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THE CHEMICAL BASIS OF PLANT FORMS.

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The boundary between the mineral and vegetable kingdom is not a definite line. The individual of the one encroaches upon the dominion of the other. The terms "non-living" and "living matter" are only relatively accurate. ¹"Nature in all its manifestations constitutes a unity," * * * and "all matter is in a sense living."

Through chemical evolution a condition of matter obtains favorable for functional activity or life. This state may be described ²"as a colloidal albuminoid united with more or less water." Its

¹ *Mineral Physiology and Physiography.* By T. Sterry Hunt. Boston, 1886, p. 18.

² *Ibid.*

simplest expression is found in the low forms of plants, slime-mould for example. This colloidal basis of life is protoplasm, a chemical compound of complex constitution, very unstable, and manifesting when alive certain properties called vital or "biotic."¹

Active chemical changes are inseparably associated with both living and dead protoplasm. Synthetical or progressive processes prevail in life, analytical or retrogressive in death.

Absorption, metabolism, excretion, reproduction, contractility, automatism, and irritability are the properties of living matter; disorganization and dissociation those of dead matter.

Chemists have to discover the subtle differences between the chemical equation of living and dead protoplasm.

I wish to speak of some of the chemical compounds of plants, or more properly the chemical forms, since the structure of all plants is built up of chemical constituents. This subject is as extensive as the genera and species of the vegetable kingdom.

Last August,² I read a paper on certain chemical constituents of plants considered in relation to their morphology and evolution. The facts cited tended to show a chemical progression in plants, and a mutual dependence between chemical constituents and change of form.

Among the conclusions reached, were the following:

(1.) A similarity of one or more chemical constituents is to be found in all plants which are equally developed, and on the same evolutionary plane.

(2.) The evolution of chemical constituents follows parallel lines with the evolutionary course of plant forms, the one being intimately connected with the other, and consequently chemical constituents are indicative of the height of the scale of progression, and are essentially appropriate for a basis of botanical classification; in other words, the theory of evolution in plant life is best illustrated by the chemical constituents of vegetable forms.

Chemistry will aid us to comprehend the laws of evolution controlling plant forms. Evolution should also apply to chemical compounds as well as to morphology, since the latter can be shown to depend upon chemistry in general.

¹ Dr. T. Sterry Hunt.

² Chem. Section Am. Assoc. for the Adv. of Science. Buffalo, 1886. Abstract, *Bol. Gazette*, xi, No. 10, Oct., 1886.

We have no certain knowledge of the precise chemical changes which take place in transforming carbon, hydrogen, oxygen, nitrogen, sulphur and other elements into the starches and proteids. We know, however, certainly the necessary conditions for many of these changes. The law controlling the absolute relation or the connective link between the form of a plant and its chemical composition is undetermined. But investigations in plant chemistry have not been conducted with this end in view. The facts which I have to offer to sustain the theory of a possible relation between plant forms and chemical compounds may seem to some inadequate, but no other explanation than the one offered to account for these statements has been suggested.

The chemical composition of the cell contents and wall has been determined in many plants; also of their roots, leaves, flowers and fruits.

Most of the ash constituents essential or injurious to the growth and development of plants are known, and also the variations in growth caused by the presence or absence of certain inorganic compounds.

The chemical changes through which many plants pass from the germination of their seed to maturity and decay are also known, each separate stage of growth showing a distinct chemical composition or a predominance of some one chemical compound.

It should be especially noted that some chemical compounds occur in certain species of plants and do not occur in others. Certain classes of compounds are found widely distributed through the plant kingdom, accompanied by correlated morphological characters. Some one compound, as saponin, will be found with similar botanical characters in plants of distinct genera and families, on the same plane of evolution or development.

It cannot be the result of accident, that cinchona and related plants contain quinine; and other plants distributed through the vegetable kingdom their own typical compounds. Nor can it be the result of accident or changes produced by climate or other causes, that an absence of some one or more compounds is accompanied by a modification of the exterior of the plant.

Before taking up the consideration of the above statements in detail, it may be well to study briefly two properties¹ of living protoplasm, namely, absorption and metabolism.

¹*Lectures on the Physiology of Plants.* By S. H. Vines. Cambridge, 1886.

The seeds of plants are the store-houses of a certain amount of latent energy or life, elaborated by the parent plant and stored up in the form of complex chemical compounds. Under suitable conditions of warmth and moisture, certain chemical changes take place within the seed. The latent energy becomes active, and the seedling grows, feeding upon its food supply until it has exhausted its store.

At this stage the little plant must seek from without its food, from the atmosphere and the soil. The soil is of varying and complex composition, containing between its particles gases and moisture. The air which surrounds the leaves of land plants is a mixture of nitrogen and oxygen with small quantities of carbon-dioxide, ammonia, varying quantities of aqueous vapor and occasionally traces of nitric acid.

The elements from these media are absorbed by different parts of the plant, and there is a difference in the manner of absorption by fungi, parasites, air plants, and green plants. However, the elements which are absolutely essential for the nutrition and maintenance of the life of all plants are carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, potassium, calcium, magnesium, iron in the case of green plants, and in certain cases chlorine.

It is characteristic of plants that they must absorb their food in the fluid form. The absorbent organs of plants are the roots for water and salts in solution, and the leaves for gases. In the lower plants, where there are no roots nor leaves, water or substances in solution and gases are absorbed, either directly by the cells of the Thallus or by root hairs. Among the higher plants, the root hairs and the unculticulated epidermal cells of the younger roots are active in absorbing material from the soil. Any part of the plant, if immersed in water, will absorb a smaller or a larger quantity of it; as, for instance, cut flowers placed with their cut ends in water will absorb, for a time, sufficient to prevent withering. The absorption of gases in higher plants is by means of the leaves, for it has been found that carbon-dioxide is absorbed from the air by those organs which are green and contain chlorophyll, and in experiments where the carbon-dioxide of the air was cut off from the leaves, though it was supplied to the roots, it was found that the plant could not live long. It has also been found that the presence of carbon-dioxide in another part of the plant does not contribute to the formation of starch in the leaves.

