers** of many plants are fleshy enlargements of the

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*Formerly *Triticum*.

extremities of subterranean stems. Their *eyes* are the points where the buds exist, usually three together, and where minute scales—rudimentary leaves—may be observed. The common potato and artichoke (*Helianthus tuberosus*) are instances of this kind of tubers. Tubers serve excellently for propagation. Each eye, or bud, may become a new plant. From the quantity of starch, etc., 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 "hilling up" earth around the base of the aerial stems during the early stages of its growth.

**Bulbs** are greatly thickened stems, whose leaves—usually having the form of fleshy scales or concentric coats—are in close contact with each other, and arise from nearly a common base, the internodes being undeveloped. The bulb is, in fact, a permanent bud, usually in part or entirely subterranean. From its apex, the proper stem, the foliage, etc., 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.—The stem is so complicated that to discuss it fully would occupy a volume. For our immediate purposes it is, however, only necessary to notice its structural composition very concisely.

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*, or is an aggregate of rounded and cohering cells, which rapidly multiply during the vigorous growth of the plant.

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 connection, and are arranged in *bundles,* which constitute the *fibers* of the stem. 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.

Flowering plants may be divided into two great classes, in consequence of important and obvious differences in the structure of their stems and seeds. These are: 1, *Monocotyledons, or Endogens;* and 2, *Dicotyledons, or Exogens.* As regards their stems, these two classes of plants differ in the arrangement of the vascular or woody tissue.

**Endogenous Plants** are those whose stems enlarge by the formation of new wood in the interior, and not by the external growth of concentric layers. The embryos in the seeds of endogenous plants consist of a single piece —do not readily split into halves—or, in botanical language, have but one *cotyledon;* hence are called monocotyledonous. Indian corn, sugar-cane, sorghum, wheat, oats, rye, barley, the onion, asparagus, and all the grasses, belong to this tribe of plants.

If a stalk of maize, asparagus, or bamboo be cut across, the fiber-like bundles of ducts and wood-cells are seen disposed somewhat uniformly throughout the section, though less abundantly towards the center. On splitting the fresh stalk lengthwise, these *vascular bundles* may be torn out like strings. At the nodes, where the stem is branched, or where leaf-stalks are attached, the vascular bundles likewise divide and form a *net-work.* In a ripe maize-stalk which is exposed to circumstances favoring 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. 47, where the vascular bundles are seen arranged parallel to each other in the internodes, and curiously interwoven and branched at the nodes, both at those (*a* and *b*) from which roots issued, 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 aerial 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 center. 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 after-

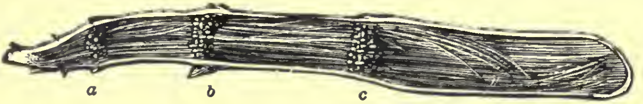

Fig. 47.

wards outwards and downwards, and hence the designation endogenous, which in plain English means *inside-grower*.

In consequence of this inner growth, 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.

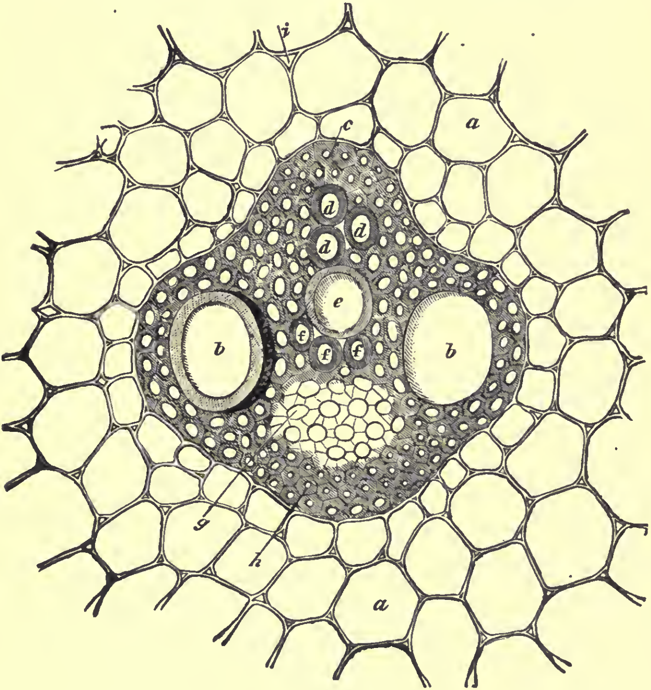

Fig. 48.

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.

**The Minute Structure of the Endogenous Stem** is exhibited in the accompanying cuts, which represent highly magnified sections of a *Vascular Bundle* or fiber 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. 48 represents a cross section of one of these bundles, *c, g, h,* as well as of a portion of the surrounding cell-tissue, *a, a.* The latter consists of quite large cells, which have between them considerable inter-cellular spaces, *i.* The vascular bundle itself is composed 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 center of the stem, *c*, are *wood-cells.* In the maize stem, bast-cells and wood-cells are quite alike, and are

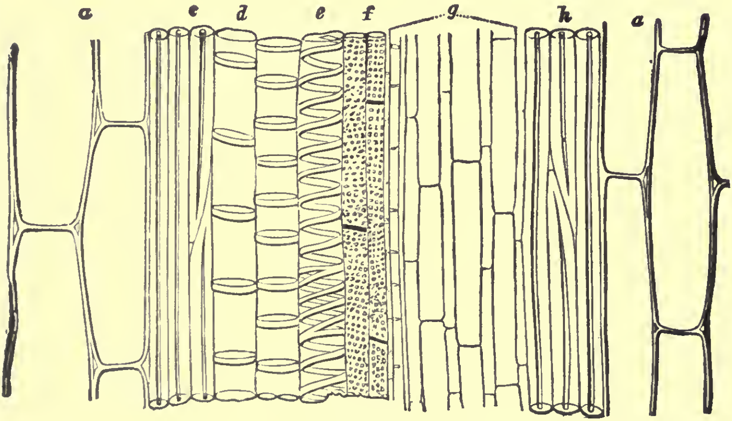

Fig. 49.

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. 49 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, hickory, and the toughest woods, as well as the bast-cells of flax and hemp, are quite similar in form and appearance. The proper ducts of the stem 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 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 of cellulose (see Fig. 32, p. 248). Wood or bast-cells that consist mainly of cellulose are pliant and elastic. It is the deposition of other matters (so-called *lignin*) in their walls which renders them stiff and brittle.

At *g,* the cambial 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. (Sieve-cells, p. 303.) The *cambium* is the seat of growth by cell-formation. Accordingly, when a vascular bundle has attained maturity, it no longer possesses a cambium.

To complete our view of the vascular bundle, Fig. 50 represents a vertical section made at right angles to the last, cutting two large ducts, *b*, *b*; *a*, *a* is cell-tissue; *c*, *c* are bast or wood-cells less thickened by interior deposition than those of Fig. 49; *d* is a ring and spiral duct; *b*, *b* are large dotted ducts, which exhibit at *g*, *g* the places where they were once crossed by the double membrane composing the ends of two adhering cells, by whose absorption and removal an uninterrupted tube has been formed. In these large dotted ducts there appears to be no direct communication with the surrounding cells through their sides. The dots or pits are simply very thin points in the cell-wall, through which sap may soak or diffuse laterally, but not flow.

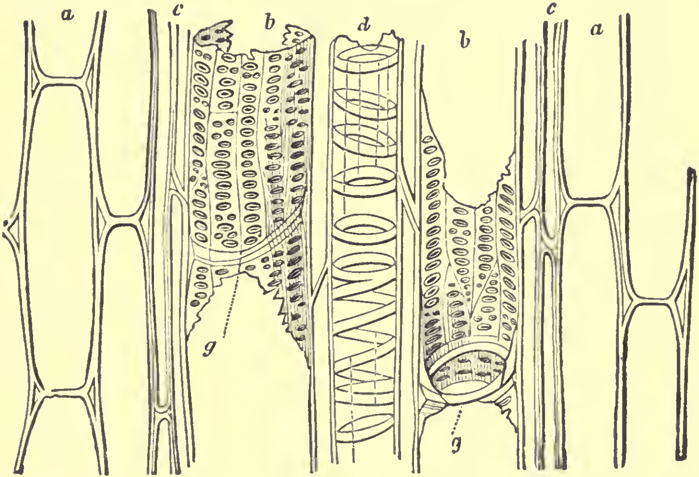

Fig. 50.

When the cells become mature and cease growth, the pits often become pores by absorption of the membrane, so that the ducts thus enter into direct communication with each other.

**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 seeds are usually made up of two loosely-united parts, or cotyledons, wherefore they are designated dicotyledonous. All the forest trees of temperate climates, and, among agricultural plants, the bean, pea, clover, potato, beet, turnip, flax, etc., are exogens.

In the exogenous stem the bundles of ducts and fibers that appear in the cell-tissue are always formed just within the rind. They occur at first separately, as in the endogens, but, instead of being scattered throughout the cell-tissue, are disposed in a circle. As they grow, they usually close up to a ring or zone of wood, which incloses unaltered cell-tissue—the pith.

As the stem enlarges, new rings of fibers 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 herbs 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 fibers 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 solution of iodine for a few minutes, the vascular ring becomes 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.

*Pith* is the cell-tissue of the center 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 center of the tuber.

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. These, together with ducts of various kinds, 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 vegetable textile materials employed in the manufacture of cloth and cordage, with the exception of cotton, as flax, hemp, New Zealand flax, etc., are bast-fibers. (See p. 248.)

In some plants the annual layers of bast are so separated by cellular tissue that in old stems they may be split from one another. Various kinds of matting are made by weaving together strips of bast layers, especially those of the Linden (Bass-wood or Bast-wood) tree. The leather-wood or moose-wood bark, often employed for tying flour-bags, has bast-fibers of extraordinary tenacity. The bast of the grape-vine separates from the stem in long shreds a year or two after its formation.

The epidermis of young stems is replaced, after a certain age, by the *corky layer*. This differs much in different plants. In the Birch it is formed of alternate layers of large- and small-celled tissue, and splits and curls up. From the Plane-tree it is thrown off periodically in large plates by the expansion of the cellular tissue underneath. In the Maple, Elm, and Oak, especially in the Cork-Oak, it receives annual 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 rifts, and it gradually decays or drops away exteriorly as the newer bark forms within.

*Pith Rays.*—Those portions of the first-formed cell-tissue which were interposed between the young and originally ununited wood-fibers 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 fibers, and are readily seen in most kinds of wood when split lengthwise. 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.*

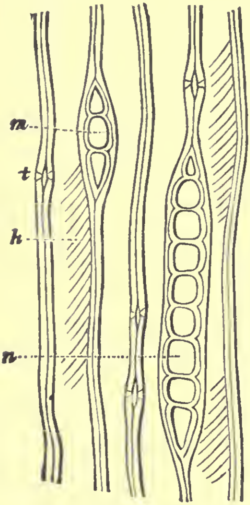

Fig. 51.

Fig. 51 exhibits a section of spruce wood, magnified 200 diameters. The section is made lengthwise of the wood-cells, four of which are in part represented, and cuts across the pith-rays, whose cell-structure and position in the wood are seen at *m, n.*

Branches have the same structure as the stems from which they spring. Their tissues traverse those of the stem to its center, where they connect with the pith and its sheath of spiral ducts.

*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 zone, from which, on the one hand, wood-fibers, and on the other, bast-fibers, 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.

**Minute Structure of Exogenous Stems.**—The accompanying figure (52) will serve to convey an idea of the minute structure of the elements of the exogenous stem. It exhibits a section *lengthwise*, through a young potato tuber magnified 200 diameters ; *a*, *b* is the rind ; *e* 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 center, *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 ; at 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, contigu-

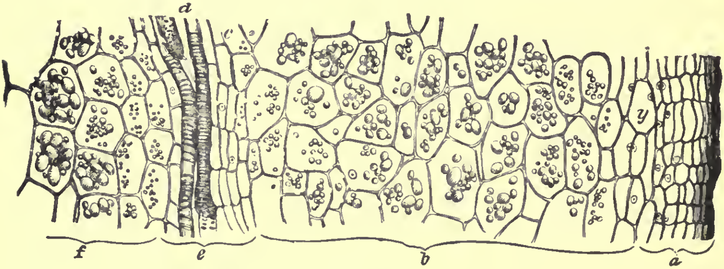

Fig. 53.

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* The word rind is here used in its botanical (not in the ordinary) sense, to denote that part of the tuber which corresponds to the rind of the stem.

ous 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 plain cells and becoming loosely filled with starch; those to the left developing new ducts.

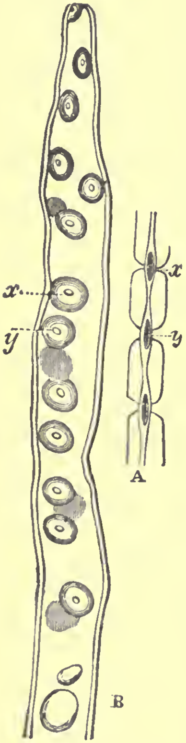

Fig. 53.

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.

**Pitted Wood-Cells of the Conifers.**—In the wood of cone-bearing trees there are no proper ducts, such as have been described. The large wood-cells which constitute the concentric rings of the wood are constructed in a special manner, being provided laterally with pits, or, according to Schacht, with visible pores, through which the fluid contents of one cell may easily diffuse (by osmose), or even pass directly into those of its neighbors.

Fig. 53, *B* 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. *A* exhibits such a section through the thickened walls of two contiguous and adhering cells. *x*, in both *A* and *B*, shows a cavity 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 at *y*, as a pit in each cell-wall, or, as Schacht believed, a pore or opening from cell to cell. In *A* it appears closed because the section passes a little to one side of the pore. (Schacht.)

In the next figure (54), representing a transverse section of the spring wood of the same tree magnified 300 diameters, the structure and the gradual formation of these pore-disks is made evident. The section, likewise, gives an instructive illustration of the general character of the simplest kind of wood. *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 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

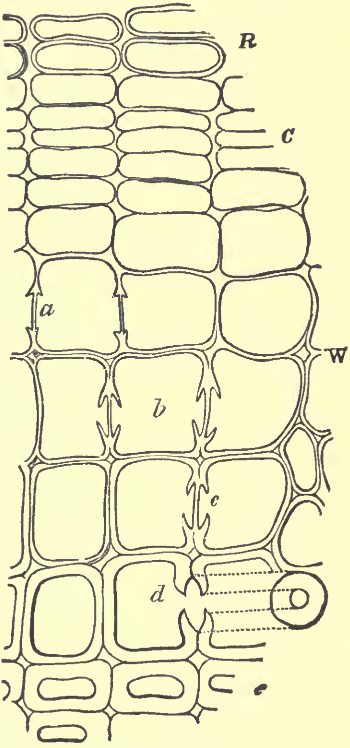

Fig. 54.

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. 53. At *e* the section passes through the new annual ring into the autumn wood of the preceding year.

