The chemistry of vegetable and animal physiology / by G.J. Mulder ; translated from the Dutch by P.F.H. Fromberg ; with an introduction by J.F.W. Johnston.

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THE

CHEMISTRY OF VEGETABLE

AND

ANIMAL PHYSIOLOGY:

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WITH AN INTRODUCTION

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THE CHEMISTRY OF VEGETABLE AND ANIMAL PHYSIOLOGY.

CHAPTER I.

CHEMICAL AND ORGANIC FORCES.

In the doctrine of life, no position has been more strenuously maintained, than that a peculiar force exists by which organic substances are governed, by which they are arranged in certain specific modes, and are enabled to assist in sustaining the living system, and to create a chain of phenomena, which as a whole are called *phenomena of life.* This vital force has been described as one quite peculiar, of which not the slightest trace is to be found in inorganic nature. Organic and inorganic nature are often indeed contrasted. We hear of the animate and inanimate forces of nature; we used to shrink from observing any connexion between them; and in particular, it was thought that the endeavor to explain many phenomena of life by means of the so-called dead forces might detract from the doctrine of life.

In the true study of nature the principal aim ought to be, not only to make ourselves acquainted with the phenomena and laws, which distinguish and regulate living and dead matter, but also to arrange those phenomena and laws, and exhibit them in their several relations. The more our knowledge of these two departments is extended, and the nearer the several parts of the great science of nature are seen to approximate, the more firmly must we embrace the idea, as necessarily conformable to truth, that the same forces govern alike the animate and the inanimate kingdoms.

Those who proceed on the assumption, that no such connexion exists, will certainly not be able to trace it; but a search, conducted with impartiality, will be rewarded with the discovery of whatever exists.

In the natural sciences, the words *matter* and *force* are continually recurring. We endeavor, by an effort of imagination, to separate the one idea from the other. Yet we cannot conceive of matter without force, and scarcely of any force which does not react upon matter. We encounter many difficulties, while attempting to penetrate into the properties of matter. We are perplexed, first, with its being divisible either finitely or infinitely; secondly, with the great diversity of substances which exist; thirdly, with the great number of elementary bodies now known to chemists.

Moreover the idea expressed by the word *atom* is by no means distinct, though the term must frequently occur in treating of natural philosophy.

In the natural sciences, we do not seek to go beyond the knowledge which is acquired by observation and by the comparison of visible objects, and thus we avoid that labyrinth, in which many of the wise and learned, both in former and later times, have involved themselves, by clinging to abstract ideas borrowed from the visible world. We acknowledge material diversity because we observe it; we acknowledge a great number of elements because we see them; we do not meddle with the term *atom*, but substitute for it, wherever we can, the more comprehensive and intelligible expression—*equivalent*.

In the natural sciences, *force* is used to signify an assumed cause of observed phenomena; we therefore do not observe forces, but suggest their existence to ourselves; and we do so in conformity with sound principle, for the phenomena constrain us to presume that such forces exist. No cautious inquirer into nature goes farther at the present day; we do not introduce forces, to which we assign properties; but we form the idea of some particular force, after the necessity for its existence is demonstrated by the observation of natural phenomena. The idea of force is therefore a concrete one, by which every speciality in the phenomena is embraced, and unity is given to the whole.

Such are the simple principles by which we are, in the present day, guided in our inquiries. The forces of nature, which we recognize, are in number and kind, such as we learn from the phenomena they ought to be; and the error, so prevalent in former times, of attributing properties to forces without previously proving from observation, that those properties existed, is now carefully avoided.

Proceeding from this point of view, we propose to make some observations on the organic and inorganic forces of nature, sometimes called the living and dead forces. These observations will not add any thing to the amount of our scientific knowledge, but may serve to explain and establish the proposition that a connexion exists where hitherto it has not been recognized.

It is scarcely necessary to observe that the expression *dead force*, when used to denote the operating causes in inorganic nature, has no substantial value. Still it is understood to signify the force of dead nature, in opposition to that of living nature, where a particular series of phenomena appears; and this is the meaning in which we use the expression.