Green plants obtain their carbon from the carbon-dioxide of the air. Plants which do not contain chlorophyl, obtain their carbon by the absorption of complex organic substances. Green plants can absorb complex carbon compounds, and it has been proved, by direct experiment, that they can take up these complex substances when supplied to their roots.

Darwin¹ has shown that the insectivorous plants, by means of their modified leaves, absorb complex compounds, and that these are of importance in their nutrition. Flies and other small insects may often be found clasped in the tentacles of the *Drosera*, and in those experiments small pieces of meat, when placed on the leaves, were dissolved after a time by the secretions of the leaf glands and absorbed.

Hydrogen is absorbed by all plants in combination in the form of water or ammonia and its compounds, or in the complex substances mentioned above.

Oxygen is taken up by plants free or in combination in water or in salts. The free oxygen is especially concerned in destructive metabolic processes. The large quantities of this gas absorbed by plants, and especially by Fungi, show conclusively its consumption in metabolic processes.

The process known as the respiration of plants is the absorption of oxygen and the exhalation of carbon-dioxide.

The researches of Garreau² show that two distinct processes are in operation when leaves are exposed to the light, in the one oxygen is absorbed and carbon-dioxide is exhaled; in the other, carbon-dioxide is absorbed and oxygen is exhaled. When the leaves are exposed to a very bright sunlight, carbon-dioxide is absorbed and oxygen is exhaled, and the activity of these processes is so much greater than the absorption of oxygen and the exhalation of carbon-dioxide, that it appears as if the former only were in operation.

Gases, like solids, can only be assimilated in solution, and as they are soluble in water, the cell-walls of submerged plants may absorb them, and the sap near the surface of land plants will dissolve the gases from the atmosphere. The sap of plants contains in

¹ *Insectivorous Plants*.

² *Ann. d. Sci. Nat.*, Ser. 3, t. xvi.

solution carbon-dioxide, oxygen, and also a certain amount of free nitrogen. That this nitrogen does not enter into the metabolism of the plant seems completely decided by the experiments¹ of Lawes, Gilbert, and Pugh; but the more recent experiments of Atwater² and Hellriegel³ should be compared in this connection, and the matter cannot be said to be definitely settled.

I can only enumerate in this connection, without going into the subject, the possible sources⁴ of the nitrogen supply:

- (1.) Organic, nitrogenous matter.
- (2.) The ammonia of the air, and of the ocean.
- (3.) The nitrous and nitric compounds formed by combustion and by electric discharges.
- (4.) Nitrogen fixed in the soil by microbes.
- (5.) The free nitrogen of the atmosphere.
- (6.) Mineral nitrates.

The sap which is continually flowing through living plants, is a watery fluid, holding in solution mineral matters, gases, and organic substances. The root hairs of plants penetrate the particles of soil and absorb the moisture from a film which surrounds each particle known as hygroscopic water. In thallophytes, the absorption is effected by the cells of the Thallus, and in Orchids a membrane invests the air roots especially adapted for the purpose. The distribution of water takes place, at least to some extent as its absorption, it passes by osmosis from cell to cell, as it passes originally from without into the superficial cells of the plant. The direction of this movement is not necessarily constant. The proportion of water in each cell varies, and the tendency to establish a fluid equilibrium will cause a current towards those tissues which are deficient. These statements apply equally to gases and other substances held in solution, which are needed for the continuance of the chemical and physical changes going on in the living cells of different parts of the plant.

The changes are more active for different substances in different

¹ *Phil. Trans.*, 1860.

² *Amer. Chem. Jour.*, viii, Nos. 5 and 6.

³ *Zeit. d. Ver. f. d. Rübenzucker Industrie*, Nov., 1886.

⁴ "The Economical Aspect of Agr. Chemistry." By H. W. Wiley. *Proc. A. A. A. S.*, xxxv, 1886.

parts of the plant. The mineral substances absorbed by the roots pass up to the leaves, where they are concerned in the constructive metabolism going on in those organs. The products of these processes pass from the leaves to parts of the plant which are actively growing, and where plastic material is required, or to the seeds or other organs in which organic stores are being laid up.

If the stems or plants are cut in the spring, a flow of sap proceeds from the cut surface of that portion of the stem which is connected with the roots. This fact was investigated by Hales;¹ he concluded that there is "a considerable energy in the root to push up sap in the bleeding season." This force is termed the root pressure, and is the measure of the absorbent activity of the root hairs. The root pressure is not only manifested by causing the flow of sap; it also may cause the exudation of drops of sap on the surface. There is a marked periodicity in the flow of sap, which is not due to the immediate result of variations in external conditions, but is inherent in the absorbent cells themselves.

The current travels from the roots to the leaves through the lignified cell walls of the wood of the plant. The activity of the exhalation of watery vapor from the plant is not the same from their surfaces. The refreshing effect of a shower on withered leaves is due to the moisture penetrating the soil and being absorbed by the root hairs. From experiments² it has been shown that if the air is very moist and the leaves dry, that the leaf surfaces may absorb a little water.

The cuticle offers a certain amount of resistance to the passage through it of vapor which is due to resinous or waxy substances contained in it. The Mexican *Ocotilla*³ offers a striking example. It grows in very dry and exposed parts of the country, where rain-falls are infrequent. The bark is chiefly composed of wax and resinous substances.

Other substances, as well as water, can be absorbed by leaves,⁴

¹ *Statical Essays*, I, 1769 (4th Edition).

² Detmer and Boussingault.

³ H. C. De S. Abbott, *Proc. A. A. A. S.*, xxxiii. (*Am. Journal Pharm.*, Feb., 1885.)

⁴ Boussingault; *Ann. Chem. et Phys.*, sér. V, xiii; also, *Agronomie*, VI, 1878. Mayer; *Landwirthschaftl. Versuchs-Stat.*, xvii, 1874.

experiments having shown that if a drop of calcium sulphate solution be placed on a leaf, it will have disappeared in the course of a few hours. This is more rapid when placed on the under surface. Though it seems that leaves may absorb water and substances in solution under certain circumstances, the especial absorptive function of leaves is the absorption of gases, as has been already explained.