**Sieve-cells, or Sieve-ducts.**—The spiral, ring, and dotted ducts and pitted wood-cells already noticed, appear only in the older parts of the vascular bundles, and, although they may be occupied with sap at times when the stem is surcharged with water, they are ordinarily filled with air alone. The real transmission of the nutritive juices of the growing plant, so far as it goes on through actual tubes, is now admitted to proceed in an independent set of ducts, the so-called sieve-tubes, which are usually near to and originate from the cambium. These are extremely delicate, elongated cells, whose transverse or lateral walls are perforated, sieve-fashion (by absorption of the original membrane) so as to establish direct communication from one to another, and this occurs while they are yet charged with juices and at a time when the other ducts are occupied with air alone. These sieve-ducts are believed to be the channels through which the organic matters that are formed in the foliage mostly pass in their downward movement to nourish the stem and root. Fig. 55 represents the sieve-cells in the overground stem of the potato ; *A, B,* cross-section of parts of vascular bundle ; *A,* exterior part towards rind ; *B,* interior portion next to pith ; *a, a,* cell-tissue inclosing the smaller sieve-cells, *A, B,* which contain sap turbid with minute granules ; *b,* cambium cells ; *c,* wood-cells (which are absent in the potato tuber) ; *d,* ducts intermingled with wood-cells. *C* represents a section lengthwise of the sieve-ducts ; and *D,* more highly magnified, exhibits the finely perforated, transverse partitions, through which the liquid contents more or less freely pass.

**Milk Ducts.**—Besides the ducts already described, there is, in many plants, a system of irregularly branched channels containing a milky juice (*latex*) as in the sweet potato, dandelion, milk-weed, etc. These milk-ducts occur in all parts of the plants, but most abundantly in the pith and inner bark of stems and in the cellular tissue of roots. They often so completely permeate all the organs of the plant that the slightest wound breaks some of them and causes a flow of latex. The latter, like animal milk, is a watery fluid holding in suspension minute granules or drops which make it opaque. The latex often contains the organic substances peculiar to the plant, acquires a sticky, viscid character, and hardens on exposure to the air. Opium, India-rubber, gutta-percha, and various resins are dried latex. Alkaloids frequently occur, and ferments like papain (p. 104) are probably not uncommon in this secretion.

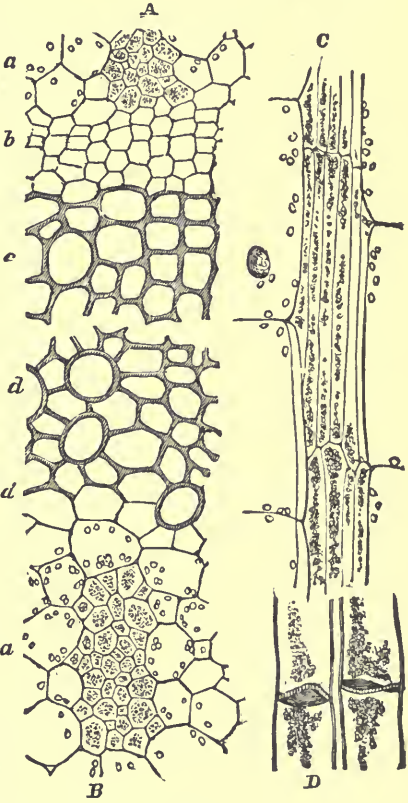

Fig. 55.

**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.*

**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. 54, *e*, while the vigorous renewal of activity in the cambium at springtime 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.

**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 color different from the outer or sap-wood (alburnum), 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 cell 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 vigor of the tree.

**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 plant 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.

These most important organs issue from the stem, are at first folded curiously 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 net-work of fibers 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.

**Color of Leaves.**—A peculiarity most characteristic of the leaves of the higher orders of plants, so long as they are in vigorous discharge of their proper vegetative activities, is the possession of a *green color*, due to the presence of *Chlorophyl.* (See p. 124.) This color is also proper in most cases to the young bark of the stem, a fact further indicating the connection 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 latter being, in fact, growths from and extensions of the bark.

The loss of green color that occurs in autumn, in the foliage of our deciduous trees, or on the maturing of the plant, as with the cereal grains, is related to the cessation of growth and death of the leaf, and results from chemical changes in the chlorophyl-pigment.

Plants naturally destitute of chlorophyl, like Indian pipe (*Monotropa*), Dodder (*Cuscuta*), Mushrooms, Toadstools, and fungi generally, are parasites on living or dead organisms, from which they derive their nourishment. Such plants cannot construct organic substances out of inorganic matters, as do the plants having chlorophyl.

When leaves, ordinarily green, are totally excluded from light, or develop at a low temperature, they have a pale yellow color; on exposure to light and warmth they become green. In both cases the *Chlorophyl-granules* are formed, but the chlorophyl-pigment appears only in the latter. In absence of iron, leaves are white, contain no chlorophyl granules, and growth is arrested.

There are many leafy plants cultivated for ornamental purposes with more or less brown, red, yellow, white, or variegated foliage, which are by no means destitute of chlorophyl, as is shown by microscopic examination, though this substance is associated with other coloring matters which mask its green tint.

**Structure of Leaves.**—While in shape, size, modes of arrangement upon and attachment to the stem, we find among leaves no end of diversity, there is great simplicity in the matter of their internal structure.

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. 56.)

Fig. 56 represents the appearance of a bit of bean-leaf as seen on a section from the upper to the lower surface, and highly magnified.

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 flat 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.

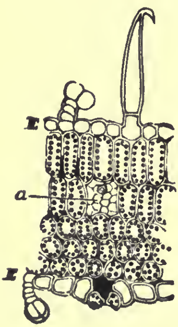

Fig. 56

The interspaces among the leaf-cells are occupied with air, which is also, in most cases, the only content of the epidermal cells. The interior cells of the leaf are filled with sap and contain the *chlorophyl-granules*. Under the microscope, these are commonly seen attached to the walls of the cells, as in Fig. 56, or coating grains of starch, or else floating free in the cell-sap.

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. 56, 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 irritating liquid.

**Leaf-Pores.**—The epidermis of the mature leaf is provided with a vast number of "breathing pores," or *stomata*, by means of which the intercellular spaces in the interior of the leaf are brought into direct communication with the outer atmosphere. Each of these stomata consists usually of two curved *guard-cells*, which are disposed toward each other like the halves of an elliptical carriage-spring. (Figs. 52 and 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 strong light they curve outwards, and the aperture is enlarged; in darkness they straighten and shut together, like the springs of a heavily-loaded carriage, and nearly or entirely close the entrance. The effect of water usually is to close their orifices.

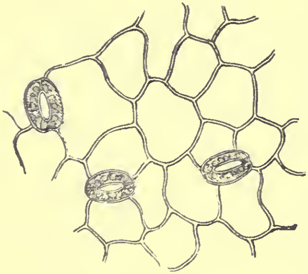
Fig. 57.

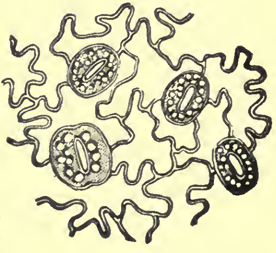
Fig. 58.

In Fig. 56 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-pores contain chlorophyll granules.

Fig. 57 represents a portion of the epidermis of the upper surface of a potato-leaf, and Fig. 58 a similar portion of the under surface of the same leaf, magnified 200 diameters. In both figures are seen the open stomata between the semi-elliptical cells. The outlines of the other epidermal cells are marked by irregular double lines. The round bodies in the guard-cells of the pores are starch-grains, often present in these cells, when not existing in any other part of the leaf.

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 the foliage of land plants, which are exposed to the heat of the sun, while they occur abundantly 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.

The epidermis itself is most dense—consists of thick-walled cells and several layers of them—in case of 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.

**Exhalation of Water-Vapor.**—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 vapor. 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 vigorous sunflower, three and a half feet high, whose foliage had an aggregate surface of 39 square feet, gave off 30 ounces av. of water in a space of 12 hours, during a very warm, dry day. The average "rate of perspiration" for 15 days, in July and August, was 20 ounces av. At night, with "any sensible, though small dew, the perspiration was nothing." Knop observed a maize-plant to exhale, between May 22d and September 4th, no less than 36 times its weight of water. Hellriegel (at Dahme, Prussia) found that summer wheat and rye, oats, beans, peas, buckwheat, red clover, yellow lupine and summer colza, on the average exhaled 300 grams of water for 1 gram of dry matter produced above ground, during the entire season of growth, when stationed in a sandy soil. (*Die Methode der Sandkultur*, p. 662.)

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 favorable to evaporation, the loss from the plant is rapid and large. When the air is loaded with moisture, as during dewy nights or rainy weather, then exhalation is nearly or totally checked.

The temperature of the soil, and even its chemical composition, the condition of the leaf as to its texture, age, and number of stomata, likewise affect the rate of exhalation.

Exhalation is rather incidental than necessary to the life of many plants, since it may be suppressed or reduced to a minimum, as in a Wardian case or fernery, without evident influence on growth; but plants of parentage naturally accustomed to copious exhalation of water flourish best where the conditions are favorable to this process. Exhalation is not injurious, unless the loss be greater than the supply. If water escapes from the leaves faster than it enters the roots, the succulent organs soon wilt, and if this disturbance goes on too far the plant 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 vapor occurs through the stomata. These pores appear to have the function of facilitating exhalation, by their property of opening when exposed to sunlight. Thus evaporation from the leaves is favored at the time when root-action is most vigorous, and the plant is to the greatest degree surcharged with water.

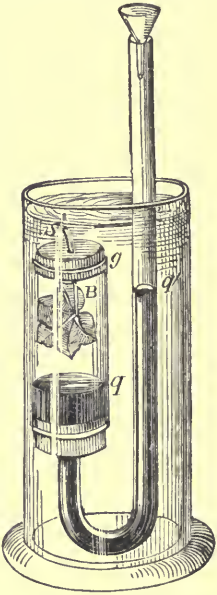

Fig. 59.

**Access of Air to the Interior of the Plant.**—Not only does the leaf allow the escape of vapor 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 or exhaling certain gaseous ingredients of the atmosphere during the whole of their healthy existence.

The entire plant is, often, 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.

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. 59, 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 air-passages of the stem 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 external pores, and are not pervious to air or vapor in the sense 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.

**The Offices of Foliage** are to put the plant in communication with the atmosphere and with the sun. On the one hand it permits, and to a certain degree facilitates, 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 that freely penetrates it, certain gases which furnish the principal materials for the construction 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 reorganization 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.

## REPRODUCTIVE ORGANS OF PLANTS.

### § 1.

### MODES OF REPRODUCTION.

Plants are reproduced in various ways. The simplest cellular plants have no evident special organs of reproduction, but propagate themselves solely by a process of division which begins in the protoplasm, as already described in case of Yeast, p. 253. The lower so-called flowerless plants (*Cryptogams*), including molds, blights, mildews, mushrooms, toadstools (*Fungi*), mosses, lichens, etc., reproduce themselves in part by *spores*, each of which is a single minute cell that is capable of developing into a plant like that from which it was thrown off.

In very many cases a portion or "cutting" of root, stem or leaf, from herb or tree, placed in moist, warm earth, will grow and develop into a new plant in all respects similar to the original. The potato, grape, banana, and sugar-cane plants are almost exclusively propagated in this manner. In budding and grafting a portion of stem, carrying a single bud or a number of buds (*scion*), is planted, not in the soil, but in the cambial layer of a living root or stem with which it unites and thenceforward grows.

The higher orders of plants (*Phanerogams*) have special reproductive organs, constituting or contained in their *flowers*, whose office it is to produce *seed*, the essential part of which is the *embryo*, a ready-formed miniature plant which may grow into the full likeness of its parent.

## § 2.

### THE FLOWER.

In the higher plants 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 color.

**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, color, 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 case of the apple, potato, and many common plants. Fig. 60 represents the complete flower of the *Fuchsia,* or ladies' ear-drop, now universally cultivated. In Fig. 61 the same is shown in section.

**The Calyx** (cup) *cx,* is the outermost floral envelope. Its color 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. In the Fuchsia it firmly adheres at its base to the seed-vessel, and is divided into four lobes.

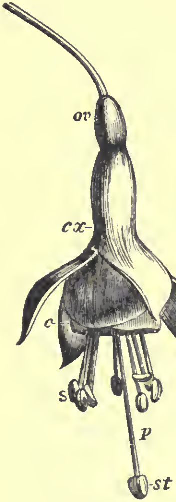

Fig. 60.

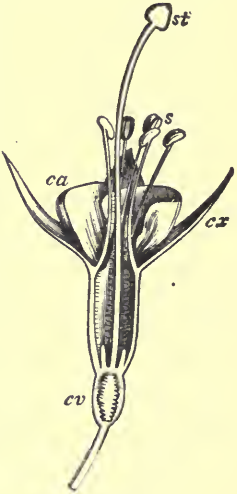

Fig. 61.

**The Corolla** (crown), *c*, or *ca,* is one or several series of leaves which are situated within the calyx. It is usually of some other than a green color (in the Fuchsia, purple, etc.), 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*. The Fuchsia has four petals, which are attached to the calyx-tube.

**The Stamens**, *s*, in Figs. 60 and 61, are generally slender, thread-like organs, 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 anthers, as well as the grains of pollen, vary in form with nearly every kind of plant. The yellow pollen of Pine and Spruce is not infrequently transported by the wind to a great distanee, and when brought down by rain in considerable quantities, has been mistaken for sulphur.

**The Pistil**, *p*, in Figs. 60 and 61, or pistils, occupy the center of the perfect flower. They are exceedingly various in form, but always have at their base the seed-vessels, or *ovaries*, *ov*, 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*, *st*.

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 structure.

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 ; the flower becoming "double." The tulip, poppy, and numerous garden-flowers, illustrate this interesting metamorphosis, and in these flowers we may often see the various stages intermediate between the perfect petal and the unaltered stamen.

On the other hand, the reversion of all the floral organs into ordinary green leaves has been observed not infrequently, in case of the rose, white clover, and other plants.

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 in which calyx and corolla are represented by scale-like leaves, which, as the plants mature, become chaff.

In various plants the stamens and pistils are borne on separate flowers. Such are called *monœcious* plants, of which the birch and oak, maize, melon, squash, cucumber, and often the strawberry, are examples.

In case of 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 fiber of which has an ovary at its base, that, if fertilized, develops to a kernel.

*Diœcious* plants are those which bear the staminate (male, or sterile) flowers and the pistillate (female, or fertile) flowers on different individuals; the willow, the hop-vine, and hemp, are of this kind.

**Nectaries** are special organs—glands or tubes—secreting a sugary juice or *nectar*, which serves as food to insects. The clovers and honeysuckles furnish familiar examples.

**Fertilization and Fructification.**—The grand function of the flower is *fructification*. For this purpose 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 microscopic tube which penetrates the interior of the pistil until it enters the seed-vessel 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. 62 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.

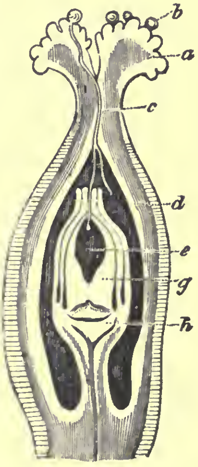

Fig. 62.

**Self-Fertilization** occurs when ovules are impregnated by pollen from the same flower. In many plants self-fertilization is favored by the position of the organs concerned. In the pendent flower of the Fuchsia as well as in the upright one of the strawberry the stigma is just below and surrounded by the anthers, so that when the mature pollen is discharged it cannot fail to fall upon the stigma. Some flowers, as those of the closed gentian (*Gentiana Andrewsii*) and the small subterranean blossoms of sheep-sorrel (*Oxalis acetosella*), touch-me-not (*Impatiens*), and of many violets, never open, and not only are self-fertile but cannot well be otherwise. Some plants which carry these closed and inconspicuous subterranean flowers depend upon them for reproduction by seed, their large and showy ærial flowers being often barren, as in violets, or totally infertile (*Voandzeia.*) Flax and turnips are self-fertilizing.