The chemistry of the present day, which is occupied especially with the doctrine of molecular forces, perceives peculiar causes, operating in the small particles of matter. Our inquiries may not inappropriately be commenced with the investigation of this subject, the study of which is the foundation of any knowledge we acquire in regard to organic forces; for every organism is composed of materials which are subject to the laws of those peculiar forces that belong to chemical substances.

While, however, we would endeavor to show that in all organisms, living or not, the same molecular forces operate as efficient causes, we are not to be understood as holding, that they are combined necessarily with consciousness, or the more elevated rational principle.

I will not venture to raise the veil, by which the action of the nerves, or the higher functions of the mind, have hitherto been shrouded from our observation. As man has an immaterial and immortal part, which is identical with his real being, and of which alone he will consist, when the material frame by which he is bound to the earth, shall be dissolved; and as the inferior animals possess, in common with man, certain powers of perception, associated with certain appropriate organs, whose functions have no connexion with consciousness; so do animals and plants perform in common a great many operations which are distinct from both of those now mentioned, or which at least have their origin in distinct causes.

It is only the latter class of which I speak, and to which I apply the general term of organic life. To that subject I shall restrict my remarks.

It is well known that in animals, such operations are performed through the agency of the nerves, and in them, therefore, they are generally more complicated than in plants. The similarity of the operations themselves, however, intimates the existence of a connexion between the causes from which they respectively arise. But the nature of this connexion, as well as its strength, is and ever will be an enigma, as much as the action of the nerves itself. The peculiar nature of organic life—the difference between living nature and what is called dead nature—is, however, not determined by the action of nerves. The properties which are common to animals and plants will alone be treated of; these properties being included in the general idea of functions of life. In the first place, we shall review in succession, the properties of the elements, which enter into the composition of all that exists in nature.

We shall be the first to admit the force of the objection, with which we may be met, that it is more easy to pull down than to build up. Science has not yet made such progress as to enable us, from a more elevated point of view, to take a comprehensive survey; but this will never afford a rational ground for adhering to incorrrect propositions. The suggestions which follow are therefore to be regarded as thrown out only for consideration. They will require to be much more fully developed before they can pretend to form a complete system.

§ 1. Chemical Forces.

We see in all the elementary substances, without exception, a disposition to combine with each other, and we therefore form the idea that a force exists in them, which is called *the force of affinity*. We see this combination effected; and infer, that there necessarily exists in substances a cause of the property which they possess, of uniting together. There is no element which cannot be united with others; there is none, therefore, which is destitute of that property in a greater or less degree. The power of combination is thus a property of matter, produced by a force, to which every material thing is subject, whatever its name may be, or to whatever part of nature it belongs.

We observe, however, in the elementary bodies many other properties besides that of uniting together. It would not be a simplification of science to assign a specific force to each effect produced by these elementary bodies; but it is impossible to have an accurate idea of any element, if we think of it only as impenetrable and ponderable, extended and in substance different from every other, indivisible and endowed with a tendency to combine with other elements. If we do not go farther, how should we be able to form a conception of isomorphism and of isomeric combinations—of the distinct character which belongs to each elementary body, as compared with others—of their dynamical differences? We are too much accustomed to confine our attention to the sensible properties of matter. We speak of copper and mercury as red and white, solid and fluid, fixed and volatile, and we dwell too much upon these and similar physical differences. We do not sufficiently inquire why the one forms combinations with different quantities of the same substances, accompanied with entirely different phenomena, as contrasted with those combinations which are formed by the other. We arrange the elements in groups, in so far as they agree in some of their properties; but we do not investigate in the first place, the cause why such agreement is exhibited by some, and why the opposite is exhibited by others. How do we account for the great difference between the two metals sodium and platinum? The one cannot combine directly with oxygen, though the other does, exhibiting at the same time very interesting phenomena. Sodium shows itself active in all circumstances; platinum is generally passive, and incapable of producing any marked phenomena. We say that sodium has a greater degree of affinity; but we derive the idea of affinity from observing the production of a combination—the final result of the power which is lodged in the sodium. When water is violently decomposed by it, this effect ought undoubtedly to be ascribed to the power possessed by sodium of combining with oxygen; but is this combination produced by nothing but the attraction between sodium and oxygen? We do not see any of these phenomena produced by general or physical attraction, and we must therefore superadd something to the idea of attraction to constitute what we understand by affinity. The question arises, whether the attraction by affinity operates in certain definite and invariable proportions? This consideration is necessary to an accurate notion of affinity; but it does not comprehend all that requires solution. It does not explain any thing as to the differences among bodies in regard to their color, smell, and taste; their being solid, fluid, or gaseous, fixed or volatile; their boiling point, density, specific heat, atomic weight;—nor any thing in regard to isomorphism, to isomerism, or the evolution of heat, light, and electricity in chemical combinations;—nor any thing respecting the singular quality, which each element possesses, of forming 1, 2, 3, and so on to the number of 7 combinations with another element, in certain invariable proportions—combinations which are formed from the same two elements, under conditions, that differ from each other only in a small degree.