The subject of the ash constituents of plants is a very important one in this connection. The essential mineral constituents of plants have already been mentioned: silicon, fluorine, manganese, sodium, lithium, rubidium, caesium, barium, aluminium, zinc, copper, titanium, iodine, and bromine have also been found among the ash ingredients of certain plants.

The method of absorption of soluble mineral salts has already been described. A solution of insoluble salts is brought about in a different way. A soil rich in organic matter is always charged with carbon-dioxide, and this gas is also given off by the roots of living plants. Water containing this gas is able to dissolve calcium carbonate and some silicates, which are insoluble in pure water. The presence of certain soluble salts in the soil brings about a decomposition and renders the insoluble salts more readily soluble. Finally, the insoluble salts are brought into solution by means of the acid sap which saturates the cell wall of the root hair. This acid is not carbonic acid, for its reddening of litmus paper is permanent.

It has been shown by experiment that the chemical elements are not universally absorbed by roots in their combinations in the soil.

The wide differences in the composition of the ashes of plants show that each plant is endowed with a specific absorbent capacity. It is upon this fact that the "rotation of crops" in farming depends. A gramineous plant¹ is able to withdraw relatively larger quantities of silica from the soil than a leguminous plant. The latter can only do so to a very slight extent.

The absorbent capacities of nearly allied species are very different; again, individuals of the same species yield different ash compositions, depending upon their vigor; and the absorbent capacity of the plant varies at different periods of its life. It has

¹ Wolff; *Aschen Analysen*, 1871.

been stated that "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."¹ If an ash constituent can pass through a cell wall, its absorption will take place independently of its use or harmfulness to the plant, but the absorption of essential inorganic constituents will depend upon its relation to the metabolism of the plant.

The ash constituents of a plant increase from the roots upwards to the leaves, a fact showing that the leaves are the organs in which more especially active chemical changes take place.

The ash ingredients are usually present in each plant cell; in the cell wall, imbedded in the cellulose, and partly in the contents of the cell. The salts of the alkaline metals and of the sulphates and the chlorides of magnesium and calcium occur in the solution of the sap. Silica and phosphates of calcium and magnesium are mostly insoluble and exist in the tissues of the plant.

Water culture experiments² have shown the essential ash ingredients. Potassium, like phosphorus, is always found in relation with living protoplasm. If³ the plant was not supplied with potassium, it grew very little, and very little starch was formed in the chlorophyl corpuscles of the leaves. On the addition of potassium chloride, the starch grains became more numerous in the leaves, and made their appearance in other parts of the plants. Potassium, doubtless, plays an important rôle in the formation and the storing up of carbo-hydrates, for the organs in which these processes are active, as the leaves, seeds and tubers are found to be the richest in this element.

It has been observed that caesium⁴ and rubidium can replace potassium in the food of certain *Fungi* (mould, yeast and bacteria).

Salm-Horstmar describes⁵ some experiments, from which he infers that minute traces of lithium and fluorine are indispensable

¹ *How Crops Grow*. By S. W. Johnson. London, p. 145.

² Nobbe, Siegert, Wolff, Stohmann, Sachs, and others.

³ Nobbe; *Die organische Leistung des Kaliums*, 1871.

⁴ Naegeli; *Sitzber. d. Akad. d. Wiss. zu München*, 1880.

⁵ *Jour. für Prakt. Chem.*, 1884, p. 140.

to the fruiting of barley. The same investigator has concluded that a trace of titanio acid is a necessary ingredient of plants.

Zinc¹ is also a frequent constituent of plants growing about zinc mines. Certain marked varieties of plants are peculiar to, and appear to have been developed by such soils, as the Violet, *var calaminarias* and Penny-cress. In the leaves of the latter plants, thirteen per cent. of zinc oxide was found; in other plants, from .3 per cent. to 3.3 per cent.

From the investigations of Baumann,² insoluble zinc salts in the soil are harmless to plants. All plants excepting the Coniferæ speedily die in a solution containing 10 mg. zinc to the litre, though traces of zinc in solution are harmless.

The specific action of zinc on the vegetable organism consists in a destruction of the chlorophyl coloring matter and a consequent stoppage of the whole process of assimilation.

Experiments³ on maize, oats, buckwheat, show that arsenic attacks the protoplasm of the cell and destroys the power of osmose by the roots.

Sulphates occur in the cell sap of organs where chemical changes are rapidly taking place, and are doubtless formed in connection with the decomposition of proteids. Phosphorus occurs in actively growing cells in the most various plants. It has been found present in the green coloring matter of the leaves and is always found in relation with living protoplasm. Schumacher⁴ holds, that the chief work of the alkaline phosphates is the acceleration of the diffusion of these difficultly diffusible albuminoids.

Calcium is especially abundant in the leaves of green trees and it cannot be replaced in the food of green leaves by any other metal. It can be replaced by strontium,⁵ barium, or magnesium in the food of certain Fungi. Magnesium⁶ resembles lime in many

¹ A. Braun and Risse (Sachs; *Exp. Physiologie*, 153).

² *Landw. Versuchs-Stat.*, xxxi, 1-53 (*Jour. Chem. Soc.*, 1884, p. 1408.)

³ F. Nobbe and others. *Landw. Versuchs-Stat.*, xxx, 381-422. (*Jour. Chem. Soc.*, 1884, p. 1409.)

⁴ *Physik der Pflanze*, p. 128.

⁵ Naegeli.

⁶ R. Hornberger and E. V. Raumer; *Bied. Centr. Bl.*, 1882, 837-844 (*Jour. Chem. Soc.*, 1883, p. 491.)

points, but is present in larger quantity in the stem and grain, and not in the leaves of the maize plant.