**Cross-Fertilization** results from the contact of the pollen of one flower with the ovules of another. In many plants remarkable arrangements exist that hinder or totally prevent self-fertilization and favor or ensure cross-fertilization.

In *monœcious* plants, as hazel or squash, flowers of one sort yield pollen, others, different, contain the ovules; so that two distinct and more or less distant blossoms of the same plant are necessary for seed-production.

In the *diœcious* poplar and hops, the plant that produces pollen never carries ovules and that which bears the latter is destitute of the former, so that two distinct plants must co-operate to form seeds.

It often happens that the pollen of a flower cannot fertilize the ovules of the same flower. This may be either because the stigma is behind the pollen in development, as in case of various species of geranium, or because the stigma has passed its receptive period before the pollen is mature, as in Sweet Vernal Grass (*Anthoxanthum odoratum*). In both instances the ripened pollen may reach stigmas that are ready in other flowers and fertilize their ovules, insects being often the means of transportation.

In a large number of flowers, whose pollen and stigmas are simultaneously prepared, the position of the organs is such that self-fertilization is difficult or impossible. The Iris, Crocus, Pansy, Milk-weed (*Asclepias*), and many Orchids, are of this class. The offices of insects in search of nectar, or attracted by odors, are here indispensable. The common red clover cannot produce seed without insect aid, and the bumblebee customarily performs this service. The insect, in exploring a flower for nectar, leaves upon its stigma pollen taken from the flower last visited, and in emerging renews its burden of pollen to bestow it in turn upon the stigma of a third flower.

Cross-fertilization is doubtless often effected by insects in case of flowers which are in all respects adapted for self-fertilization, while flowers that casual examination would pronounce self-fertile are in fact of themselves sterile. The flowers of rye open singly, the long stamens shortly mature and discharge their pollen, which falls on the stigmas of flowers standing lower in the same head, or on neighboring heads. According to Rimepare, the individual rye-flower can fertilize neither itself nor the different flowers of an ear, nor can the different ears of one and the same plant pollinate one another with success, although no mechanical hindrance exists. (Sachs, *Physiology of Plants*, p. 790.)

**Results of Self-Fertilization and Cross-Fertilization.**—Sprengel, one of the early students of Plant-Reproduction, wrote in 1793, "Nature appears to be unwilling that any flower shall be fertilized by its own pollen." Extensive observation indicates decidedly that cross-fertilization is far more general than self-fertilization, especially among the higher plants. Darwin has shown that, *in many cases*, the pollen of a flower is incapable of fertilizing its own ovules, and that the pollen from another flower of the same plant is scarcely more potent. In these cases the pollen from a flower borne by another plant of the same kind is potent, and *the more so the more unlike the two plants are.*

In Darwin's trials on the reproduction of the Morning Glory, *Ipomea purpurea,* carried out through ten generations, the average height of 73 self-fertilized plants was 66 inches, while that of the same number of crossed plants was 85.8 inches, or in the ratio of 77 to 100. The relative number of seeds produced by the self-fertilized and cross-fertilized plants in the 1st, 3d, and 9th generations were respectively as 64 to 100; 35 to 100, and 26 to 100.

In other cases, but, so far as observed, much less commonly, self-fertilization gives the best results both as regards numbers and vigor of offspring. In Darwin's experiments a variety of *Mimulus luteus* originated, of which the self-fertilized progeny surpassed the cross-fertilized, during several generations. In the seventh generation the ratio of superiority of the self-fertilized, as regards numbers of fruit, was as 137 to 100, and in respect to size of plants as 126 to 100.

Continued self-fertilization, is thus limited by its tendency, as statistically determined, to reduce both the vegetative and reproductive vigor of the plant. On the other hand, cross-fertilization is possible or practicable only within very narrow bounds, and the increased productiveness that follows it soon reaches a limit, as is shown by the history of vegetable hybrids.

That neither mode of fertilization is exclusively or specially adapted to the highest development of plants in general, or of particular kinds of plants, is shown by the fact that in the course of Darwin's researches on the *Ipomea purpurea*, just referred to, in the sixth generation a self-fertilized plant (variety) appeared, which was superior to its crossed collateral, and was able to transmit its vigor and fertility to its descendants.

It is evident, therefore, that the causes which lead to higher development co-operate most fully, sometimes in the one, sometimes in the other, mode of impregnation and do not necessarily belong to either. We must believe that excellence in offspring is the result of excellence in the parents, no matter what lines their heredity may have followed, except as these lines have influenced their individual excellence. That crossing commonly gives better offspring than in-and-in breeding is due to the fact that in the latter both parents are likely to possess by inheritance the same imperfections, which are thus intensified in the progeny, while in cross-breeding the parents more usually have different imperfections which often, more or less, compensate each other in the immediate descendants.

Hybridizing.—As the sexual union of quite different kinds of animals sometimes results in the birth of a hybrid, so, among plants, the ovules of one kind (species, or even genus) may be fertilized by the pollen of another different kind, and the seed thus developed, in its growth produces a hybrid plant. As in the animal, so in the vegetable kingdom, the range within which hybridization is possible appears to be very narrow. It is only between rather *closely allied* plants that fecundation can take place, and the more close the resemblance the more ready and fruitful the result. Wheat, rye, and barley, in ordinary cultivation, show no tendency to "mix;" the pollen of one of these similar plants rarely fertilizing * the ovules of the others. But external similarity is no certain mark of capacity for hybridization. The apple and pear have never yet been crossed, while the almond and nectarine readily form hybrids. (Sachs.)

Hybrids are usually less productive of seeds than the parent plants, and sometimes are entirely sterile, but, on the other hand, they are often more vigorous in their vegetative development—produce larger and more numerous leaves, flowers, roots, and shoots, and are longer-

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*In the first edition was written, "being incapable of fertilizing." The experiments of Mr. Carman have lately shown that wheat and rye may be made to produce fertile hybrids. A beardless wheat was fertilized by rye-pollen and produced nine seeds, eight of which were fully fertile, one nearly sterile. The last yielded 20 heads, which bore only a few grains. The plants from the nine fertile seeds were pollinated again with rye and produced but a few fertile seeds. A few plants, seven-eighths rye, were finally produced, which were, however, totally sterile. Of the three-fourths cross, fertile progeny has been raised for several years, and the characters of this genus-hybrid appear to be nearly fixed, though occasionally a sterile head appears.—*Rural New Yorker*, 1883, p. 644.

lived than their progenitors. For this reason hybrids are much valued in fruit- and flower-culture.

Some genera of plants have great capacity for producing hybrids. The Vine and the Willow are striking examples. The cultivated Vine of Europe and Western Asia is *Vitis vinifera.* In the United States some twelve distinct species are found, of which three, *Vitis riparia, Vitis æstivalis,* and *Vitis labrusca,* are native to New England. Nearly all these kinds of grape cross with such readiness that scores of new hybrids have been brought into cultivation. "The kinds now known as Clinton, Taylor, Elvira, Franklin, are hybrids of *V. riparia* and *V. labrusca.* York-Madeira, Eumelan, Alvey, Morton's Virginia, Cynthiana, are crosses of *V. labrusca* and *V. æstivalis.* Delaware is a hybrid of *V. labrusca, V. vinifera,* and *V. æstivalis.* Herbemont, Rulander, and Cunningham are hybrids of *V. æstivalis, V. cinerea,* and *V. vinifera.* The vine known in France as "Gaston-Bazille" is a hybrid of *V. labrusca, V. æstivalis, V. rupestris,* and *V. riparia.*"* The foregoing are "spontaneous wild hybrids." The "Rogers Seedlings," including Salem, Wilder, Barry, Agawam, Massasoit, etc., are examples of artificial hybrids of *V. vinifera* and *V. labrusca.*

Hybridization between plants is effected, if at all, by removing from the flower of one kind the stamens before they shed their pollen, and dusting the summit of the properly-matured pistil with pollen from another kind. Commonly, when two plants hybridize, the pollen of either will fertilize the ovules of the other. In some cases, however, two plants yield hybrids by only one order of connection.

The mixing of different Varieties, as commonly happens among maize, melons, etc., is not hybridization,

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*Millardet in *Sachs's Lectures on the Physiology of Plants*, 1887, p. 785.

in the long-established sense of this word, but rather "cross-breeding." The two processes are, however, fundamentally the same, and their results are sufficiently distinguished by the terms Species-hybrid, or Genus-hybrid, and Variety-hybrid. We are thus led to brief notice of the meaning of the terms *Species* and *Variety*, and of the distinctions employed in Botanical Classification.

**Species.**—Until recently naturalists generally held the view that in "the beginning" certain kinds of plants and animals were separately created, with the power to reproduce their own kind, but incapable of fertile hybridization, so that only such original kinds could be perpetuated. Such supposed original kinds were called **Species.** At present, on the contrary, most biologists regard all existing kinds of plants and animals as probably the results of a very slow and gradual development or evolution from one vastly remote ancestor of the simplest type. On this view a Plant-Species comprises a number of individuals, "among which we are unable to distinguish greater differences than experience shows us we should find among a number of plants raised from the seed of the same parent."

On the former view, plants yielding fertile hybrids or crosses must be Varieties of the same species. On the latter view different Species may hybridize. They are not originally different, and by Evolution or Reversion may pass into each other. On either view, the distinction of plants into species is practically the same, being largely a matter of expert judgment or agreement among authorities, and not capable of exact decision by reference to fixed rules or known natural laws. The characters that are taken to be common to all the individuals of a species are termed *specific characters.* The differences used to divide plants into species are called *specific differences.*

Naturalists, acting under the older view, attempted to draw specific characters more finely than is now thought practicable. Many plants formerly described as separate species are now united together into a single species, the various forms at first supposed to be specifically or originally distinct having been shown to be of common origin, either by producing them from each other or by observing that they were connected through a series of intermediate forms, insensibly grading into each other.

**Varieties.**—The individuals of any "species" differ. In fact, no two individuals are quite alike. Circumstances of climate, soil, and situation increase these differences, and *varieties* originate when such differences are inherited and in the progeny assume a *comparative permanence.* But as external conditions cause variation away from any particular representative of a species, so they may cause variation back again to the original type.

Varieties most commonly *originate* in propagation by seed, especially in case of the trees or plants commonly cultivated for their fruit. Seedling grapes, apples, or potatoes are very likely to differ from their parents. Seed which has been imperfectly ripened or long kept is said to be prone to yield new varieties.

Less frequently variations arise in propagation by cuttings, buds, grafts, or tubers. Pinks and Pelargoniums in the florist's hands are prolific of these "sports."

The causes that produce varieties are probably numerous, but in many cases their nature and their mode of action is obscure or unknown. Scarcity or abundance of nutriment, we can easily comprehend, may, on the one hand, dwarf a plant, or, on the other, lead to the production of a giant individual; but how, in some cases, the peculiarities thus impressed upon individuals become fixed, and are transmitted to subsequent generations, while in others they disappear, is difficult to explain.

Varieties may often be *perpetuated* for a long time by the seed. This is true of our cereal and leguminous plants, which commonly reproduce their kind with striking regularity. Varieties of some plants cannot, with certainty, be reproduced unaltered by the seed, but are continued in the possession of their peculiarities by cuttings, layers, and grafts. 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 (variety-hybridization) 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 case of varieties that have, to the greatest degree, departed from the original specific type and of course, in sterile hybrids.

The sports which originate in the processes of propagating from buds (grafts, tubers, cuttings) are perpetuated by the same processes.

Species and Varieties, as established in our botanical literature, are exemplified by the Vine, whose species are *vinifera, riparia, labrusca*, etc., and some of whose North American Varieties, the results of hybridization, have already been enumerated.

**Genus** (plural **Genera**).—Species which resemble each other in most important points of structure are grouped together by botanists into a *genus*. Thus the various species of oaks,—white, red, black, scrub, live, etc.,—taken together, form the Oak-genus *Quercus*, which has a series of characters common to all oaks (generic characters), that distinguishes them from every other kind of tree or plant.

**Families, or Orders,** in botanical language, are groups of genera that agree in certain particulars. Thus the several plants well-known as mallows, hollyhock, okra, 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.

**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 follows:

1. *Flowering Plants* (*Phanerogams*), which produce flowers and seeds with embryos, and
2. *Flowerless Plants* (*Cryptogams*), that have no proper flowers nor seeds, and are reproduced, in part, by *spores* which are in most cases single cells. This series includes Ferns, Horse-tails, Mosses, Liverworts, Lichens, Sea-weeds, Mushrooms, and Molds.

It was believed, until recently, that there exists a sharp and absolute distinction between flowering and flowerless plants, but our larger knowledge now recognizes that here, as among genera, species, and varieties, kinds merge or shade into each other.

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.

**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*, etc.

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 alfalfa 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, water-cress, etc., are termed *Cruciferous* plants, because their flowers have four petals arranged like the four arms of a cross (Latin, *crux*).

The flowers of 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, etc., which, from bearing such compound heads, are called *Composite* plants.

The *Coniferous* (cone-bearing) plants comprise the pines, spruces, larches, hemlocks, etc., whose flowers are arranged in conical receptacles.

The flowers of the carrot, parsnip, and caraway are stationed at the extremities of stalks which radiate from a central stem like the arms of an umbrella ; hence they are called *Umbelliferous* plants (from *umbel*, Latin for little screen).

## § 2.

### THE FRUIT.

THE FRUIT comprises the *seed-vessel* and the *seeds*, together with their various appendages.

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 base of the pistil in its matured state, 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.

**The Nut** has a hard, leathery or bony indehiscent shell, that usually contains a single seed. Examples are the acorn, chestnut, beech-nut, and hazel-nut. The cup of the acorn and the bur or shuck of the others is a sort of fleshy calyx.

**The Stone-fruit, or Drupe,** is a nut enveloped by a fleshy or leathery coating, like the peach, cherry, and plum, also the butternut and hickory-nut. Raspberries and blackberries are clusters of small drupes.

**Pome** is a term applied to fruits like the apple and pear, the core of which is the true seed-vessel, originally belonging to the pistil, while the often edible flesh is the enormously enlarged and thickened calyx, whose withered tips are 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, and huckleberry.

**Gourd fruits** have externally a hard rind, but are fleshy in the interior. The melon, squash, and cucumber are of this kind.

**The Akene** is a fruit containing a single seed which does not separate from its dry envelop. The so-called seeds of the composite plants—for example, the sunflower, thistle, and dandelion—are *akenes*. On removing the outer husk or seed-vessel we find within the true seed. Many akenes 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. The fruit or grain of buckwheat is akene-like.

**The 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-grain, in addition to the seed-vessel, has the petals of the flower or inner chaff, and oats have, besides these, the calyx 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.

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 connection.

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 fiber. 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*.

**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. 63, which is the embryo, to be presently noticed. The remainder of 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.

**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 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. 63 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, etc., 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 seedling. The first leaves which ap-

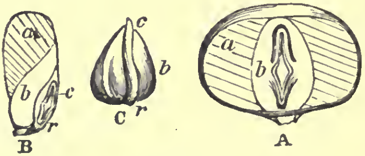

Fig. 63.

pear above-ground, in the case of maize and the other grains (buckwheat 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.

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. 290).

The seeds of the *Exogens* (outside-growers—p. 296) 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 ordinary 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. 64, are found separated 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.