If we consider the molecular forces in elementary bodies only as producing combinations between molecules of dissimilar kinds, the idea at which we arrive is limited and unproductive, and we overlook a long series of singular phenomena, which cannot be reduced to that principle.

The observation and arrangement of phenomena, the investigation of the laws which regulate them, and the ascribing to bodies of powers which are in accordance with the character of the phenomena dependent upon them, are all required for a correct knowledge of nature. In the present condition of chemistry, we are obliged to form a more distinct idea of the forces by which the molecules of matter are governed, than was sufficient in former times; because we know, with positive certainty, that there is nothing in common between the quality of the matter in one element and the quantity of another combined with it; and also, that the crystalline form of the compound is independent of the quantity also. Sulphur, selenium, chromium, and manganese, bodies of very different natures, take each three equivalents of oxygen (O^3), and yield with bases salts of the same crystalline form. The sulphates, seleniates, chromates, and manganates are all isomorphous. And so with a great many other elementary substances.

The conclusion which we draw, therefore, is legitimate,—that there are certain analogous powers present in sulphur, selenium, chromium, and manganese; and thus we arrive at the idea, that the chemical relations of these elements are not dependent upon their matter, but upon the analogous forces by which their molecules are governed. Thus the idea of the matter of sulphur is associated with somewhat of the idea of force, and of the same force which operates in selenium also—which operates not only in forming combinations, but in contributing also to the formation of the whole character of the compound substances produced. We observe the effects of this force which exists in sulphur, selenium, &c., even in more complicated compounds than those to which we have referred. Sulphate of soda and seleniate of soda, for instance, are both efflorescent salts, and both possess the singular property of being more easily soluble in water of 33° Centigrade (=91½° Fahr.) than in water of 100° Cent. (=212° Fahr.),—a property which is extremely rare, and which does not depend here on the substance of sulphur or selenium, but on the similar molecular forces, by which both sulphur and selenium are governed. Phosphorus and arsenic are isomorphous. Both combine with oxygen, and form acids, whose composition is represented by RO^5. Each of these acids forms with soda two analogous salts. All the four salts contain one equivalent of acid, two of base, and one of basic water; but one phosphate and one arseniate contain in addition 24, the other phosphate and arseniate only 14, atoms of water of crystallization.*

If, in the same manner, we pass in review the whole series of the elementary bodies; if we consider them abstractly

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* The fact here stated is represented by the following general expression:—

$$2\dot{Na}+\dot{H}+\left\{\begin{matrix}\overset{\cdot\cdot}{\overset{\cdot\cdot\cdot}{P}}\\ \overset{\cdot\cdot}{\overset{\cdot\cdot\cdot}{As}}\end{matrix}\right.+\left\{\begin{matrix}14Aq\\ 24Aq\end{matrix}\right.$$

from their matter, then we recognize innumerable modifications of those molecular forces, in the phenomena which each of them exhibits. These forces are often exercised in the production of chemical combinations, but this is by no means their sole characteristic.