Iron is found to be essential to green plants only. If a seedling be cultivated by water culture in a fluid containing no iron, the leaves will become pale until at length they are nearly white, but on the addition of a small quantity of iron to the solution, or if the white leaves are painted with a dilute iron solution, they will very shortly become green. It plays an important part in the formation of the green coloring matter, though it does not enter into its chemical composition.

"Buckwheat,¹ barley and oats do not flourish when grown in solutions containing no chlorides, and as in these plants the chlorophyl corpuscles become overfilled with starch grains, it was thought that this element was of importance in connection with the translocation of carbo-hydrates."

Sodium² has been used in water culture to replace potassium, but the plants deprived of potash did not develop.

Manganese is abundant in the ash of *Trapa natans*. I also found it in the different portions of *Yucca angustifolia*.³

Iodine and bromine are found in marine *Algæ* and in minute quantity in some plants grown far from the sea.

Silica is found in the form of soluble or insoluble silicic acid. It occurs principally in the cell wall, but it has been found in the cell sap of a plant (*Equisetum hiemale*⁴), and certain cells in the pseudo bulbs of epiphytic Orchids⁵ contain each a plate of silica.

Experiments have shown that the absorption of silicic⁶ acid greatly assists the assimilation of other plant foods, and that plants to which it is supplied show a decidedly more healthy development of grain and straw than others not so treated. Silica is doubtless of mechanical use, giving firmness and rigidity to plant

¹ Vines; Cambridge Edition, p. 136. Also, Beyer; *Landw. Versuchs-Stat.*, xi. Leydhecker; *ibid*, viii.

² Salm-Horstmar; Knop and Schreber.

³ *Yucca Angustifolia*. Helen C. DeS. Abbott, *Trans. Am. Philos. Soc.*, Dec., 18, 1885.

⁴ Lange; *Ber. d. deutsch. chem. Ges.*, xi.

⁵ Pfitzer; *Flora*, 1877.

⁶ C. Kreuzhage and E. Wolff; *Landw. Versuchs-Stat.*, xxx, 161-198. (*Jour. Chem. Soc.*, 1884, p. 1112.)

tissues; though the real cause of "laying" of crops has been found to be due to the imperfect development of the tissue and not to an insufficient supply of silica.

The percentage of ash constituents in plants varies, but the quantity is sufficient to be a very important factor in the consideration of chemical forms of plants.

I have already said that the albuminous cell contents, called protoplasm, are always present in the living cells of plants. The introduction into the cell of the gases, water, and inorganic substances goes to the direct formation of this colloidal body, or assists in it.

It has been stated that the soil, water, and atmosphere supply the food of all plants. It would be of interest to dwell upon the processes of assimilation, and the chemical changes that go on within the living plant, if our time would allow. It may be mentioned that nowhere in any department of chemistry have our former views been more modified than in the physiological chemistry of the vegetable cell during the last three years.

For example, I may say, that, at least in some plants, nascent starch passes in a soluble form from cell to cell by osmosis without conversion into sugar, as was formerly held.

Sugar in some plants may be regarded as a waste product, resulting from the breaking down of more complex substances, of no further service in the development of the plant.

Sorghum¹ cane, at the time of the maturing of the seed and the full growth of the plant, contains the largest percentage of sugar, and this sugar appears to be really a waste product.

The classification² of *Plastic and Waste Products*, in Vines's late *Physiology*, cannot be accepted as final, since many changes in plant chemistry have resulted since 1882—the date of his chemical bibliography.

It may be generally said that the proteids or albuminoid substances are formed in the cell from a simple carbo-hydrate and some nitrogenous body, probably an amide.

The inorganic acids supply sulphur and other substances necessary to enter into combination with the proteid, or act mechanically by removing waste material.

¹ H. W. Wiley; *Botanical Gazette*, 1887.

² Cambridge Edition, 1886.

The function of chlorophyl may be briefly stated :¹ It absorbs certain rays of light, and thus enables the protoplasm of the cell to avail itself of the radiant energy of the sun's rays for the construction of organic substances from carbon-dioxide and water.

Plants which are grown in the dark, or at low temperature, are usually of a yellow color. Such plants are said to be etiolated. There is reason to think that this yellow substance, etiolin, is an intermediate substance in the formation of chlorophyl, for if it is exposed to light it is converted into a green color ; these complex coloring matters are probably derivatives of protoplasm.

The autumnal change of leaves is owing to a third coloring matter, called xanthophyl ; in many cases, the leaves also contain a red coloring matter, erythrophyl.

The importance of chlorophyl in the plant will be admitted when it is said that the absorption of carbon-dioxide, the evolution of oxygen, and the formation of many organic substances are effected solely by chlorophyl corpuscles.

The organic acids occur in plants free and also in combination with bases. It is to the presence of these bodies that the acid reaction of plant tissues is due. Some organic acids are assimilated by plants ; the turgidity of cells is to be ascribed to their presence, and the acid sap in root hairs renders possible the solution and absorption of mineral substances insoluble in water.

The primary function of the resins² of Coniferæ and analogous juices of other plants is to render service in cases of injury, and, by covering the wound with a protecting coating, to favor its healing.

During my studies on the *Yucca*³, resins and saponin were separated from each part of the plant. Experiments were made to determine the emulsive power of saponin on resins. It was found that aqueous solutions of saponin were able to emulsify many classes of resins, and in my paper it was pointed out that saponin may serve mechanical purposes in the plant as well as those of nutrition.

The succession of plants from the lower to the higher forms

¹ Cambridge Edition, p. 157.

² H. De Vries ; *Chem. Centr. Bl.* **8**, xiii, 565. (*Jour. Chem. Soc.*, 1883, p. 365.)

³ *Trans. Am. Phil. Soc.*, Dec., 1885.

will be reviewed superficially, and chemical compounds noted where they appear.

When the germinating spores of the Fungi, *myxomycetes*, rupture their walls and become masses of naked protoplasm, they are known as plasmodia. The plasmodium *Aethalium septicum* occurs in moist places, on heaps of tan or decaying barks. It is a soft, gelatinous mass of yellowish color, sometimes measuring several inches in length.