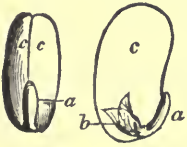

Fig. 64.

These leaves are folded together along their mid-ribs, and may be opened and spread out with help of a needle.

When the kidney-bean (*Phaseolus*) 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 aerial organs develop in succession.

In the horse-bean (*Vicia faba*), 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, shriveling 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.

**Duration of Vitality.**—In the mature seed 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.

On the other hand, single seeds of various plants, as of sorrel (*Oxalis stricta*), shepherd's purse (*Thlaspi arvense*), and especially of trees like the oak, beech, and cherry, remain with moist embryos many months or several years before sprouting. (Nobbe & Haenlein, *Vs. St.*, XX, p. 79.)

Among the seeds of various plants, clover for example, which, under favorable circumstances, mostly germinate within one or two weeks, may often be found a number which remain unchanged, sound and *dry within*, for months or years, though constantly wet externally. The outer coat of these seeds is exceptionally thick, dense, and resistant to moisture. If this coat be broken by the scratch of a needle the seed will shortly germinate. In a collection of such seeds, kept in water, individuals sprout from time to time. In case of common sorrel (*Rumex acetosella*), Nobbe & Haenlein found that 10 per cent of the seeds germinated between the 400th and 500th day of keeping in the sprouting apparatus.

The appearance of strange plants in earth newly thrown out of excavations may be due to the presence of such resistant seed, which, scratched by the friction of the soil in digging, are brought to germination after a long period of rest. Lyell states that seeds of the yellow Nelumbo (water lily) have sprouted after being in the ground for a century, and R. Brown is authentically said to have germinated seeds of a Nelumbo taken by him from Hans Sloane's herbarium, where they had been kept dry for at least 150 years.

The seeds of wheat usually, for the most part, lose their power of growth after having been kept from three to seven years. Count Sternberg and others are said to have succeeded in germinating wheat taken from an Egyptian mummy, but only after soaking it in *oil*. Sternberg relates that this ancient wheat manifested no vitality when placed in the soil under ordinary circumstances, nor even when submitted to the action of acids or other substances which gardeners sometimes employ with a view to promote sprouting.

Girardin claims to have sprouted beans that were over a century old. It is said that Grimstone with great pains raised peas from a seed taken from a sealed vase found in the sarcophagus of an Egyptian mummy, presented to the British Museum by Sir G. Wilkinson, and estimated to be near 3,000 years old.

Vilmorin, from his own trials, doubts altogether the authenticity of the "mummy wheat," and it is probable that those who have raised mummy wheat or mummy peas were deceived either by an admixture of fresh seed with the ancient, or by planting in ordinary soil, which commonly contains a variety of recent seeds that come to light under favorable conditions.

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 favor 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. Commonly, among the freshest seeds, when put to the sprouting trial, some will mold or putrefy.

The fact appears to be that the circumstances under which the seed is kept greatly influence the duration of its vitality. If seeds, when first gathered, be thoroughly dried, and then sealed up in air-tight vessels, there is no evident reason why their vitality should not endure for long periods. Moisture and the microbes that flourish where it is present, not to mention insects, are the agencies that usually put a speedy limit to the duration of the germinative power of seeds.

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, '55, '54, and '53. The following table exhibits the results :

| | *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:*

| | 1850 | 1851 | 1854 | 1855 | 1857 | 1858 | 1859 | 1860 |
|---|---|---|---|---|---|---|---|---|
| Wheat | 0 | 0 | 8 | 4 | 73 | 60 | 84 | 96 |
| Rye | 0 | 0 | 0 | 0 | 0 | 0 | 48 | 100 |
| Barley | 0 | 0 | 24 | 0 | 48 | 33 | 92 | 89 |
| Oats | 60 | 0 | 56 | 48 | 72 | 32 | 80 | 96 |
| Maize | 0 | not tried | 76 | 56 | not tried | 77 | 100 | 97 |

**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.

**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 connection 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 shriveled seeds will furnish low plants with double flowers throughout.

Cohn found that seeds not fully ripe germinate somewhat sooner than those which are more mature, and he believes that seeds in a medium stage of ripeness germinate most readily.

**Quick- and Slow-Sprouting Seeds.**—When a considerable number of agricultural or garden seeds, fresh and of uniform appearance, are placed under favorable circumstances for germinating, it is usually observed that sprouting begins within two to ten days, and continues for one or several weeks before all or nearly all the living embryos have manifestly commenced to grow. Nobbe (in 1886 and 1887) found in extensive trials with 12 varieties of stocks, *Matthiola annua*, that the quick-sprouting seeds, which germinated in three to four days, yielded earlier and larger plants, which blossomed with greater regularity and certainty, and produced a preponderance (82 per cent) of sterile double flowers, while the slow-sprouting seeds, that were ten to twelve days in germinating, gave smaller plants that came later to bloom, and yielded 73 per cent of fertile single flowers.

Should continued trials prove these results to be of constant occurrence, it is evident that by breeding exclusively from the quick-sprouting seeds, the double-flowering varieties should soon become extinct, from failure to produce seed. On the other hand, exclusive use of the slow-sprouting seeds would extinguish the tendency to variation and double-blooming, which gives this plant its value to the florist.

**Dwarfed or Light Seeds.**—Müller, as well as Hellriegel, found in case of the cereals that light or small grain sprouts quicker but yields weaker plants, and is not so sure of germinating as heavy grain.

Liebig asserts (*Natural Laws of Husbandry, Am. Ed.*, 1863, p. 24) that "poor and sickly seeds will produce stunted plants, which will again yield seeds bearing in a great measure the same character." This is true "in the long run," i. e., small or light seeds, the result of unfavorable conditions, will, under the continuance of those conditions, produce stunted plants (varieties), whose seeds will be small and light. (Compare Tuscan and pedigree wheat, p. 158.)

Schubart, whose observations on the roots of agricultural plants are detailed in a former chapter (p. 263), 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." Reference is here had to the immediate produce under ordinary agricultural conditions.

**Value of Seed as Related to its Density.**—From a series of experiments made at the Royal Agricultural College at Cirencester, in 1863–6, Church concludes that the value of seed-wheat stands in a certain connection 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 wheat-seeds are the most translucent or horny, and contain about one-fourth more proteids (or 3 per cent more) than the opake or starchy grains from the same kind of wheat, or even from the same individual plant, or even from the same ear.

7. The weight of wheat per bushel depends 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.

Marek has shown that specific gravity is no universal test of the quality of seed, for while, in case of wheat, flax, and colza, the large seeds are generally the denser, the reverse is true of horse-beans (*Vicia faba*) and peas (*Vs. St.*, XIX, 40).

**The Absolute Weight of Seeds** from different varieties of the same species is known to vary greatly, as is well exemplified by comparing the kernels of common field maize with those of "pop corn." Similar differences are also observable in different single seeds from the same plant, or even from the same pod or ear. Thus, Harz obtained what were, to all appearance, normally developed seeds that varied in weight as follows :

| FROM SINGLE PLANTS. | | *Milligrams.* |
|---|---|---|
| Wheat, *Triticum vulgare*, | from | 15 to 37 |
| Wheat, *Triticum polonicum*, | " | 21 to 55 |
| Barley, *Hordeum distichon*, | " | 31 to 41 |
| Oats, *Avena sativa*, | " | 19 to 30 |
| Maize, *Zea Mays cinquantino*, | " | 169 to 201 |
| Pea, *Pisum sativum*, | " | 143 to 502 |
| FROM SINGLE FRUIT (PODS). | | |
| Pea, | from | 309 to 473 |
| Vetch, | " | 33 to 66 |
| Lupin, | " | 486 to 639 |

Differences often no less marked are found among the seeds in any considerable sample, gathered from a large number of plants and representing a crop. Nobbe, with great painstaking, has ascertained the average, maximum and minimum weights, of 180 kinds of seeds, such as are found in commerce or are used in Agriculture, Horticulture, and Forestry. The following table gives some of his results :

*Absolute Weight of Commercial Seeds.*

| | Number of Samples Examined. | Weight of one Seed in Milligrams. | | |
|---|---|---|---|---|
| | | Average. | Maximum. | Minimum. |
| Oats,........................ | 84 | 28.8 | 54.1 | 14.7 |
| Barley,....................... | 66 | 41.0 | 48.9 | 27.7 |
| Rye,.......................... | 119 | 23.3 | 47.9 | 13.0 |
| Wheat,........................ | 95 | 37.6 | 45.8 | 15.2 |
| Maize,........................ | 22 | 282.7 | 382.9 | 114.5 |
| Beet,......................... | 39 | 22.0 | 42.4 | 14.2 |
| Turnip, *Brassica rapifera*,.. | 23 | 2.2 | 3.0 | 1.4 |
| Carrot,....................... | 35 | 1.2 | 1.7 | 0.8 |
| Pea,.......................... | 43 | 185.8 | 564.6 | 46.1 |
| Kidney Bean, *Phaseolus*,.... | 5 | 585.6 | 926.3 | 367.3 |
| Horse Bean, *Vicia*,.......... | 7 | 676.0 | 2061.0 | 256.4 |
| Potato,....................... | 3 | 0.6 | 0.7 | 0.5 |
| Tomato,....................... | 5 | 2.5 | 2.7 | 2.4 |
| Spinage,...................... | 4 | 6.9 | 9.0 | 2.4 |
| Radish,....................... | 5 | 7.1 | 9.7 | 5.7 |
| Lettuce,...................... | 18 | 1.1 | 1.7 | 0.8 |
| Parsnip,...................... | 3 | 3.1 | 3.8 | 2.3 |
| Squash,....................... | 5 | 173.0 | 322.0 | 106.7 |
| Musk Melon,................... | 3 | 32.9 | 35.5 | 28.2 |
| Cucumber,..................... | 6 | 25.4 | 27.0 | 21.0 |
| Timothy, *Phleum pratense*,. | 73 | 0.41 | 0.59 | 0.34 |
| Blue Grass, *Poa pratensis*,.. | 28 | 0.15 | 0.21 | 0.10 |
| Red Clover,................... | 355 | 1.60 | 2.08 | 1.14 |
| White Clover,................. | 53 | 0.61 | 0.69 | 0.47 |
| Ten-weeks-stocks, *Matthiola annua*,............... | 4 | 1.50 | 1.60 | 1.39 |
| Oak, *Quercus pedunculata*,. | 15 | 2013.4 | 4213.5 | 761.6 |

It is noteworthy, that in case of Oats, Rye, Wheat, Maize, Beet, Spinage, and Squash, the heaviest seeds weigh *thrice* as much as the lightest. With Turnip, Carrot, Kidney-bean, Lettuce, and Blue grass, some seeds are double the weight of others. The horse-bean gives some seeds eight times as heavy as others. The differences brought out in the Table in many cases are due to the representation of different varieties; the larger seeds, to some extent, belonging to larger plants; but the great range of weight, noted with regard to the seed of the Oak, applies to 15 crops of sound acorns from one and the same tree, gathered in 15 successive years.

In many varieties of Indian Corn, the kernels at the base of the ear are larger, and those at the tip are smaller, than those of the middle portion. Other varieties are characterized by great uniformity in the size of the kernels, having been "bred up" to this quality by careful seed-selection.

It is well-known that the middle part of the ears of wheat and barley produce the heaviest kernels. Nobbe numbered and weighed the spikelets from an ear of six-rowed barley and from one of winter wheat. Either ear contained 27 spikelets, each with three kernels. The kernels of the smallest barley-spikelet, No. 2, from the base of the ear, weighed 1.5 milligrams; those of the largest, No. 10, weighed 103.5 mg. No. 27 weighed 32.5 mg. The corresponding numbers in wheat weighed 0.5, 34.5 and 10.8 mg.

In case of barley, each of the first five spikelets, counting from the base, weighed less than 70 milligrams. The 6th to the 22d, inclusive, weighed 75 mg. or more. The 7th to the 16th weighed 90 mg. or more. The 17th to the 21st, 80 mg. or more. Thence, to the tip, the weight rapidly declined to about 30 milligrams.

The wheat kernels exhibited quite similar variation of weight.

Dividing the 27 spikelets into three groups of nine each, we have the following comparison of weights of seeds, to which is added the total lengths of the rootlets that were formed after germination had gone on for five days:

| | BARLEY. | | WHEAT. | |
|---|---|---|---|---|
| | Weight. | Length of Root. | Weight. | Length of Root. |
| Spikelets, 1 to 9 | 426 mg. | 670 mm. | 153 mg. | 223 mm. |
| " 10 to 18 | 828 " | 3281 " | 282 " | 1094 " |
| " 18 to 27 | 512 " | 1364 " | 191 " | 454 " |

The seeds of the middle portion of the ears of barley and wheat are thus seen to be very considerably heavier than those of either the base or tip, and also show greater germinative vigor, as measured by the comparative growth of the roots in a given short time.

The greater weight and germinative energy of the seeds from the middle of the ears, stand in relation to the fact that these seeds are the oldest—the flowers from which they develop being the first to open and fructify. In case of a head of summer rye, Nobbe found that the

33 spikelets, each with two buds, *required a week for blossoming;* the first of the 66 flowers to open were mostly those of the thirties and forties, and the last those of the tens, fifties, and sixties, counting from the base upward. These middle seeds had accordingly an earlier start, and better chance for full development, than those at the base and tip of the ear.

Oat kernels usually grow in pairs, the upper one of each pair being in general lighter and smaller than the lower one. Nobbe counted out 200 upper kernels, 200 lower kernels, and 200 average kernels, without selection. These were weighed, and, after soaking in water for 24 hours, were placed in a sprouting apparatus at a temperature of about 70° F. The results were as follows:

| | 100 seeds weighed. | Number of seeds that sprouted. On the | | | | | | | | Total in |
|---|---|---|---|---|---|---|---|---|---|---|
| | Grams. | 3d, | 4th, | 5th, | 6th, | 7th, | 8th, | 9th, | 10th days. | 10 days. |
| Upper Kernels, | 1.53 | 2 | 100 | 76 | 15 | 3 | 2 | | 1 | 199 |
| Lower Kernels, | 3.46 | 109 | 75 | 9 | 3 | 2 | | | | 198 |
| Average Kernels, | 2.69 | 45 | 110 | 30 | 8 | 4 | 1 | 1 | | 199 |

Here, as in case of wheat and barley, the light seeds were slower to germinate.

In general, it would appear that, other things being equal, stronger and more perfect plants and larger crops are produced from heavy than from small seeds. Many comparisons are on record that have given such results; not only small trials in garden plats, but also field experiments on a larger scale.

Lehmann sowed, on each of three plats of 92 square feet, the same number (528) of peas, of the same kind but of different weight, with results as here tabulated·

| | Weights of 100 seed-peas. | No. of plants. | Yield (grams). Kernels. | Pods. | Straw. | Total. |
|---|---|---|---|---|---|---|
| Small seed-peas, | 160 gm. | 423 | 998 | 280 | 2010 | 3288 |
| Medium seed-peas, | 221 " | 478 | 1495 | 357 | 2630 | 4482 |
| Large seed-peas, | 273 " | 480 | 1814 | 437 | 3170 | 5421 |

Of the peas sown, there failed to germinate about 9 per cent, both of the large and medium sizes, and 20 per cent of the small ones.

The total produce from the small seeds was less abundant in all respects than that of the medium, and this less than that of the large seeds.