The combination of two or more elements into one whole, is the best known effect of all the existing molecular forces. And the phenomena which we observe during this combination of substances, and the results of such combination, have enabled us to form a definite idea of a cause adequate to produce them. The combination is attended with phenomena which can be traced, and the results of which can be measured and weighed. We must be content with having reached this point, and can only hope that the time will yet arrive, when we shall be able to form more just conceptions of the other forces by which the molecules are governed. We can scarcely, as yet, give a name to the science of this subject—a science which appears to be actually boundless in extent.

The effect which we call affinity, is to be ascribed to a power of mutual chemical attraction, which dwells in the elementary bodies. Before such a combination is completed, and before they come into contact, they must possess a power, by which they are enabled to effect the combination *at a fitting time*, or they must acquire this power *as soon as they touch each other*. Here it is difficult to choose our way; but it does not seem impossible. So far as the idea refers to the excitation of force, the principle is the same as that of electricity, which is an operating cause also present in the molecules; but though it be so, yet it is not identical with the force of affinity.*

If we touch a piece of wood with a pen, we observe no sign of combination; but when antimony and chlorine come into contact, they unite immediately. The wood does not possess any power of exciting in the pen a combining force, neither has the pen any power of doing so in the wood. The chlorine, on the other hand, has the power of exciting a force of combination in the antimony; and the antimony of

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* We cannot, of course, attempt here, however briefly, to indicate in what respects the forces of affinity and electricity either coincide or differ.

doing so in the chlorine. Now, it is a matter of indifference, whether we conceive that the forces slumber in the antimony and the chlorine, and are brought into operation by contact; or that those forces were present in the two bodies in an active state, *previous* to the contact, but produced the phenomena of combination only *during* the contact. These two ideas may be reckoned of equal value for scientific purposes; because the power, exerted by the chlorine, of exciting the slumbering forces in antimony, and the similar power exerted by the antimony upon the chlorine, must undoubtedly, one or both, pre-exist before contact; if not so, then two slumbering forces are excited by each other, which is absurd. Whatever excites action we call force. Chlorine excites action in antimony, and antimony in chlorine; so that before contact a power exists either of *excitation* or of *combination*,—and that, if not in both, at least in one of these bodies. The mode of considering this point is almost a matter of indifference; but we must always bear in mind that it is a power, a force which is exerted by the one, and which acts upon the other. This force, I repeat, must exist in one of the bodies before contact, and may be called its *chemical tendency.* It manifests itself *during* contact, but cannot be produced *by* contact, any more than electricity or other forces. We cannot conceive of a force being produced *by* contact. Contact is a condition to which substances must be subjected, in order that some phenomenon may be produced; as touching the ground with the feet is a *condition* required to enable us to walk. A *condition* necessary to any phenomenon differs entirely from a source of action, from the cause of the phenomenon; and the theory of contact, therefore, seems to me impossible and absurd, at least in the sense in which it has so often been maintained.

We are conducted by the phenomena to the recognition of a power in substances, which can be excited under certain circumstances, and which is capable of producing a combination. This power necessarily *exists* before it is excited, and often requires only the *contact* of substances to allow the phenomena, called *combination*, to be produced. According to our view, therefore, we must suppose a power in *all* the elements, either of exciting or of exhibiting a force which causes a combination. This is what we call *chemical tendency.*

This power varies greatly in different elements. It varies in respect, first, of quantity, and secondly, of quality.

Those elements only which have the same atomic weight attract an equal quantity of the same element, while all the other elements, with but a few exceptions, attract very different quantities. There is also a very considerable variety in their mode of combining with other bodies; the phenomena which they produce are very different, and there is especially a great diversity in their power of combining, in one or more proportions, with another element. How is this latter difference caused, if not by the difference in their combining quantities, and by the special nature of their chemical tendencies? For (with the exception of the isomorphous bodies, and those which have the same atomic weight) every elementary body has its own peculiar qualities, and its own combining quantity, showing that the substances are specifically distinct. Each element also might be made to appear in a specific form, even though they were all derived from the same base, because every one of them is governed by specific forces;—in other words, a different distribution of the chemical tendency in an element would be sufficient to make the same element appear specifically different.