The plasmodium¹ has been chemically analyzed, though not in a state of absolute purity. The table of Reinke and Rodewold gives an idea of its proximate constitution.

Many of the constituents given are always present in the living cells of higher plants. It cannot be too emphatically stated that where "biotic" force is manifested, these colloidal or albuminous compounds are found.

The simplest form of plant life is an undifferentiated individual, all of its functions being performed indifferently by all parts of its protoplasm.

The chemical basis of plasmodium is almost entirely composed of complex albuminous substances, and correlated with this structureless body are other compounds derived from them. Aside from the chemical substances which are always present in living matter, and are essential properties of protoplasm, we find no other compounds. In the higher organisms, where these functions are not performed indifferently, specialization of tissues is accompanied by many other kinds of bodies.

The Algæ are a stage higher in the evolutionary scale than the undifferentiated non-cellular plasmodium. The simple *Alga protococcus*² may be regarded as a simple cell. All higher plants are masses of cells, varying in form, function and chemical composition.

A typical living cell may be described as composed of a cell wall and contents. The cell wall is a firm, elastic membrane closed on all sides, and consists mainly of cellulose, water, and inorganic constituents. The contents consists of a semi-fluid colloidal substance, lying in contact with the inner surface of the membrane.

¹ *Studien über das Protoplasma*, 1881.

² Vines, p. 1. Rostafinski; *Mem. de la Soc. des Sc. Nat. de Cherbourg*. 1875. Strasburger; *Zeitschr.*, XII, 1878.

and like it closed on all sides. This always is composed of albuminous substances. In the higher plants, at least, a nucleus occurs embedded in it, a watery liquid holding salts and saccharine substances in solution, fills the space called the vacuole enclosed by the protoplasm.

These simple plants may be seen as actively moving cells, or as non-motile cells. The former consist of a minute mass of protoplasm, granular and mostly colored green, but clear and colorless at the more pointed end, and where it is prolonged into two delicate filaments called cilia. After moving actively for a time they come to rest, acquire a spherical form and invest themselves with a firm membrane of cellulose. This firm, outer membrane of the *Protococcus* accompanies a higher differentiation of tissue and localization of function than is found in the plasmodium.

Hæmatococcus and plasmodium come under the classes Algæ and Fungi of the Thallophyta group. The division¹ of this group into two classes is based upon the presence of chlorophyl in Algæ and its absence in Fungi. Gelatinous starch is found in the Algæ; the Fungi contain a starchy substance called glycogen, which also occurs in the liver and muscles of animals. Structureless bodies, as *æthaliæ*, contain no true sugar. Stratified starch² first appears in the Phanerogams. Alkaloids have been found in Fungi, and owe their presence doubtless to the richness of these plants in nitrogenous bodies.

In addition to the green coloring matter in Algæ are found other coloring matters.³ The nature⁴ of these coloring matters is usually the same through whole families, which also resemble each other in their modes of reproduction.

In form, the Algæ differ greatly from filaments or masses of cells; they live in the water and cover damp surfaces of rocks and wood. In these they are remarkable for their ramifications and colors and grow to a gigantic size.

¹ *Botany*; Prantl and Vines. London, 1886, p. 110.

² For the literature of Starch, see p. 115, *Die Pflanzenstoffe*, von Hilger and Husemann.

³ *Kützing*; *Arch. Pharm.* xli, 38. Kraus and Millardet; *Bul. Soc. Sciences. Nat.*, Strasbourg, 1868, 22. Sorby; *Jour. Lin. Soc.* xv, 34. J. Reinke; *Jahrb. Wissensch. Botan.*, x, B. 399. Phipson; *Phar. Jour. Trans.* clxii, 479.

⁴ Prantl and Vines, p. 111.

The physiological functions of Algæ and Fungi depend upon their chemical differences.

These facts have been offered, simple as they are, as striking examples of chemical and structural opposition.

The Fungi include very simple organisms, as well as others of tolerably high development, of most varied form from the simple bacillus and yeast to the truffle, lichens, and mushrooms.

The cell membrane of this class contains no pure cellulose, but a modification called fungus cellulose. The membrane also contains an amyloid substance, amylomycin.¹ Many of the chemical constituents found in the entire class are given in *Die Pflanzenstoffe*.²

Under the *Schizomycetes* to which the *Micrococcus* and *Bacterium*³ belong are found minute organisms differing much in form and in the coloring⁴ matters they produce, as that causing the red color of mouldy bread.

The class of lichens⁵ contains a number of different coloring substances, whose chemical composition has been examined. These substances are found separately in individuals differing in form. In the *Polyporus*⁶ an acid has been found peculiar to it, as in many plants special compounds are found. In the Agaricæ the different kinds of vellum distinguish between species, and the color of the conidia is also of differential importance. In all cases of distinct characteristic habits of reproduction and form, one or more different chemical compounds is found.

In the next group of the Musicæ, or mosses, is an absence of some chemical compounds that were characteristic of the classes

¹ L. Crie; *Compt. Rend.*, lxxxviii, 759 and 985. J. de Seynes, 820, 1043.

² Page 279.

³ M. Nencki and F. Schaffer. N. Sieher; *Jour. Pract. Chem.*, 23, 412.

⁴ E. Klein; *Quar. Jour. Micros. Science*, 1875, 381. O. Helm; *Arch. Pharm.*, 1875, 19-24. G. Gugini; *Gaz. Chem.*, 7, 4. W. Thörner; *Bul. Ber.*, xi, 533.

⁵ *Handbook of Dyeing*. By W. Crookes, London, 1874, p. 367. Schunck; *Ann. Chem. Pharm.*, 41, 157; 54, 261; 61, 72; 61, 64; 61, 78. Rochelder and Heldt, *Ibid*, 48, 2; 48, 9. Stenhouse, *Ibid*, 68, 57; 68, 72; 68, 97, 104; 125, 353. See also researches of Strecker; O. Hesse; Reymann; Liebermann; Lamparter; Knop and Schnedermann.