Calculated upon the same number of plants, the differences, though less in degree, are still very decided :

| 100 Plants Yielded | Kernels. | Pods. | Straw. | Total. |
|---|---|---|---|---|
| From small seeds, | 236 | 66 | 475 | 777 |
| From medium seeds, | 313 | 75 | 550 | 938 |
| From large seeds, | 378 | 91 | 660 | 1129 |

Lehmann, in another experiment, found that from the same weight of seed a larger crop is given by large seed than by small, although the number of plants may be considerably less.

From the same weight (188 gm.) of seed-peas were produced :

| | Number of | | Weight of Kernels | |
|---|---|---|---|---|
| | Seed-peas. | Plants. | per 92 sq. ft. | Per 100 plants. |
| By small seed, | 780 | 680 | 1590 | 234 |
| By medium seed, | 530 | 505 | 2224 | 440 |
| By large seed, | 384 | 360 | 2307 | 640 |

Driesdorff sowed separately, on the same land, winter wheat, as winnowed, and the same divided by sifting into three sizes. In April and May the vegetation from the largest seed was evidently in advance, and at harvest the relative yield for 100 of unsifted seed was 121 from the largest, 105 for the medium, and 95 for the smallest seed.

Improved varieties are often the result of continued breeding from the heaviest or largest seeds, accompanied by high culture on rich soil, and thin planting, so that the roots have abundant earth for unhindered development.

Hallet, in 1857, selected two ears of Nursery Wheat, "the finest quality of red wheat grown in England," containing, together, 87 grains, and planted the kernels 12 inches apart every way. At harvest one prime grain produced 10 ears, that contained in the aggregate 688 kernels. The finest 10 ears that could be selected from the whole produce of the other 86 grains yielded but 598 kernels. The 79 kernels of the one best ear were planted as before, and the produce of the finest seed, *as shown by the harvest*, was used for the next year's sowing. The results of continuing this process of selection are tabulated below :

| Year. | | Length, inches. | Containing, grains. | Number of ears on finest stool. |
|---|---|---|---|---|
| 1857. | Original,.............................. | 4⅜ | 47 | |
| 1858. | Finest ear,.......................... | 6¼ | 79 | 10 |
| 1859. | Finest ear,.......................... | 7¾ | 91 | 22 |
| 1860. | *Ears imperfect from wet season,...* | | | 39 |
| 1861. | Finest ear,.......................... | 8¾ | 123 | 52 |

In five years, accordingly, the length of the ears was doubled, their contents nearly trebled, and the tillering capacity of the plant increased five-fold. (*Journal Royal Ag. Soc.*, XXII, p. 374.)

Wollny has given account of 27 garden trials, with large and small seeds of rye, buckwheat, beans, vetches, peas, lupins, soybeans, colza, mustard, maize, and red-clover, on plats of four square meters (43 sq. ft.), during the years 1873 to 1880, with the nearly invariable results : 1, that the quantity of crop increases with the size of the seed ; 2, that the large seed produces principally large seed, and the small seed small ; 3, that the relative productiveness of the small seed is greater than that of the large ; and 4, that the vitality of the plants from small seed is usually less than that of the plants from large seed.

The facts of experience fully justify the conclusion that, in general, other things being equal, the heaviest seed is the best.

**Signs of Excellence.**—So far as the common judgment can determine by external signs, the *best seed* is that which, on the one hand, is large, plump, and heavy, and on the other is fresh or bright to the eye, and free from musty odor. The large, plump, and heavy seeds are those which have attained the fullest development, and can best support the embryo when it shall begin to grow; those fresh in color and odor are likely to be new, and to have the most vigorous vitality.

**Ancestry; Race-Vigor; Constancy.**—There are, however, important qualities in seed that are involved in their heredity and give no outward token of their presence. Race-vigor and Constancy are qualities of this sort, and these wonderfully persist in some kinds of seed and are lacking in others. All cultivated plants occur in numerous varieties, and, as the years go on, older varieties "run out" or are neglected and forgotten, their place being taken by newer and often, or for a time, better ones. It would appear that a long course of careful cultivation under the most favorable and uniform conditions, coupled with careful and intelligent selection of seed from the best-developed plants, not only leads to the formation of the best varieties, but tends to establish their permanence, so that when soil, climate, and care are unfavorable, the kind maintains its character and makes a stout resistance to deteriorating influences.

In order to properly appreciate the value of seed, its Pedigree must therefore be known. But seed of ancestry, that has a long-established character for certain qualities, in a given locality, may prove of little value under widely different circumstances, or, if its products be cultivated under new conditions, it may lose its characteristics more or less, and develop into other varieties. It is well known that various perennial plants of tropical climates, like the castor bean, become annuals in northern latitudes, and it may easily happen that the seed of some prized variety which is of unquestioned pedigree, as far as the remote lines of its descent can indicate, is of little worth in soils or climates to which it is unaccustomed, from not having the power to transmit the specially valuable qualities of its progenitors. In high, northern latitudes, the summer cereals ripen after a short period of rapid growth, but seed of such grain, sown in the soil of temperate regions, does not produce early varieties; its rate of growth, after a few years at most, is governed by the climate to which it is exposed. In considering the pedigree of seed, therefore, it is not merely the repute or characters of the ancestry, but the probability that the ancestral excellencies reside in and will be transmitted by the seed, that constitutes the practical point.

# DIVISION III.

# LIFE OF THE PLANT.

## CHAPTER I.

## GERMINATION.

### § 1.

### INTRODUCTORY.

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, etc., which constitute directly or indirectly almost the entire food of animals.

The beginning of the agricultural plant is in the flower, 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, or weeks, 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 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, one-half, 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 12 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, of 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.

In all agricultural plants the radicle buries itself in the soil. The plumule ascends into the atmosphere and seeks exposure to the direct light of the sun.

The endosperm, if the seed have one, and in many cases the cotyledons (so with the horse-bean, pea, maize, and barley), remain in the place where the seed was deposited. In other cases (kidney-bean, buckwheat, squash, radish, etc.) the cotyledons ascend and become the first pair of leaves.

The ascending plumule shortly unfolds new leaves, and, if coming from the seed of a branched plant, lateral buds make their appearance. The radicle divides and subdivides in beginning the issue of true roots.

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 :—

*a.* **Temperature.**—Seeds sprout within certain more or less narrow limits of warmth.

Sachs has approximately ascertained, for various agricultural seeds, the limits of warmth at which germination is possible. The lowest temperatures range from below 40° to 55°, the highest, from 102° to 116°. 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 79° and 93°. Either elevation or reduction of temperature from these degrees retards the act of sprouting.

In the following table are given the special temperatures for six common plants :

| | Lowest Temperature. | Highest Temperature. | Temperature of most rapid Germination. |
|---|---|---|---|
| Wheat,* | 40° F. | 104° F. | 84° F. |
| Barley, | 41 | 104 | 84 |
| Pea, | 44.5 | 102 | 84 |
| Maize, | 48 | 115 | 93 |
| Scarlet-bean, | 49 | 111 | 79 |
| Squash, | 54 | 115 | 93 |

For the agricultural plants cultivated in New England, a range of temperature of from 55° to 90° 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. Some seeds will germinate near 32°, the freezing point of water, as is true of wheat, rye, and water-cress, as well as of various alpine plants that grow in soil wet with the constant drip from melting ice. On the other hand, the cocoanut is said to yield seedlings with greatest certainty when the heat of the soil is 120°.

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. Very low temperatures retard the production of new rootlets, buds, and leaves. The rootlets which are rudimentary in 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 favorable temperatures bring the parts of the embryo first into development, at the same time the rudiments of new organs are formed which are afterwards to unfold.

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* Wheat, and probably barley, may, occasionally, germinate at, or very near, 32°.

*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 of the contents of the germ-cells can take place. 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.

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 most agricultural plants, indeed, will quicken under water, but they germinate most healthfully when moist but not wet. Excess of water often causes seeds to rot.

*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 an atmosphere of other gases. The chemical activity of oxygen appears to be the means of exciting the growth of the embryo.

*d.* **Light.**—It has been erroneously taught that *light* is prejudicial to germination, and that therefore seed must be covered. (*Johnston's Lectures on Ag. Chem. & Geology,* 2d Eng. Ed., pp 226 and 227.) 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. The warm and moist forests of tropical regions, which, though shaded, are by no means dark, are covered with sprouting seeds. 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 certainty than when buried out of sight.

Finally, R. Hoffmann (*Jahresbericht über Agricultur Chem.*, 1864, p. 110) found, in special experiments with 24 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. It is said that the fresh seeds of the willow begin to sprout within 12 hours after falling to the ground. Those of clover, wheat, and other grains, mostly germinate in three to ten 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 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 or otherwise resistant envelopes require the longest periods to excite growth.

The time necessary for germination depends naturally upon the favorableness of other conditions. Cold and drought delay the process, 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 action.

Notice has already been made of the frequent presence in clover-seed, for example, of a small proportion of seeds that have a dense coat which prevents imbibition of water and delays their germination for long periods. See p. 335.

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 41° F., 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 22 days before beginning to sprout.

At 51°, the time was shortened about one-half in case of the seeds just mentioned. Maize required 11, kidney-beans 8, and tobacco 31 days at this temperature.

At 65° the cereals, clover, peas, and flax began to sprout in one to two days; maize, beans, and sugar-beet in three days, and tobacco in six days.

The time of completion varies with the temperature much more than that of beginning. It is, for example, according to Sachs,

at 41—55° for wheat and barley 40—45 days.
at 95—100° " " 10—12 "

At a given temperature small seeds complete germination much sooner than large ones. Thus at 55–60° the process is finished

with beans in 30—40 days.
" maize in 30—35 "
" wheat in 20—25 "
" clover in 8—10 "

These differences are simply due to the fact that the smaller seeds have smaller stores of nutriment for the young plant, and are therefore more quickly exhausted.

**Proper Depth of Sowing.**—The soil is usually the medium of moisture, warmth, etc., 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 nearly universal result of experience in temperate regions that agricultural seeds germinate most surely when sown at a depth not exceeding one or two 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 six to eight inches deep without detriment, and are thereby better secured from the ravages of the domestic pigeon.

The Moqui Indians, dwelling upon the table lands 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 100° 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 snows.*

R. Hoffmann, experimenting in a light, loamy sand, upon 24 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, horse-radish, hemp, and turnips; finally, at 3 inches, lucern also appeared. Hoffmann states that the deep-planted seeds generally sprouted most quickly, and all early dif-

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* For these interesting facts, the writer is indebted to Prof. J. S. Newberry.

ferences 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 three-eighths to one and a fourth inches gave the earliest and strongest plants; seeds deposited at a depth of two and a half inches required five days longer to come up than those planted at three-eighths of an inch. 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 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.

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, Transfer;* and 3, *Assimilation* of the same.

1. **The Act of Solution** has no difficulty in case of

dextrin, gum, the sugars, and soluble proteids. The water which the seed imbibes, to the extent of one-fourth to five-fourths of its weight, at once dissolves them.

It is otherwise with the fats or oils, with starch and with proteids, 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 follows:

*Solution of Fats.*—Sachs was the first to show that squash-seeds, which, when ripe, contain no starch, sugar, or dextrin, but are very rich in oil (50%) and albuminoids (40%), suffer by germination such chemical change that the oil rapidly diminishes in quantity (nine-tenths disappear), while, at the same time, ***starch, and*** *in some cases sugar, is formed.* (*Vs. St.*, III, p. 1.)

*Solution of Starch.*—The starch that is thus organized from the fat of the oily seeds, or that which exists ready-formed in the farinaceous (floury) seeds, undergoes further changes, which have been previously alluded to (p. 50), whereby it is converted into substances that are soluble in water, viz., dextrin and dextrose.

*Solution of Albuminoids.*—Finally, the insoluble albuminoids are gradually transformed into soluble modifications.

**Chemistry of Malt.**—The preparation and properties of *malt* may serve to give an insight into the nature of the chemical metamorphoses that have just been indicated.

The preparation is in this wise. Barley or wheat (sometimes rye) is soaked in water until the kernels are soft to the fingers; then it is drained and thrown up in heaps. The masses of soaked grain shortly dry, become heated, and in a few days the embryos send forth their radicles. The heaps are shoveled 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 dry mass, after removing the sprouts (radicles), is malt, such as is used in the manufacture of beer.

Malt thus consists of starchy seeds, whose germination has been checked while in its early stages. 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, 2, pp. 8–23), exhibit the composition of 100 parts of Barley, and of the 92 parts of Malt, and the two and a half of Sprouts which 100 parts of Barley yield.*

| 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 Albuminoids, | 1.26 | 1.96 | 0.40 |
| Dextrin,† | 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. | 92. | 2.5 |

It is seen from the above statement that starch, fat, and insoluble albuminoids have diminished in the malting process; while soluble albuminoids, dextrin, and other soluble non-nitrogenous matters have somewhat increased in quantity. With exception of 3% of soluble "extractive matters," ‡ the differences in composition between barley and malt are not striking.

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* The analyses refer to the materials in the dry state. Ordinarily they contain from 10 to 16 per cent of water. It must not be omitted to mention 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.

† Later investigators deny the existence of dextrin in barley, but find, instead, amidulin and amylan. See p. 62, note.

‡ The term *extractive matters* is here applied to soluble substances, whose precise nature is not understood. They constitute a mixture which the chemist is not able to analyze.

The properties of the two are, however, remarkably different. If malt be pulverized and stirred in warm water (155° F.) for an hour or two, the whole of the starch disappears, while sugar and dextrin take its place. The former is recognized by the sweet taste of the wort, as the solution is called. On heating the wort to boiling, a little albuminoid is coagulated, and may be separated by filtering. This comes in part from the transformation of the insoluble albuminoids of the barley. On adding to the filtered liquid its own bulk of alcohol, dextrin becomes evident, being precipitated as a white powder.

Furthermore, if we mix two to three parts of starch with one of malt, we find that the whole undergoes the same change. An additional quantity of starch remains unaltered.

The process of germination thus develops in the seed an agency by which the conversion of starch into soluble carbhydrates is accomplished with great rapidity.

**Diastase.**—Payen & Persoz attributed this action to the nitrogenous ferment which they termed *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 dextrin and finally into sugar, and that malt yields one five-hundredth of its weight of this substance. See p. 103.

A short time previous to the investigations of Payen & Persoz (1833), Saussure found that *Mucedin,** the soluble nitrogenous body which may be extracted from gluten (p. 92, note), transforms starch in the manner above described, and it is now known that various albuminoids may produce the same effect, although the rap-

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* Saussure designated this body *mucin*, but this term being established as the name of the characteristic ingredient of animal mucus, Ritthausen has replaced it by mucedin.

idity of the action and the amount of effect are usually far less than that exhibited by the so-called diastase.

It must not be forgotten, however, that in all cases in which the conversion of starch into dextrin 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 or even low 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, etc., of the cotyledons.

This may be true at first, but, as we shall presently see, the chief action of oxygen is probably of another kind.

How diastase or other similar substances accomplish the change in question is not certainly known.

**Soluble Starch.**—The conversion of starch into sugar and dextrin is thus in a sense 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 starch, without conversion into dextrin 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. 52, *Amidulin*,

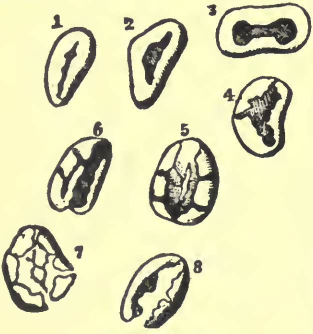

Fig. 65.