But, however this may be, either one and the same principle, differing from all others, not materially but dynamically, may be the base of all the elements, or there may be as many elements as there are groups of isomorphic substances, or as many as are designated, in the chemistry of the present day, elementary bodies. This question cannot yet be determined. Adhering to what we observe and know with certainty, we conclude that every elementary body is endowed with a great many specific properties, which, to a large extent, are dependent on the same principle that causes their combination, and thus on the proportion and character of the chemical tendency.

If we adopt this idea, we have the advantage of seeing somewhat of vitality, energy and activity in dead matter. It is an idea derived from the endless series of phenomena which are observed in the laboratory, in daily occurrences, and in nature at large. This series of phenomena, exhibiting the effects of that diversified chemical tendency in bodies, which is already observed in science, is fitted to excite admiration. Elementary works are filled with descriptions of substances which exist in consequence of that tendency, and the chemist cannot see the end of that series of new combinations which are continually formed by these substances, as so many results of the primitive forces. With such an idea, we do not confine ourselves exclusively to the material character of each element; for in this way we could not attain to a correct, certainly not to a practical conception of this subject, inasmuch as this material character presents a union of the physical properties of bodies, and not of those properties by which the elements appear capable of producing phenomena.

If the question be raised, whether the introduction of this idea will produce immediate fruits, we must reply in the negative. Hitherto the subject has not been studied from this point of view, and science is not yet supplied with sufficient data to allow of its being so studied. To view it, however, in this light, may be considered as an attempt to find a better way.

Four of the elements have a wholly peculiar character; all the others are more or less limited in their capacity of mutual combination, while carbon, hydrogen, nitrogen and oxygen are apparently unlimited in this respect. We may modify, in almost innumerable ways, the quantity and quality of the affinity found in these four elements. For that reason they deserve a prominent place in chemistry. Lead and oxygen combine in two proportions only, the protoxide PbO, and the peroxide PbO^2, and these unite to form a third combination, (red lead;) but the combinations of carbon and hydrogen are innumerable, and differ not only in relative but also in absolute quantities. We have not only the series, CH, CH^2, &c., but also C^2H^2, C^4H^4, &c. The combination C^5H^4 is also inexhaustible, either in the simpler form of C^5H^4, or as $C^{10}H^8$, $C^{15}H^{12}$, $C^{20}H^{16}$, &c. We know a combination, C^2H; another C^4H^3, another C^4H^5, &c.—and so with C and N, N and H, and CNH and CNO, CHO and CHNO. In one word, though these four elements have a great many properties in common, they exist as a distinct group, endowed with forces of affinity which are susceptible of infinitely more modifications than those which are presented by the other elements. We now proceed to examine somewhat more closely the character of the chemical combination of elementary bodies.

A. *Determinate value of the forces which produce combination. Apparent quiescence of the forces during combination.*

The simple substances differ in their power of mutual combination. They differ, therefore, in respect to the several forces which cause this combination, or in the capacity of having those forces excited in peculiar circumstances. The substances which seem to possess this tendency at every temperature, are potassium and sodium when combining with oxygen, chlorine when combining with a great many metals, &c. This tendency is peculiar to these substances, and, according to our observation, it is correct to say, that there exists in potassium, independent of circumstances, a tendency to combine with oxygen, and in oxygen a tendency to combine with potassium.

This tendency is clearly characterized by its operating between molecules of different kinds at distances too small to be measured, and by its producing from these a combination in a fixed proportion.

If substances chemically different yield to this tendency, a combination of two unlike bodies results,—an intimate union, in which each new molecule is composed of the two combined. A mass of potassium does not possess this power as a mass. It is peculiar to its small particles. The smaller even those particles are, the more easy is their combination.