⁶ Stahlschmidt.

just described. Many of the albuminous substances are present. Starch¹ is found often in large quantities, and also oily fats, which are contained in the oil bodies of the liverworts; wax,² organic acids, including aconitic acid, and tannin which is found for the first time at this evolutionary stage of the plant kingdom.

The vascular Cryptogams are especially characterized by their mineral composition.³ The ash is extraordinarily rich in silicic acid and alumina.

Equisetum, ⁴	silicic acid	60 per cent.
Aspidium,	" "	13 " "
Asplenium,	" "	35 " "
Osmunda,	" "	53 " "
Lycopodium, ⁵	" "	14 " "
"	alumina	26 to 27 " "
"	manganese	2 to 2.5 " "

These various plants contain acids and compounds peculiar to themselves.

As we ascend in the plant scale, we reach the Phanerogams. These plants are characterized by the production of true seeds, and many chemical compounds not found in lower plants.

It will be convenient in speaking of these higher groups, to follow M. Heckel's⁶ scheme of plant evolution. All these plants are grouped under three main divisions: apetalous, monocotyledonous, and dicotyledonous, and these main divisions are further subdivided.

It will be observed that these three main parallel columns are divided into three general horizontal planes.

On plane 1, are all plants of simplicity of floral elements, or parts; for example, the black walnut with the simple flower contained in a catkin.

On plane 2, plants which have a multiplicity of floral elements, as the many petals and stamens of the rose; and finally, the higher

¹ E. Treffner; *Inaugur. Diss. Dorpat*, 1880.

² W. Pfeffer; *Flora*, 1874.

³ *Die Pflanzenstoffe*, p. 323. W. Lange; *Bul. Ber.*, xi, 822.

⁴ *Ann. Chim. Phys.*, 41, 62, 208; *Ann. Chim. Pharm.*, 77, 295.

⁵ Flückiger; *Pharmakognosie*. Kamp; *Ann. Chim. Pharm.*, 100, 300.

⁶ *Revue Scientifique*, 13 Mars, 1886.

plants, the Orchids among the monocotyledons and the Compositæ among the dicotyledonous plants, come under the third division of condensation of floral elements.

It will be impossible to take up in order for chemical consideration all these groups, and I shall restrict myself to pointing out the occurrence of certain constituents.

I desire now to call attention to chemical groups under the apetalous plants having simplicity of floral elements.

*Cassuarina equisetifolia*¹ possibly contains tannin, since it is used for curing hides. The bark contains a dye. It is said to resemble *Equisetum*² in appearance, and in this latter plant, a yellow dye is found.

The *Myrica*³ contains ethereal oil, wax, resin, balsam, in all parts of the plant. The root contains in addition fats, tannin and starch, also myricinic acid.

In the willow and poplar,⁴ a crystalline, bitter substance, salicin or populin, is found. This may be considered as the first appearance of a real glucoside, if tannin be excluded from the list.

The oak, walnut, beech, alder, and birch contain tannin in large quantities; in the case of the oak ten to twelve per cent. Oak galls yield as much as seventy per cent.⁵

The numerous genera of pine and fir trees are remarkable for ethereal oil, resin, and camphor.

The plane⁶ trees contain caoutchouc and gum; peppers,⁷ ethereal oils, alkaloids, piperin, white resin and malic acid. *Datisca cannabina*⁸ contains a coloring matter and another substance peculiar to itself, datiscin, a kind of starch, or allied to the glucosides.

¹ *Dictionary of Economic Plants*. By J. Smith. London, 1882, p. 294.

² *Ibid*, p. 160. *Pharmakognosie des Pflanzenreichs*, Wittstein, p. 736. *Ann. Chem. Pharm.*, 77, 295.

³ Rabenhorst; *Repert. Pharm.*, ix, 214. Moore; *Chem. Centralbl.*, 1862, 779, Dana.

⁴ Johansen; *Arch. Pharm.*, 3, ix, 210. *Ibid*, 3, ix, 103. Bente; *Berl. Ber.*, viii, 476. Braconnot; *Ann. Chim. Phys.*, 2, 44, 296.

⁵ Wittstein; *Pharm. des Pflanzenreichs*, p. 249.

⁶ John; *Ibid*, p. 651.

⁷ Dulong, Oersted, Lucas, Poutet; *Ibid*, p. 640.

⁸ Braconnot; *Ann. Chim. Phys.*, 2, 3, 277. Stenhouse; *Ann. Chim. Pharm.*, 198, 166.

Upon the same evolutionary plane among the monocotyledons, the dates and palms¹ contain in large quantities special starches, and this is in harmony with the principles of the theory. Alkaloids and glucosides have not yet been discovered in them.

Other monocotyledonous groups with simplicity of floral elements, such as the Typhaceæ, contain large quantities of starch; in the case of *Typha latifolia*,² 12.5 per cent., and 1.5 per cent. gum. In the pollen of this same plant, 2.08 per cent. starch has been found.

Under the dicotyledonous groups, there are no plants with simplicity of floral elements.

Returning, now, to apetalous plants of multiplicity and simplification of floral elements, we find that the Urticaceæ³ contain free formic acid; the hemp⁴ contains alkaloids; the hop,⁵ ethereal oil and resin; the rhubarb,⁶ crysophonic acid, and the begonias,⁷ chicharin and lapacho dyes. The highest apetalous plants contain camphors and oils. The highest of the monocotyledons contain a mucilage and oils, and the highest dicotyledons contain oils and special acids.

The trees yielding common camphor and Borneol are from genera of the Lauraceæ family; also sassafras camphor is from the same family. Small quantities of Stereoptenes are widely distributed through the plant kingdom.

The Gramineæ, or grasses, are especially characterized by the large quantities of sugar and silica they contain. The ash of the rice hull, for example, contains ninety-eight per cent. silica.

The Ranunculaceæ contain many plants which yield alkaloids, as *Hydrastia canadensis*, or Indian hemp, *Helleborus*, *Delphinium*, *Aconitum*, and the alkaloid berberine has been obtained from genera of this family.