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 (as seen in Fig. 65, 1). This at first becomes filled with a liquid. Next, the cavity appears enlarged (2), its borders assume a corroded appearance (3, 4), and frequently channels are seen extending to the surface (4, 5, 6). Finally, the cavity becomes so large, and the channels so extended, that the starch-grain falls to pieces (7, 8). Solution continues on the fragments until they have completely disappeared.

**Soluble Albuminoids.**—The insoluble proteids of the seed are gradually transferred to the young plant, probably by ferment-actions similar to those referred to under the heading "Proteoses and Peptones," p. 100.

The production of small quantities of acetic and lactic acids (the acids of vinegar and of sour milk) has been observed in germination. These acids perhaps assist in the solution of the albuminoids.

**Gaseous Products of Germination.**—Before leaving this part of our subject, it is proper to notice some other results of germination which have been thought to belong to the process of solution. On referring to the table of the composition of malt, we find that 100 parts of dry barley yield 92 parts of malt and 2½ of sprouts, leaving 5½ parts unaccounted for. In the malting process, 1½ parts of the grain are dissolved in the water in which it is soaked. The remaining 4 parts escape into the atmosphere in the gaseous form.

Of the elements that assume the gaseous condition, carbon does so to the greatest extent. It unites with atmospheric oxygen (partly with the oxygen of the seed, according to Oudemans), producing carbonic acid gas ($CO_2$). Hydrogen is likewise separated, partly in union with oxygen, as water ($H_2O$), but to some degree in the free state. Free nitrogen appears in considerable amount (Schulz, *Jour. für Prakt. Chem.*, 87, p. 163), while very minute quantities of Hydrogen and of Nitrogen combine to gaseous ammonia ($NH_3$).

**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 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.

**2. The Transfer of the Nutriment of the Seedling** from the cotyledons or endosperm 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 downwards into the extending radicles, after a little while both downwards and upwards toward the extremities of the seedling.

Sachs has observed that the carbhydrates (sugar and dextrin) 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.

In another chapter we shall notice at length the phenomena and physical laws which govern the diffusion of liquids into each other and through membranes similar to those which constitute the walls of the cells of plants, and there shall be able to gather some idea of the causes which set up and maintain the transfer of the materials of the seed into the infant plant.

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 or similar chemical composition. Thus, dextrin 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.

**Oxygen Gas needful to Assimilation.**—Traube has made some experiments, which prove conclusively that the process of assimilation requires free oxygen to surround and to be absorbed by the growing parts of the germ. This observer found that newly-sprouted pea-seedlings continued to develop in a normal manner when the cotyledons, radicles, and lower part of the stem were withdrawn from the influence of oxygen by coating with varnish or oil. On the other hand, when the tip of the plumule, for the length of about an inch, was coated with oil thickened with chalk, or when by any means this part of the plant was withdrawn from contact with free oxygen, the seedling ceased to grow, withered, and shortly perished. Traube observed the elongation of the stem by the following expedient.

A young pea-plant was fastened by the cotyledons to a rod, and the stem and rod were both graduated by delicate cross-lines, laid on at equal intervals, by means of a brush dipped in a mixture of oil and indigo. The growth of the stem was now manifest by the widening of the spaces between the lines; and, by comparison with those on the rod, Traube remarked that no growth took place at a distance of more than ten to twelve lines from the base of the terminal bud.

Here, then, is a coincidence which appears to demonstrate that free oxygen must have access to a growing part. The fact is further shown by varnishing one side of the stem of a young pea. The varnished side ceases to extend, the uncoated portion continues enlarging, which results in a curvature of the stem.

Traube further indicates in what manner the elaboration of cellulose from sugar may require the co-operation of oxygen and evolution of carbon dioxide, as expressed by the subjoined equation.

$$\begin{array}{ccccccccc} \text{Glucose.} & & \text{Oxygen.} & & \text{Carbon dioxide.} & & \text{Water.} & & \text{Cellulose.} \\ 2\,(C_{12}H_{24}O_{12}) & + & 24\,O & = & 12\,(CO_2) & + & 14\,(H_2O) & + & C_{12}H_{20}O_{10}. \end{array}$$

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.

## CHAPTER II.

### § 1.

### THE FOOD OF THE PLANT WHEN INDEPENDENT OF THE SEED.

This subject will be sketched in this place in but the briefest outlines. To present it fully would necessitate entering into a detailed consideration of the Atmosphere and of the Soil, whose relations to the Plant, those of the soil especially, are very numerous and complicated. A separate volume is therefore required for the adequate treatment of these topics.

The Roots of a plant, which are in intimate contact with the soil, absorb thence the water that fills the active cells; they also imbibe such salts as the water of the soil holds in solution; they likewise act directly on the soil, and dissolve substances, which are thus first made of avail to them. 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 unessential to its growth, viz., silica and sodium salts, the roots absorb the following substances, viz. :

| | | |
|---|---|---|
| Sulphates | of | Potassium, |
| Phosphates | | Calcium, |
| Nitrates and | | Magnesium and |
| Chlorides | | Iron. |

These salts enter the plant by the absorbent surfaces of the younger rootlets, and pass upwards, through the stem, to the leaves and to the new-forming buds.

The Leaves, which are unfolded to the air, gather from it *Carbon dioxide Gas*. This compound suffers decomposition in the plant; its *Carbon* remains there, its *Oxygen* or an equivalent quantity, very nearly, is thrown off into the air again.

The decomposition of carbon 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 with the co-operation of the ash-ingredients, the plant organizes the Carbhydrates. Probably some of the glucoses are the first products of this synthesis. Starch, in the form of granules, is the first product that is recognizable by help of the microscope.

The formation of carbhydrates appears to proceed in the chlorophyl-cells of the leaf, where starch-granules first make their appearance.

The Albuminoids require for their production the presence of a compound of *Nitrogen*. The salts of *Nitric Acid* (nitrates) are commonly the chief, and may be the only, supply of this element.

The other proximate principles, 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 carbhydrates, albuminoids, etc., that are organized in the foliage, are not only transformed into the solid tissues of the leaf, but descend and diffuse to every active organ of the plant.

The plant has, within certain limits, a power of selectting its food. The sea-weed, as has been remarked, contains more potash than soda, although the latter is 30 times more abundant than the former in the water of the ocean. Vegetation cannot, however, entirely shut out either excess of nutritive matters or bodies that are of no use or even poisonous to it.

The functions of the Atmosphere are essentially the same towards plants, whether growing under the conditions of water-culture or under those 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. 184), in order to appropriate one of their ingredients, the other being rejected. In water-culture, the experimenter must have a care 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, commonly 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 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, may accumulate large supplies of all the elements of the Volatile part of Plants. Carbon, certainly in the form of carbon dioxide, probably or possibly in the condition of Humus (Vegetable Mold; Swamp Muck), may thus be put as food, at the disposition of the plant. Nitrogen is chiefly furnished to crops by the soil. Nitrates are formed in the latter from various sources, and ammonia-salts, together with certain proximate animal principles, viz., urea, guanin, tyrosin, uric acid and hippuric acid, likewise serve to supply nitrogen to vegetation and are often ingredients of the best manures. It is, too, from the soil that the crop gathers all 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.

Very erroneous notions have been entertained with regard to the nature and motion of sap. It was formerly taught that there are two regular and opposite currents of sap circulating in the plant. It was stated that the "crude sap" is taken up from the soil by the roots, ascends through the vessels (ducts) of the wood, to the leaves, there is concentrated by evaporation, "elaborated" by the processes that go on in the foliage, and thence descends through the vessels of the inner bark, nourishing these tissues in its way down. The facts from which this theory of the sap naturally arose admit of a very different interpretation; while numerous considerations demonstrate the essential falsity of the theory itself.

**Flow of Sap in the Plant—not Constant or Necessary.**—We speak of the *Flow of Sap* as if a rapid current were incessantly streaming through the plant, as the blood circulates in the arteries and veins of an animal. This is an erroneous conception.

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 water under pressure, which escapes at any outlet that may be opened for it. The sap is at rest until motion is caused by a perforation of the bark and new wood. So, too, when a plant in early leaf is situated in an atmosphere charged with moisture, as happens on a rainy day, there is little motion of its sap, although, if wounded, motion may be established, and water may stream more or less from all parts of the plant towards the cut.

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 vapor. When a wet cloth hung out, dries rapidly by giving up its moisture to the air, then the leaves of plants lose their water 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. Hellriegel, in the drier climate of Dahme, Prussia, observed exhalation to average 300 times the dry weight of various common crops (p. 312). The water that thus evaporates from the leaves is supplied by the soil, and, entering the roots, more or less rapidly streams upwards through the stem as long as a waste is to be supplied, but this flow ceases when evaporation from the foliage is suppressed.

The upward motion of sap is therefore to a great degreat independent of the vital processes, and comparatively unessential to the welfare of the plant.

**Flow of Sap from the Plant; "Bleeding."**—It is a familiar fact, 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 very many plants.

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.* This water

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* Experiments made in Tharand, Saxony, under direction of Stoeckhardt, show that the proportion of water, both in the bark and wood

is either pumped into the plant, so to speak, by the root-power already noticed (p. 269), or it is generated in the trunk itself. The water contained in the stem in winter is undoubtedly that raised from the soil in the autumn. That which first flows from an auger-hole, in March, may be simply what was thus stored in the trunk; but, as the escape of sap goes on for 14 to 20 days at the rate of several gallons per day from a single tree, new quantities of water must be continually supplied. That these are pumped in from the root is, at first thought, difficult to understand, because, as we have seen (p. 272), the root-power is suspended by a certain low temperature (unknown in case of the maple), and 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 to have 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 to admit the movement of water in it. That water may be produced in the trunk itself to a slight extent is by no means impossible, for chemical changes go on there in spring-time with much rapidity, whereby the sugar of the sap is formed. These changes have not been sufficiently investigated, however, to prove or disprove the generation of water, and we must, in any case, assume that it is the root-power which chiefly maintains a pressure of liquid in the tree.

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

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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. *Chem. Ackersmann*, 1866, p. 159.

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 absorbed by the dark, rough surface of the tree most abundantly; 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.

Duchartre (*Comptes Rendus,* IX, 754) passed a vine situated in a grapery, out of doors, and back again, through holes, so that a middle portion of the stem was exposed to a steady winter temperature ranging from 18° to 10° F., while the remainder of the vine, in the house, was surrounded by an atmosphere of 70° F. Under these circumstances the buds within developed vigorously, but those without remained dormant and opened not a day sooner than buds upon an adjacent vine whose stem was all out of doors. That sap passed through the cold part of the stem was shown by the fact that the interior shoots sometimes wilted, but again recovered their turgor, which could only happen from the partial suppression and renewal of a supply of water through the stem. Payen examined the wood of the vine at the conclusion of the experiment, and found the starch which it originally contained to have been equally removed from the warm and the exposed parts.

That the rate at which sap passed through the stem was influenced by its temperature is a plain deduction from the fact that the leaves within were found wilted in the morning, while they recovered toward noon, although the temperature of the air without remained below freezing. The wilting was no doubt chiefly due to the diminished power of the stem to transmit water; the return of the leaves to their normal condition was probably the consequence of the warming of the stem by the sun's radiant heat.*

One 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 32° to 212°, 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

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* The temperature of the *air* is not always a sure indication of that of the solid bodies which it surrounds. A thermometer will often rise by exposure of the bulb to the direct rays of the sun, 30 or 40° above its indications when in the shade.

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.

As the season advances and the soil becomes heated, the root-power undoubtedly acts with increased vigor 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. At this point we have a proper motion of sap *in the tree,* whereas before there was little motion at all in the sound trunk, and in the tapped stem the motion was towards the orifice and thence *out of the tree.*

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 wilt 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. In case of evergreens we have a stem destitute of all proper vascular tissue, and admitting a flow of liquid only through perforations of the wood-cells, if these really exist (which Sachs denies). Again, the leaves admit of continual evaporation, and furnish an outlet to the water. The colored 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. In the young branches, there are no channels that permit the rapid efflux 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, etc., of potassium, calcium, and magnesium. 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 spring sap of trees; or may be newly formed, as in summer growth.

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.*, 5, 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 carbon dioxide and unite its carbon to the elements of water, with the production of sugar and other carbhydrates. 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 proteids 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 color, and of different flavor.

It is a matter of observation that maple-sugar is whiter, purer, and "grains" or crystallizes more readily in those years when spring-rains or thaws are least frequent. This fact would appear to indicate that the brown organic matters which water extracts from leaf-mold may enter the roots of the trees, as is the belief of practical men.

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 appears to consist mostly or entirely of dextrose.

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 dextrin is found in its stead.

What has already been stated makes evident that 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 sun-flower plants. He found that successive portions, collected separately, exhibited a decreasing concentration. In sunflower sap, gathered in five successive portions, the liter contained the following quantities (grams) of solid matter :

| | 1. | 2. | 3. | 4. | 5. |
|---|---|---|---|---|---|
| Volatile substance,... | 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.

**Different Kinds of Sap.**—It is necessary at this point in our discussion to give prominence to the fact that there are different kinds of sap in the plant. As we have seen (p. 289), the cross section of the plant presents two kinds of tissue, the cellular and vascular. These carry different juices, as is shown by their chemical reactions. In the cell-tissues exist chiefly the non-nitrogenous principles, sugar, starch, oil, etc. The liquid in these cells, as Sachs has shown, commonly contains also organic acids and acid-salts, and hence gives a red color 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, p. 304), 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 milkweed (*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 the Nutrient Matters of the Plant.**—The occasional rapid passage of a current of water upwards through the plant must not be confounded with the normal, necessary, and often contrary motion of the nutrient matters out of which new growth is organized, but is an independent or highly subordinate process by which the plant adapts itself to the constant changes that are taking place in the soil and atmosphere as regards their content of moisture.

A plant supplied with enough moisture to keep its tissues turgid is in a normal state, no matter whether the water within it is nearly free from upward flow or ascends rapidly to compensate the waste by evaporation. In both cases the motion of the matters dissolved in the sap is nearly the same. In both cases the plant develops nearly alike. In both cases the nutritive matters gathered at the root-tips ascend, and those gathered by the leaves descend, being distributed to every growing cell; and these motions are comparatively independent of, and but little influenced by, the motion of the water in which they are dissolved.

The upward *flow* of sap in the plant is confined to the vascular bundles, whether these are arranged symmetrically and compactly, as in exogenous plants, or distributed singly through the stem, as in the endogens. This is not only seen upon a bleeding stump, but is made evident by the oft-observed fact that colored liquids, when absorbed into a plant or cutting, visibly follow the course of the vessels, though they do not commonly penetrate the spiral ducts, but ascend in the sieve-cells of the cambium.*

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 plant—of the salts disssolved 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. New growth is the formation and expansion of new cells into which nutritive substances are *imbibed,* but not poured through visible passages. When closed cells are converted into ducts or visibly communicate with each other by pores, their expansion has ceased. Henceforth they merely become thickened by interior deposition.

**Movements of Nutrient Matters in the Bark or Rind.**—The ancient observation of what ordinarily ensues when a ring of bark is removed from the stem of an exogenous tree, led to the erroneous assumption of a formal downward current of "elaborated" sap in the bark. When a cutting from one of our common trees is girdled at its middle and then placed in circumstances favorable

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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.)