This peculiar power in potassium of attracting oxygen, and in oxygen of attracting potassium, thus resides in the most minute particles; that is to say, in those which we can divide no further. The two particles now closely approximate to each other, and present new properties, which are chiefly dependent on the character of the combined substances, but result in part also from the forces by which those substances are governed.

After the combination is completed, the power of uniting still further with oxygen, at least under the same circumstances, is lost to the potassium. The two molecules have wholly satisfied their desire of combination, and the two opposite forces have therefore made each other quiescent, either in part or in whole. If they have made each other wholly quiescent, the new substance cannot combine further with any other. But if the force in potassium (K) be not wholly counterbalanced by the force in oxygen (O), more or less of K remains in the combination, and *vice versa* with O. It seldom happens that the two forces entirely counterbalance each other; but, in general, an excess of the one or of the other remains, which appears externally, and impresses on the combination a character conformable to that which is proper to the predominating element.

The constancy of the proportions in which the elements combine with each other, proves that the forces are of equal value in determinate circumstances. The cause of this constancy cannot be traced to one of the combined substances only, but it must be present in both, so as to complete the combination, of which the principal characteristic is a perfect constancy of quantities. While the combination is in progress, the sensible action of quantities of equal amount is apparently annihilated. If we suppose, for instance, that oxygen has a force of affinity of 3(O), and potassium of 6(K), 3(K) must necessarily remain after their combination, in certain circumstances, whilst 3(K) and 3(O) make each other quiescent.

This is proved by observation. Potash is not inactive, but possesses in its turn a tendency to combine with other substances, which, though less powerful than that of potassium, operates in the same manner; thus there is a quantity of chemical tendency, which has not passed into a state of rest, whilst the metal was combining with oxygen. We would call the remaining part of this force in potash 3(K).

Sulphur and oxygen (S and O) combine with each other, when favored by peculiar circumstances, in the same manner as potassium and oxygen combine at the common temperature. It is thus indispensable to this union that sulphur should have a certain quantity of force, which disposes it to combine with oxygen and produce sulphuric acid, and *vice versa*. By this combination the whole quantity of the opposite forces is apparently lost; but yet a portion of the force, either of the oxygen or of the sulphur, remains. If we suppose that the forces by which oxygen and sulphur (O and S) operate upon each other, have the proportion of 3(O) : 1(S), we have remaining 2(O) after the combination of O and S into SO^3.

Potash, therefore, retains a force of 3(K), and sulphuric acid of 2(O). According to this view, neither potash nor sulphuric acid is neutral, but they are both still supplied with forces of affinity opposite to each other, so that they are able to produce a new combination of the substances already in composition; that is, of the sulphuric acid and the potash into sulphate of potash. As soon as these combine with each other, potassium (K) is again neutralized by oxygen (O). If we assume that of the 3(K) and 2(O), 2(K) are counterbalanced by 2(O), there remains 1(K) after sulphate of potash has been produced.

In this sulphate of potash, two forces, opposite to two others, are thrice enveloped; two of them in the elements of the potash, two in the elements of the sulphuric acid, and two in the elements of the sulphate of potash. These forces counterbalance each other; the feebler of them, (O), has been made imperceptible, but the stronger of them, (K), is able to act on other substances through the force which remains active after the oxygen has been neutralized.

In our example, 1(K), or in other words, one quantity of the force originally present in potassium, still remained after the combination of SO^3 with KO. Sulphate of potash, therefore, is also not neutral, but may combine anew with other substances, and especially with those which contain oxygen (O) once, twice, or more times. Supposing we have such a substance in sulphate of alumina, we see alum formed on the same principles by the combination of the sulphate of alumina with the sulphate of potash. Thus it appears that the same force originally residing in the elements, is capable of producing all the chemical combinations of the first, second, and third orders.

The value of the forces which are originally involved in the elements is still undetermined. In course of time, however, it will be ascertained. The quantities which we have assumed merely to explain our views, must therefore not be regarded as having a real value. It is, however, certain that there must always be two forces of opposite character where attraction and combination are the effects.