¹ *Pflanzenstoffe*, p. 412.

² Lecocq; Braconnot; *Pharmacog. Pfl.*, p. 693.

³ Gorup-Besanez.

⁴ Siebold and Brodbury; *Phar. Jour. Trans.* **3**, 590, 1881, 326.

⁵ Wagner; *Jour. Prakt. Chem.*, 58, 352. E. Peters, v. Gohren; *Jahresb. Agric.*, viii, 114; ix, 105; v, 58. *Am. Jour. Pharm.* **4**, 49.

⁶ Dragendorff; *Pharm. Zeitschr. Russ.*, xvii, 65-97.

⁷ Boussingault; *Ann. Chim. Phys.* **2**, 27, 315. Erdmann; *Jour. Pract. Chem.* **71**, 198.

The alkaloid¹ furnishing families belong, with few exceptions, to the dicotyledons. The Colchicææ, from which is obtained veratrine, form an exception among the monocotyledons. The alkaloids of the fungus have already been noted.

² Among the greater number of plant families, no alkaloids have been found. In the Labiataæ none has been discovered, nor in the Compositæ among the highest plants.

One alkaloid is found in many genera of the Loganiaceæ Berberine in genera of the Berberidaceæ, Ranunculaceæ, Menispermaceæ, Rutaceæ, Papaveraceæ, Anonaceæ.

Waxes are widely distributed in plants. They occur in quantities in some closely related families.

Ethereal oils occur in many families, in the bark, root, wood, leaf, flower and fruit; particularly in Myrtaceæ, Laurineæ, Cyperaceæ, Crucifereæ, Aurantiaceæ, Labiataæ and Umbelliferæ.

Resins are found in most of the higher plants. Tropical plants are richer in resins than those of cold climates.

Chemical resemblance between groups, as indicating morphological relations has been well shown. For example; the similarity³ of the viscid juices, and a like taste and smell among Cactaceæ and Portulacææ, indicate a closer relationship between these two orders than botanical classification would perhaps allow. This fact was corroborated by the discovery of irritable stamens in *Portulaca* and *Opuntia*, and other genera of Cactaceæ.

Darwin⁴ states, that in the Compositæ the ray florets are more poisonous than the disc florets in the ratio of about 3 to 2.

Comparing the Cycadeæ and Palmæ, the former are differently placed by different botanists, but the general resemblance is remarkable, and they both yield sago.

Chemical constituents of plants are found in varying quantities during stated periods of the year. Certain compounds present at one stage of growth are absent at another. Many facts could be brought forward to show the different chemical composition of plants in different stages of growth. The *Thuja occidentalis*,⁵ in

¹ *Die Pflanzenstoffe*, p. 21.

² *Ibid.*

³ Meehan; *Proc. Acad. Nat. Sciences.*

⁴ Different forms of flowers on plants of the same species. Introduction.

⁵ Meehan; *Proc. Acad. Nat. Sciences.*

the juvenescent and adult form, offers an example where morphological and chemical differences go hand in hand. Analyses of this plant under both conditions show a striking difference.

Different parts of plants may contain distinct chemical compounds, and the comparative chemical study of plant orders comprises the analysis of all parts of plants of different species.

For example; four portions of the *Yucca angustifolia*¹ were examined chemically; the bark and wood of the root and the base and blades of the leaves. Fixed oils were separated from each part. These were not identical; two were fluid at ordinary temperature, and two were solid. Their melting and solidifying points were not the same.

This difference in the physical character and chemical reaction of these fixed oils may be due to the presence of free fatty acid and glycerides in varying proportions in the four parts of the plants. It is of interest to note that, in the subterranean part of the *Yucca*, the oil extracted from the bark is solid at the ordinary temperature: from the wood it was of a less solid consistency; while the yellow base of the leaf contained an oil quite soft, and in the green leaf the oil is almost fluid.

Two new resins were extracted from the yellow and green parts of the leaf. It was proposed to name them *yuccal* and *pyrophæal*. An examination of the contents of each extract showed a different quantitative and qualitative result.

Saponin was found in all parts of the plant.

Many of the above facts have been collected from the investigations of others. I have introduced these statements, selected from a mass of material, as evidences in favor of the view stated at the beginning of this paper.² My own study has been directed towards the discovery of saponin in those plants where it was presumably to be found. The practical use of this theory in plant analysis will lead the chemist at once to a search for those compounds which morphology shows are probably present.

I have discovered saponin in all parts of the *Yucca angustifolia*.

¹ H. C. DeS. Abbott; *Trans. Amer. Philos. Soc.*, 1886.

² For further facts confirming this theory, see "Comparative chemistry of Higher and Lower Plants." By H. C. DeS. Abbott, *Amer. Naturalist*, August, 1887.

in the *Y. filimentosa* and *Y. gloriosa*, in several species of *Agavæ*, and in plants belonging to the *Leguminosæ* family.

The list¹ of plants in which saponin has been discovered is given in the note. All these plants are contained in the middle plane of Heckel's scheme. No plants containing saponin have been found among apetalous groups. No plants have been found containing saponin among the lower monocotyledons.

The plane of saponin passes from the *Liliaceæ* and allied groups to the *rosales* and higher dicotyledons.

Saponin belongs to a class of substances called glucosides. Under the action of dilute acids, it is split up into two substances, glucose and sopogenin. The chemical nature of this substance is not thoroughly understood. The commercial² product is probably a mixture of several substances.

This complexity of chemical composition of saponin is admirably adapted for the nutrition of the plant, and it is associated with the corresponding complexity of the morphological elements of the plant's organs. According to M. Perrey³, it seems that the power of a plant to direct the distribution of its carbon, hydrogen, and oxygen to form complex glucosides is indicative of its higher functions and developments.

The solvent action of saponin on resins has been already discussed. Saponin likewise acts as a solvent upon barium⁴ sulphate and calcium⁵ oxalate, and as a solvent of insoluble or slightly soluble salts would assist the plant in obtaining food, otherwise difficult of access.