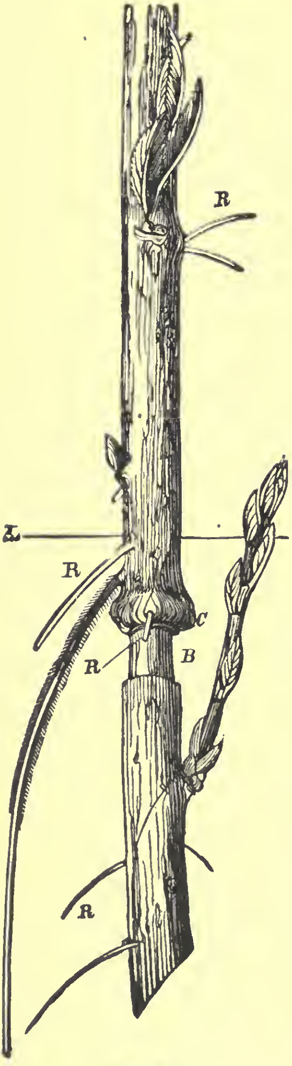

Fig. 66.

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 grape-vine near its junction with the older wood has the effect of greatly enlarging the fruit. 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. 66, 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 malfestation of growth is the formation of a protuberance at the lower edge of the bark, which is known to gardeners as a *callous, C.* This is an extension of the cellular tissue. From the callous shortly appear rootlets, *R*, which originate from the vascular tissue. Rootlets also break from the stem above the callous and also above the water, if the air be moist. They appear, likewise, though in less number, below the girdled place.

Nearly all the organic substances (carbhydrates, albuminoids, acids, etc.) that are formed in a plant are produced in the leaves, and must necessarily find their way down to nourish the stem and roots. The facts just mentioned demonstrate, indeed, that they do go down in the bark. We have, however, no proof that there is a downward *flow of sap.* Such a flow is not indicated by a single fact, for, as we have before seen, the only current of water in the uninjured plant is the upward one which results from root-action and evaporation, and that is variable and mainly independent of the distribution of nutritive matters. Closer investigation has shown that the *most abundant* downward movement of the nutrient matters generated in the leaves proceeds in the thin-walled sieve-cells of the cambium, which, in exogens, is young tissue common to the outer wood and the inner bark—which, in fact, unites bark and wood. The 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. If they pass with greatest freedom through the sieve-cells, the fact is simply demonstration that the latter communicate most directly with those parts of the leaf in which the matters they conduct are organized.

In endogenous plants and in some exogens (*Piper medium, Amaranthus sanguineus*), the vascular bundles containing sieve-cells 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, is still decided below—goes on, in fact, 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 carbhydrates—starch, sugar, inulin—the fats, and acids, chiefly occur and move. In the large ducts, air is contained, except when by vigorous root-action the stem is surcharged with water. In the sieve-ducts (cambium) are found the albuminoids, though not unmixed with carbhydrates. If a tree have a deep gash cut into its stem (but not reaching to the colored 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.* In these cases it is obvious that the substances which commonly preponderate in the sieve-ducts must pass through the

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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.

cell-tissue in order to reach the point where they nourish the growing organs.

Evidence that nutrient matters also pass *upwards* in the bark is furnished, not only by tracing the course of colored liquids in the stem, 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, and thereby demonstrate that they are the channels of this movement. A minority of these exceptions again makes evident that the sieve-cells are the path of transfer, for, as Hanstein has shown, in certain plants (Solanaceæ, Asclepiadeæ, etc.), sieve-cells penetrate the pith unaccompanied by any other elements of the vascular bundle, and girdled twigs of these plants grow above as well as beneath the wound, although all leaves above the girdled place be cut off, so that the nutriment of the buds must come from below the incision.

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. Carbhydrates pass from the leaves, not only downwards, to nourish new roots, but upwards, to feed the buds, flowers, and fruit. In case of 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. 237), 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 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 of Vegetable Tissues.**—Porosity is a property of all the vegetable tissues and implies that the molecules or smallest particles of matter composing the tissues are separated from each other by a certain space. In a multitude of cases bodies are visibly porous. In many more we can see no pores, even by the aid of the highest magnifying powers of the microscope; nevertheless the fact of porosity is a necessary inference from another fact which may be observed, viz., that of absorption. A fiber of linen, to the unassisted eye, has 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 colored by solution of indigo or cochineal, the fiber is visibly

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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.

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 throughout its apparently imperforate substance innumerable channels in which liquids can freely pass. In like manner, all the vegetable tissues are more or less penetrable to 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 a 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, pectin, gum tragacanth, and boiled starch hold a vastly greater amount of water in their pores or among their molecules.

In case of vegetable and animal tissues, or membranes, we find a greater or less degree of expansibility from the same cause, but here the structural connection 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.

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% 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 the gummy carbhydrates and the albuminoids. In the living plant the protoplasmic membrane exhibits great absorbent power. Of mineral matters, gelatinous silica (Exp. 58, p. 137) 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.

One hundred 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%). |
| 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 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 caliber, is such a pore. In a tube of 1 millimeter (about $\frac{1}{25}$ of an inch), in diameter, water rises 30 mm. In a tube of $\frac{1}{10}$ millimeter, 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.)

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 hot 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. 51.) 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.

**Adhesive Attraction.**—The absorption of a liquid into the cavities of a porous body, as well as its rise in a narrow tube, are 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, a film of water comes away with it—the adhesive force of water to glass being greater than the cohesive force among the water molecules.

**Capillary Attraction.**—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 to a hight of several inches where they are in very near proximity, and curves downwards to their base where the interval is large.

*Capillary attraction,* which thus causes liquids to rise in narrow channels or fine tubes, involves indeed the adhesion of the liquid to the walls of the tube, but also depends on a tension of the surface of the liquid, due to the fact that the molecules at the surface only attract and are only attracted by *underlying* molecules, so that they exert a pressure on the mass of liquid beneath them. Where the liquid adheres to the sides of a containing tube or cavity, this pressure is diminished and there the liquid rises.

**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 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.

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 vigor. 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 falls 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 the oil has been shared nearly equally between them.

In 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.

The exhalation of water as vapor from the foliage of a plant thus necessitates the entrance of water as liquid at the roots, and maintains a flow of it in the sap-ducts, or causes it to pass 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. 43, p. 248), 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.

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 colored 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 colored 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.

**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 toward 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.

**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 characterized 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, dextrin, the gums, the albuminoids, pectin and pectic acid, gelatin (glue), tannin, the hydroxides of iron and aluminium 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 admits of no such change.

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, | “ | 2⅓. |
| Cane Sugar, | “ | 7. |
| Magnesium Sulphate, | “ | 7. |
| Albumin, | Colloid, | 49. |
| Caramel, | “ | 98. |

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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. 107). This use of the word was proposed by Nägeli, in 1862. Graham had employed it, as opposed to colloid, in 1861.

The table shows that the diffusive activity of hydrochloric acid through water is 98 times as great as that of caramel (see p. 66, Exp. 29). In other words, a molecule of the acid will travel 98 times as far in a given time as the molecule of caramel.

**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 septum is able to exert upon the liquid molecules supervenes upon 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 membrane 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

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* From a Greek word meaning impulsion.

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.

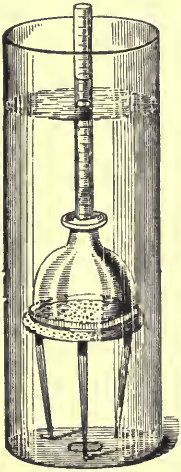
Fig. 67.

**Osmometer.**—When the apparatus employed by Dutrochet is so constructed that the diameter of the narrow tube has a known relation to, is, for example, exactly one-tenth that of the membrane, and the narrow tube itself is provided with a millimeter scale, we have the Osmometer of Graham, Fig 67. 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. 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, 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 Membrane.**—When an attraction exists the membrane itself and 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 (cellulose nitrate 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 (porcelain biscuit), Graham found that in case of neutral organic bodies, as sugar and alcohol, or neutral salts, like the alkali-chlorides and nitrates, very little osmose is exhibited, i. e., the diffusion is not perceptibly greater than it would be in 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, viz., acid potassium oxalate, sodium phosphate, and carbonates of potassium and sodium, exhibit a still more vigorous osmose. For example, a solution of one part of potassium carbonate in 1,000 parts of water gains volume rapidly, and to one part of the salt that passes into the water 500 parts of water enter the solution.

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. In case earthenware is employed as a diaphragm, portions of its calcium and aluminium are always attacked and dissolved by 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.

**Hydration of the membrane.**—It is remarkable that the rapid osmose of potassium carbonate and other alkali-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. 393), 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 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 connection between the hydrating effect of acids and alkalies on colloid membranes and their osmotic rate.

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* In case *water* is employed as the liquid.

"It is well known that fibrin, albumin, 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 :

A cavity is scooped out in a carrot, as in Fig. 68, so that the sides remain ¼ 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 with them, into which water diffuses from the adjoining cells. Doubtless, also, sugar penetrates the parenchyma of the carrot.

Fig. 68.

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.

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 disturbances needful to maintain motion are to be found 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, dextrin, albumin, etc., 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.

**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 |

**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 very delicate in their walls.

Fig. 69 represents a simple apparatus by Sachs for imitating the supposed mechanism and process of Root-action. In the Fig., *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 similar manner by a piece of parchment-paper (p. 59). 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's experiment it attained a height of 4 or 5 inches in 24 to 48 hours, the tube, *r*, being about 5 millimeters wide and the area of *b*, 700 sq.

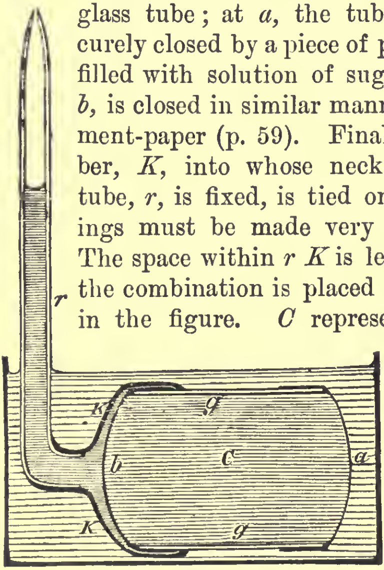

Fig. 69.

mm. When we consider the vast root-surface exposed to the soil, in case of 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.

**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 carbhydrate generated in the leaves is diffusing against the water, and finding its 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 roots 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. This tendency makes valid for the organism of the plant the law that 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 exerts an opposing and preponderating attraction.

In the simplest phases of diffusion each substance is, to a certain degree, independent of every other. Any salt 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 the salt, a proportion equal to that in the soil-water, more *cannot* enter it. 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.

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. 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.

Strong chemical affinities may be overcome by help of osmose. Graham long ago observed the decomposition of alum (sulphate of aluminium and potassium) by mere diffusion ; its potassium sulphate having a higher diffusive rate than its aluminium sulphate. In the same manner acid potassium sulphate, put in contact with water, separates into neutral potassium sulphate and free sulphuric acid.*

We have seen (pp. 170–1) 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 chloride of ammonium,—taking up ammonia and rejecting the hydrochloric acid. The action in these cases we cannot definitely explain, but our analogies leave no doubt as to the general nature of the agencies that coöperate to such results.

The albuminoids in their usual form are colloid bodies, and very slow of diffusion through liquids. They pass a collodion membrane somewhat (Schumacher), but can scarcely penetrate parchment-paper (Graham). In the plant they are found chiefly in the sieve-cells and adjoining parts of the cambium. Since for their production they must ordinarily require the concourse of a carbhydrate and a nitrate, they are not unlikely generated in the cambium itself, for here the descending carbhydrates from the foliage come in contact 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 carbonates and phosphates of the alkalies considerably increase the osmose of albumin through collodion membranes (*Physik der Pflanzen*, p. 128). It is probable that those combinations or modifications of the albuminoids

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* The decomposition of these salts is begun by the water in which they are dissolved, and is carried on by osmose, because the latter secures separation of the reacting substances.

which occur in the soluble crystalloids of aleurone (p. 105) and haemoglobin (p. 97) are highly diffusible, as certainly is the case with the peptones.

Gaseous bodies, especially the carbonic acid and oxygen of the atmosphere, which have free access to the intercellular 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.

**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-colored 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 colors are never contained in the same cell. In fruits we have coloring 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 chlorophyl, 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. Hallier, in his experiments on the absorption of colored 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 colored 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 color to the cells containing chlorophyl. (*Phytopathologie, Leipzig,* 1868, p. 67.) We must infer that the coloring matters either cannot penetrate the cells that are occupied with chlorophyl, or else are chemically transformed into colorless substances on entering them.

Sachs has shown in numerous instances that the juices of the sieve-cells and cambial tissue are alkaline, while those of the adjoining cell-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 center of the cavity, as if its contents passed out, without a corresponding endosmose being possible (p. 224).

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 exerting their 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, now more to one class of proximate ingredients, as the carbhydrates, and now to another, as the albuminoids, although the supplies of food presented are uniform both in total and relative quantity.

If a slice of red-beet be washed and put into water, the pigment which gives it color does not readily dissolve and diffuse out of the cells, but the water remains colorless 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.)

## § 4.

### 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 dor-

Fig. 70.

mant, 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 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 translocation of nutrient matters from the wood to the buds. Water enters the cut stem by imbibition or capillarity, not merely enough to replace loss by exhalation, but is also sucked in 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. 70. A twig with buds is secured by means of a perforated cork into one end of a short, wide glass tube, 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 six to eight inches above the level, *M*—after four to six weeks, unfolded their buds with normal vigor, while twigs similarly circumstanced but without pressure opened four to eight days later and with less appearance of strength.

Fr. Schulz (*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 further in development of leaves and flowers than twigs simply immersed in water.

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. (*Phytopathologie,* 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.