This mutual combination does not take place among all the elementary bodies. Those substances which do not combine with each other are either destitute of both the opposite forces referred to, or these forces are inactive in one of them, owing to the circumstances in which it may be placed. On the other hand, combination takes place every where if the forces (K) and (O) be different from each other in a determinate degree. If, for instance, there be a substance containing 20(K), and if it come in contact with another containing 1(O), the result will be a combination, and this new product will be able to act with a force represented by 19(K).

We have no reason to assume the existence of other chemical forces than those which we have called (K) and (O).* All the elementary bodies seem to possess them, though uniformly in different degrees. It results from the doctrine of chemical proportions (*stochiometry*) that the quantities of the several elements which combine with each other vary according to certain definite proportions, when the forces are excited in different degrees by different circumstances. Nitrogen (N) combines with one, two, three, four or five of oxygen, (O, O^2, O^3, O^4, O^5,) and so with regard to the other elements. We have thus solid grounds for assuming the existence of certain values of the chemical forces; the relative proportions of which values may be expressed by whole numbers.

Another result of experience is, that these forces are exhibited in ordinary circumstances by all the elementary bodies, but that the conditions require to be modified, either to excite these forces, or to fix them in the substances in determinate quantities. We see oxygen attracted by potassium at the ordinary temperature, and hence conclude that such a force is always possessed by potassium. We cannot, however, produce any proof of this, for it is possible that the common temperature causes the production of that force in potassium, seeing that it ceases to attract oxygen at a temperature of —150° Fahr. It is possible that the ordinary temperature has the same effect on potassium, as a red heat has upon iron.

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* The author employs these letters to designate the forces more commonly called the electro-positive and electro-negative powers of substances.—S.

Among the circumstances by which these forces may be excited or fixed in determinate quantities in the elements, may be reckoned a high temperature, the influence of light, the action of electricity, and especially the presence of another chemical substance. We shall here adduce a single example of each, and treat hereafter of this subject more fully in its proper place.

Heat excites the forces (K) as well as (O) in many substances; (K), for instance, in the metals which are oxidized at an elevated temperature; (O) in chlorine, which combines with hydrogen on the application of a taper, producing hydrochloric acid.

Light causes the sudden combination of hydrogen and chlorine (H and Cl), and thus excites (K) and (O) in these two gases respectively.

Hydrogen and oxygen (H and O) are at once combined by means of an electrical spark, which thus excites in them (K) and (O).

(K) and (O) are excited by other substances, as, for instance, in the combination of hydrogen and oxygen (H and O), which is effected suddenly by spongy platinum, and more slowly by platinum foil.

The peculiar forces of two substances are not lost by their mutual combination; they only become quiescent, as it were, so far as each is counterbalanced by an equal quantity of the opposite force. Alum may be decomposed into sulphate of alumina and sulphate of potash; each of which has its proper character of (K) and (O), and that in the same degree as before their combination. Finally, potash and sulphuric acid (KaO and SO^3) may be decomposed in the same manner into Ka, O, S, and O^3, each of which has the same quantity of (K) and (O) as at first.

This is proved by every chemical analysis, effected by the action of other substances upon those which are to be decomposed. The forces (K) and (O), therefore, become only quiescent, and are not lost while the combination of the substances is in progress.

We are by no means able to enter into this idea, if we assume that the molecules of the united substances are quite close to each other. In this case a reciprocal annihilation of two opposite forces must occur. If we suppose that the molecules are very near, though not in contact with each other, we can easily conceive that the forces which proceed from the molecules, having a certain tendency towards each other, may seem to our senses to lose that portion of their strength which is expended in producing the combination, and yet may appear again in their original quantity as soon as the combination is dissolved.