Saponin is found in Endogens and Exogens. The line dividing these two groups is not always clearly defined. Statements pointing to this are found in the works of Haeckel, Bentham, and others.

Smilax belongs to a transition class, partaking somewhat of the

¹ Different genera and species of the following: *Ranunculaceæ*, *Berberidaceæ*, *Carophyllaceæ*, *Polygalaceæ*, *Bromeliaceæ*, *Liliaceæ*, *Smilacææ*, *Yuccas*, *Amaryllideæ*, *Leguminosæ*, *Primulaceæ*, *Rosaceæ*, *Sapindaceæ*, *Sapotaceæ*.

² Kobert; *Chem. Ztg.*

³ *Compt. Rend.*, xciv, p. 1124.

⁴ *Bul. de la Soc. Chim.*

⁵ "Yucca angus." *Trans. Am. Philos. Soc.*, Dec., 1885.

nature of Endogen and of Exogen. It is worthy of note that this intermediate group of the sarsaparillas should contain saponin.

It is a significant fact that all the groups above named containing saponin belong to Heckel's middle division.

It may be suggested that saponin is thus a constructive element in developing the plant from the multiplicity of floral elements to the cephalization of those organs.

It has been observed that the composite occurs where the materials for growth are supplied in greatest abundance, and the more simple forms arise where sources of nutrition are remote. We may gather from this fact that the simpler organs of plants low in the evolutionary scale contain simpler non-nitrogenous chemical compounds for their nutrition.

The presence of saponin seems essential to the life of the plant where it is found, and it is an indispensable principle in the progression of certain lines of plants, passing from their lower to their higher stages.

Saponin is invariably absent where the floral elements are simple; it is invariably absent where the floral elements are condensed to their greatest extent. Its position is plainly that of a factor in the great middle realm of vegetable life, where the elements of the individual are striving to condense, and thus increase their physiological action and the economy of parts.

It may be suggested as a line of research to study what are the conditions which control the synthesis and gradual formation of saponin in plants. The simpler compounds of which this complex substance is built up, if located as compounds of lower plants, would indicate the lines of progression from the lower to the saponin groups.

In my paper¹ read in Buffalo at the last meeting of the American Association for the Advancement of Science, various suggestions were offered why chemical compounds should be used as a means of botanical classification.

The botanical classifications based upon morphology are so frequently unsatisfactory, that efforts in some directions have been made to introduce other methods.²

¹ *Botanical Gazette*, October, 1886.

² Borodin; *Pharm. Jour. Trans.*, xvi, 369. Pax. Firemy; *Ann. Sci. Nat.* xiii.

There has been comparatively little study of the chemical principles of plants from a purely botanical view. It promises to become a new field of research.

The Leguminosæ are conspicuous as furnishing us with important dyes, *e. g.*, indigo, logwood, catechin. The former is obtained principally from different species of the genus *Indigofera*, and logwood from the *Hæmatoxylon* and *Saraca indica*.

The discovery¹ of hæmatoxylin in the *Saraca indica* illustrates very well how this plant in its chemical, as well as botanical, character is related to the *Hæmatoxylon campechianum*; also, I found a substance like catechin in the *Saraca*. This compound is found in the *Acacias*, to which class *Saraca* is related by its chemical position as well as botanically. Saponin is found in both of these plants as well as in many other plants of the Leguminosæ. The Leguminosæ come under the middle plane or multiplicity of floral elements, and the presence of saponin in these plants was to be expected.

From many of the facts above stated, it may be inferred that the chemical compounds of plants do not occur at random. Each stage of growth and development has its own particular chemistry.

It is said that many of the constituents found in plants are the result of destructive metabolism, and are of no further use in the plant's economy. This subject is by no means settled, and even should we be forced to accept that ground, it is a significant fact that certain cells, tissues or organs peculiar to a plant, secrete or excrete chemical compounds peculiar to them, which are to be found in one family, or in species, closely allied to it.

It is a fact that the chemical compounds are there, no matter why or whence they came. They will serve our purposes of study and classification.

The result of experiment shows that the presence of certain compounds is essential to the vigor and development of all plants and particular compounds to the development of certain plants. Plant chemistry and morphology are related. Future investigations will demonstrate this relation.

In general terms, we may say that amides and carbo-hydrates are utilized in the manufacture of proteids. Organic acids cause a turgescence of cells. Glucosides may be a form of reserve food material.

¹ H. C. DeS. Abbott, *Proc. Acad. Nat. Sciences*, Nov. 30, 1886.

Resins and waxes may serve only as protection to the surfaces of plants; coloring matters, as screens to shut off or admit certain of the sun's rays; but we are still far from penetrating the mystery of life.

A simple plant does what animals more highly endowed cannot do. From simplest substances they manufacture the most complex. We owe our existence to plants, as they do theirs to the air and soil.

The elements carbon, oxygen, hydrogen, and nitrogen pass through a cycle of changes from simple inorganic substances to the complex compounds of the living cell. Upon the decomposition of these bodies the elements return to their original state. During this transition those properties of protoplasm which were mentioned at the beginning, in turn, follow their path. From germination to death this course appears like a crescent, the other half of the circle closed from view. Where chemistry begins and ends it is difficult to say.

ON ANEMOMETERS.

BY G. A. HAGEMANN, Candidatus Polytech.

[Translated by G. E. Curtis, from the "*Annuaire météorologique*" of the Danish Meteorological Institute, Copenhagen, 1877.]

INTRODUCTION.—As the Hagemann anemometer has attracted some attention, and is easily obtained by purchase of the maker, Nyrop, of Copenhagen, and as the original memoir describing it is rather rare, I have, in compliance with several requests, suggested to the Franklin Institute, the propriety of publishing the following translation.

It is evident that Dr. Hagemann's preliminary investigation needs further development before the value of the instrument can be considered to be finally established. For measuring severe gusts and high wind velocities, an anemometer which has a minimum inertia of its own moving parts is very desirable, and this seems to be obtainable through the application of the principle of suction.

CLEVELAND ABBE.