# APPENDIX.

**Composition of various Agricultural Products** giving the Average quantities of Water, Nitrogen, Ash, and Ash-ingredients in 1,000 parts of fresh or air-dry substances. According to Prof. E. von Wolff, 1880.

| | Water. | Nitrogen. | Ash. | Potash. | Soda. | Lime. | Magnesia. | Phosphoric Acid. | Sulphuric Acid. | Silica. | Chlorine. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| GRASSES. | | | | | | | | | | | |
| Rich pasture grass,..... | 782 | 7.2 | 21.1 | 8.1 | 0.3 | 2.6 | 1.2 | 1.9 | 0.7 | 4.1 | 2.1 |
| Young grass and aftermath, .................. | 800 | 5.6 | 18.1 | 5.3 | 0.7 | 2.5 | 1.2 | 1.4 | 1.0 | 4.6 | 1.1 |
| Orchard grass,.......... | 700 | | 17.8 | 5.9 | 0.8 | 1.1 | 0.5 | 1.3 | 0.5 | 5.9 | 1.3 |
| Rye grass,.............. | 700 | 5.7 | 20.4 | 7.1 | 0.7 | 1.5 | 0.4 | 2.2 | 0.8 | 6.5 | 2.1 |
| Timothy,................ | 700 | 5.4 | 20.5 | 7.1 | 0.4 | 1.7 | 0.7 | 2.4 | 0.6 | 6.6 | 1.1 |
| CLOVERS AND LEGUMES. | | | | | | | | | | | |
| Red clover, young,...... | 860 | 6.0 | 14.0 | 5.1 | 0.3 | 3.9 | 1.3 | 1.7 | 0.3 | 0.4 | 0.6 |
| Red clover in bud,...... | 820 | 5.3 | 14.7 | 5.5 | 0.3 | 4.5 | 1.6 | 1.5 | 0.4 | 0.4 | 0.5 |
| Red clover in flower,... | 800 | 4.8 | 13.7 | 4.4 | 0.3 | 4.8 | 1.5 | 1.3 | 0.4 | 0.4 | 0.5 |
| Lucern or Alfalfa, in early bloom,........ | 740 | 7.2 | 19.2 | 4.5 | 0.3 | 8.5 | 0.9 | 1.6 | 1.1 | 1.8 | 0.6 |
| Alsike clover,.......... | 820 | 5.3 | 8.6 | 2.4 | 0.3 | 2.9 | 1.1 | 0.9 | 0.4 | 0.3 | 0.5 |
| White clover in flower, | 805 | 5.6 | 14.3 | 3.1 | 1.0 | 4.3 | 1.4 | 1.8 | 1.1 | 0.6 | 0.6 |
| ROOTS, TUBERS, BULBS. | | | | | | | | | | | |
| Beets,.................. | 880 | 1.8 | 9.1 | 4.8 | 1.5 | 0.3 | 0.4 | 0.8 | 0.3 | 0.2 | 0.9 |
| Carrots, ................ | 850 | 2.2 | 8.2 | 3.0 | 1.7 | 0.9 | 0.4 | 1.1 | 0.5 | 0.2 | 0.4 |
| Rutabagas,.............. | 870 | 2.1 | 7.5 | 3.5 | 0.4 | 0.9 | 0.3 | 1.1 | 0.7 | 0.1 | 0.5 |
| Turnips,................ | 920 | 1.8 | 6.4 | 2.9 | 0.6 | 0.7 | 0.2 | 0.8 | 0.7 | 0.1 | 0.3 |
| Sugar-beets,............ | 815 | 1.6 | 7.1 | 3.8 | 0.6 | 0.4 | 0.6 | 0.9 | 0.3 | 0.2 | 0.3 |
| Radish,................. | 933 | 1.9 | 4.9 | 1.6 | 1.0 | 0.7 | 0.2 | 0.5 | 0.3 | | 0.5 |
| Parsnip,................ | 793 | 5.4 | 10.0 | 5.4 | 0.2 | 1.1 | 0.6 | 1.9 | 0.5 | 0.2 | 0.4 |
| Horseradish,............ | 767 | 4.3 | 19.7 | 7.7 | 0.4 | 2.0 | 0.4 | 2.0 | 4.9 | 1.5 | 0.3 |
| Onion,.................. | 860 | 2.7 | 7.4 | 2.5 | 0.2 | 1.6 | 0.3 | 1.3 | 0.4 | 0.7 | 0.2 |
| Artichoke, *Helianthus*,. | 800 | 3.2 | 9.8 | 4.7 | 1.0 | 0.3 | 0.3 | 1.4 | 0.6 | 0.2 | 0.4 |
| Potato, ................ | 750 | 3.4 | 9.5 | 5.8 | 0.3 | 0.3 | 0.5 | 1.6 | 0.6 | 0.2 | 0.3 |
| "VEGETABLES." | | | | | | | | | | | |
| Cabbage, loose outer leaves,................ | 890 | 2.4 | 15.6 | 5.8 | 1.5 | 2.8 | 0.6 | 1.4 | 2.4 | 0.1 | 1.3 |
| Cabbage, heart,......... | 900 | 3.0 | 9.6 | 4.3 | 0.8 | 1.2 | 0.4 | 1.1 | 1.3 | 0.1 | 0.5 |
| Cauliflower, heart,..... | 904 | 4.0 | 8.0 | 3.6 | 0.5 | 0.5 | 0.3 | 1.6 | 1.0 | 0.3 | 0.3 |
| Cucumber, fruit,........ | 956 | 1.6 | 5.8 | 2.4 | 0.6 | 0.4 | 0.2 | 1.2 | 0.4 | 0.5 | 0.4 |
| Lettuce,................ | 940 | | 8.1 | 3.7 | 0.8 | 0.5 | 0.2 | 0.7 | 0.3 | 1.3 | 0.4 |
| Asparagus, sprouts,..... | 933 | 3.2 | 5.0 | 1.2 | 0.9 | 0.6 | 0.2 | 0.9 | 0.3 | 0.5 | 0.3 |
| Spinage,................ | 903 | 4.9 | 16.0 | 2.7 | 5.7 | 1.9 | 1.0 | 1.6 | 1.1 | 0.7 | 1.0 |
| Mushrooms, edible,.... | 888 | 4.7 | 10.0 | 5.1 | 0.2 | 0.1 | 0.3 | 3.4 | 0.4 | 0.1 | 0.1 |
| SEEDS OF CEREALS. | | | | | | | | | | | |
| Oats,................... | 143 | 17.6 | 26.7 | 4.8 | 0.4 | 1.0 | 1.9 | 6.8 | 0.5 | 10.5 | 0.3 |
| Millet,................. | 140 | 20.3 | 29.5 | 3.3 | 0.4 | 0.2 | 2.8 | 6.5 | 0.1 | 15.6 | 0.1 |
| Maize,.................. | 144 | 16.0 | 12.4 | 3.7 | 0.1 | 0.3 | 1.9 | 5.7 | 0.1 | 0.3 | 0.2 |
| Sorghum,................ | 140 | | 16.0 | 3.3 | 0.5 | 0.2 | 2.4 | 8.1 | | 1.2 | |
| Spring Wheat,.......... | 143 | 20.5 | 18.3 | 5.6 | 0.3 | 0.5 | 2.2 | 9.0 | 0.2 | 0.3 | 0.1 |
| Spring Barley,.......... | 143 | 16.0 | 22.3 | 4.7 | 0.5 | 0.6 | 2.0 | 7.8 | 0.4 | 5.8 | 0.2 |
| Spring Rye,............. | 143 | | 18.0 | 6.2 | 0.3 | | 2.2 | 9.2 | | 0.2 | |
| Winter Wheat,.......... | 144 | 20.8 | 16.8 | 5.2 | 0.3 | 0.5 | 2.0 | 7.9 | 0.1 | 0.3 | 0.1 |
| Winter Barley,......... | 145 | 16.0 | 17.0 | 2.8 | 0.7 | 0.1 | 2.1 | 5.6 | 0.5 | 4.9 | |
| Winter Rye,............. | 143 | 17.6 | 17.9 | 5.8 | 0.3 | 0.5 | 2.0 | 8.5 | 0.2 | 0.3 | 0.1 |

COMPOSITION OF VARIOUS AGRICULTURAL PRODUCTS.—[*Continued.*]

| | Water. | Nitrogen. | Ash. | Potash. | Soda. | Lime. | Magnesia. | Phosphoric Acid. | Sulphuric Acid. | Silica. | Chlorine. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SEEDS OF LEGUMES AND CLOVERS. | | | | | | | | | | | |
| Horse bean, *Vicia*,...... | 145 | 40.8 | 31.0 | 12.9 | 0.3 | 1.5 | 2.2 | 12.1 | 1.1 | 0.2 | 0.5 |
| Garden bean, *Phaseolus*, | 150 | 39.0 | 27.4 | 12.1 | 0.4 | 1.5 | 2.1 | 9.7 | 1.1 | 0.2 | 0.3 |
| Soy bean,................ | 100 | 53.4 | 28.3 | 12.6 | 0.3 | 1.7 | 2.5 | 10.4 | 0.8 | | 0.1 |
| Pea,...................... | 143 | 35.8 | 23.4 | 10.1 | 0.2 | 1.1 | 1.9 | 8.4 | 0.8 | 0.2 | 0.4 |
| Red Clover,............ | 150 | 30.5 | 38.3 | 13.5 | 0.4 | 2.5 | 4.9 | 14.5 | 0.9 | 0.5 | 0.5 |
| White Clover,........... | 150 | | 33.8 | 12.3 | 0.2 | 2.5 | 3.9 | 11.6 | 1.6 | 0.8 | 0.5 |
| OIL SEEDS. | | | | | | | | | | | |
| Cotton,.................. | 77 | 36.5 | 33.8 | 10.9 | 2.3 | 1.9 | 5.6 | 10.5 | 0.7 | 0.1 | 0.5 |
| Hemp, .................. | 122 | 26.1 | 46.3 | 9.4 | 0.4 | 10.9 | 2.6 | 16.9 | 0.1 | 5.5 | |
| Flax,. .................. | 118 | 32.8 | 32.6 | 10.0 | 0.7 | 2.6 | 4.7 | 13.5 | 0.8 | 0.4 | |
| Mustard,................. | 130 | | 36.5 | 5.9 | 2.0 | 7.0 | 3.7 | 14.6 | 1.8 | 0.9 | 0.2 |
| FRUITS. | | | | | | | | | | | |
| Apple, entire fruit,..... | 831 | 0.6 | 2.2 | 0.8 | 0.6 | 0.1 | 0.2 | 0.3 | 0.1 | 0.1 | |
| Pear, entire fruit,....... | 831 | 0.6 | 3.3 | 1.8 | 0.3 | 0.3 | 0.2 | 0.5 | 0.2 | 0.1 | |
| Cherry, entire fruit,.... | 825 | | 3.9 | 2.0 | 0.1 | 0.3 | 0.2 | 0.6 | 0.2 | 0.4 | 0.1 |
| Plum, entire fruit,...... | 838 | | 2.9 | 1.7 | | 0.3 | 0.2 | 0.4 | 0.1 | 0.1 | |
| Grape, entire fruit,..... | 830 | 1.7 | 8.8 | 5.0 | 0.1 | 1.0 | 0.4 | 1.4 | 0.5 | 0.3 | 0.1 |
| HAY. | | | | | | | | | | | |
| Alpine hay,............ | 150 | 18.5 | 29.7 | 7.7 | 0.4 | 7.1 | 2.4 | 2.7 | 1.4 | 7.2 | 6.7 |
| From very young grass, | 150 | 25.5 | 82.4 | 31.6 | 1.3 | 10.1 | 4.6 | 7.4 | 2.7 | 15.9 | 8.4 |
| From young grass and aftermath, ............ | 160 | 19.1 | 76.0 | 22.3 | 3.0 | 10.4 | 5.1 | 5.9 | 4.1 | 19.4 | 4.5 |
| From cereals cut in bloom, ................ | 150 | | 59.4 | 19.3 | 1.0 | 3.4 | 1.7 | 5.6 | 1.5 | 24.7 | 2.3 |
| English rye grass,...... | 143 | 16.3 | 58.2 | 20.2 | 2.0 | 4.3 | 1.3 | 6.2 | 2.3 | 18.5 | 6.1 |
| Red Clover, young,..... | 167 | 35.5 | 82.3 | 29.7 | 1.9 | 23.5 | 7.6 | 10.0 | 1.8 | 2.5 | 3.3 |
| Red Clover in bud,..... | 165 | 24.5 | 68.4 | 25.3 | 1.4 | 20.7 | 7.6 | 6.9 | 1.7 | 1.8 | 2.4 |
| Red Clover in flower,.. | 160 | 19.7 | 57.6 | 18.6 | 1.1 | 20.1 | 6.3 | 5.6 | 1.9 | 1.6 | 2.2 |
| Red Clover, ripe,........ | 150 | 12.5 | 44.7 | 10.0 | 1.4 | 15.8 | 6.9 | 4.4 | 1.4 | 3.0 | 1.3 |
| White Clover in flower, | 165 | 23.2 | 61.1 | 13.1 | 4.4 | 18.4 | 5.8 | 7.8 | 4.5 | 2.7 | 2.6 |
| Alsike Clover,.......... | 160 | 24.0 | 40.0 | 11.1 | 1.2 | 13.6 | 5.0 | 4.1 | 1.6 | 1.6 | 2.2 |
| Lucern (Alfalfa) early bloom, ................ | 160 | 23.0 | 62.0 | 14.6 | 1.1 | 25.2 | 3.1 | 5.3 | 3.6 | 5.9 | 1.9 |
| STRAW. | | | | | | | | | | | |
| Oat,...................... | 143 | 5.6 | 61.6 | 16.3 | 2.0 | 4.3 | 2.3 | 2.8 | 2.0 | 28.8 | 2.7 |
| Barley,................... | 143 | 6.4 | 45.9 | 10.7 | 1.6 | 3.3 | 1.2 | 1.9 | 1.8 | 23.4 | 1.5 |
| Maize,.................... | 150 | 4.8 | 45.3 | 16.4 | 0.5 | 4.9 | 2.6 | 3.8 | 2.4 | 13.1 | 0.6 |
| Spring Wheat,.......... | 143 | 5.6 | 38.1 | 11.0 | 1.0 | 2.6 | 0.9 | 2.0 | 1.2 | 18.2 | 0.8 |
| Winter Wheat,.......... | 143 | 4.8 | 46.0 | 6.3 | 0.6 | 2.7 | 1.1 | 2.2 | 1.1 | 31.0 | 0.8 |
| Winter Rye,............. | 143 | 4.0 | 38.2 | 8.6 | 0.7 | 3.1 | 1.2 | 2.5 | 1.6 | 18.8 | 0.8 |
| Buckwheat, ............. | 160 | 13.0 | 51.7 | 24.2 | 1.1 | 9.5 | 1.9 | 6.1 | 2.7 | 2.9 | 4.1 |
| Pea,...................... | 160 | 10.4 | 43.1 | 9.9 | 1.8 | 15.9 | 3.5 | 3.5 | 2.7 | 2.9 | 2.3 |
| CHAFF, ETC. | | | | | | | | | | | |
| Oat Chaff,.............. | 143 | 6.4 | 71.2 | 4.5 | 2.9 | 4.0 | 1.5 | 1.3 | 3.5 | 50.4 | 0.8 |
| Rye Chaff,.............. | 143 | 5.8 | 82.7 | 5.2 | 0.3 | 3.5 | 1.1 | 5.6 | 0.1 | 66.4 | 0.4 |
| Wheat Chaff,............ | 143 | 7.2 | 92.0 | 8.4 | 1.7 | 1.7 | 1.2 | 4.0 | | 74.7 | |
| Corn Cobs,.............. | 140 | 2.3 | 4.5 | 2.3 | 0.1 | 0.2 | 0.2 | 0.2 | 0.1 | 1.3 | 0.2 |
| MISCELLANEOUS. | | | | | | | | | | | |
| Tobacco leaves,......... | 180 | 34.8 | 140.7 | 40.9 | 4.5 | 50.7 | 10.4 | 6.6 | 8.5 | 8.1 | 9.4 |
| Tobacco stems,......... | 180 | 24.6 | 64.7 | 28.2 | 6.6 | 12.4 | 0.5 | 9.2 | 2.2 | 1.6 | 2.4 |
| Flax stalks,............. | 120 | | 31.1 | 9.7 | 2.5 | 6.9 | 2.0 | 4.2 | 2.0 | 1.7 | 1.3 |
| Hemp stalks,............ | 108 | | 31.7 | 5.5 | 0.6 | 16.8 | 2.1 | 2.1 | 0.6 | 3.1 | 0.6 |
| Hops, entire plant,..... | 140 | 25.0 | 72.9 | 17.9 | 1.9 | 19.7 | 7.0 | 5.8 | 2.9 | 13.3 | 3.7 |
| Cottonseed Cake,....... | 112 | 62.1 | 66.4 | 15.8 | | 2.9 | 10.1 | 30.5 | 0.8 | 5.5 | |
| Linseed Cake,.......... | 122 | 47.2 | 51.3 | 12.5 | 0.8 | 4.3 | 8.1 | 16.2 | 1.7 | 6.4 | 0.4 |

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