Substances *persist*, therefore, in their combinations, by the same law in obedience to which they *become* chemically united; they are *decomposed* again by the same law if more powerful forces than those which bring them together, act upon their component parts. They *become* combined, because two opposite forces which either are present in the elements, or are excited by circumstances to a determinate degree, act upon each other, and so accompany the substances with which they are connected. They *persist* in their combination because these forces are not annihilated, though part of each is brought into equilibrium with part of the other. This part is thus prevented from acting externally. They may be *decomposed*, if more powerful forces act upon one of them, and if the decomposing forces be of the same species. Copper, for instance, separates silver from its solution in nitric acid; thus withdrawing the oxygen from the silver, and itself combining with the oxygen. Suppose copper to contain 4(K), silver 1(K), and the oxygen of the oxide of silver 3(O); a separation of the silver, which has but 1(K), must necessarily take place, because 3(O) may be neutralized by 3(K).

We have, therefore, a direct proof that these chemical forces are only quiescent, inasmuch as chemical substances are decomposed by others, which exercise a more powerful influence upon one of the combined substances than on the other. Hence again we deduce the conclusion, that substances are kept in combination by the same forces, in virtue of which they enter into combination.

B. *Chemical Action is Action at Unmeasurable Distances. Polarity of the Molecules.*

It is a peculiar feature of chemical combination, that it acts at distances too small to be measured. To effect the combination, it is therefore indispensable that the particles should come very near each other. This is the reason why substances, if put in mutual contact while still in a mass, have for the most part either no action at all, or only an imperfect action upon each other, and why they act upon each other even at the ordinary temperature, if they are reduced to a very fine powder. This may be seen in the case of sulphur and copper. These substances have no effect at all on each other when in mass; but when reduced to powder they are combined by simple trituration, a great deal of heat being evolved in the process. We should err, however, if we supposed that minute division was the only cause of combination; trituration is, in the case supposed, only a powerful assistance. We see, however, when bodies are dissolved in water, that this state of division is a principal condition of combination. If anhydrous sulphate of soda and chloride of barium are triturated together, no change will take place at all; but if they are brought together in a dissolved state, that is, in a state of the minutest division, a perfect decomposition will result.

The effect of temperature, in such cases, is not simply to promote the combination of substances. Temperature facilitates combination in the same way as solution in water does, where either one or both of the acting substances can be fused. No doubt the oxidation of metals in oxygen is promoted by an elevated temperature, owing either to the excitation of peculiar forces in the metal and the oxygen, or to the increase of these forces to a limited extent: but fused lead or volatilizing zinc, for instance, has the particles very much divided and very movable, under the influence of an elevated temperature. These particles, for this reason, are enabled to turn to the oxygen that very side which is necessary for the combination. We must therefore add this greater mobility also to the influence of the temperature, (as we remarked of solutions of salts,) wholly independent of the elevated temperature itself. So with pulverized lead, we find that if shaken in air and water, it is soon changed into hydrate of oxide of lead; though a lump of lead under the same conditions is but slowly acted upon. Two gases, if mixed with a third of a neutral character, combine but slowly; the result of their action, however, is a perfect mutual attraction; as, for instance, when ammonia, carbonic acid and atmospheric air are mixed. Thus the combination of gases is promoted by the mobility of the particles.

As it is necessary to the production of a chemical combination that the particles should be movable, we infer that the different sides of the molecules have a different power of combining with a molecule supplied with an opposite force. The particles must be able to move, and it seems, therefore, that there are determinate sides in every molecule which prefer being united with molecules of an opposite force. In many combinations, when observed with the microscope, we perceive a vehement rotation of the particles, before they combine with each other.* This fact directly demonstrates a certain property of polarization, an action of the force of affinity in a determinate direction, influencing an opposite force which also operates in a determinate direction.

That this must necessarily be the case, will appear if we examine somewhat more deeply the nature of the union between two elements. Potassium and oxygen unite by means of a force, which is not altogether annihilated after the combination, but of which a part still remains active externally; the other part is rendered quiescent by the mutual counterbalancing of two opposite forces. A particle of potassium, if it be an indivisible one, must be placed in *juxtaposition* with an indivisible particle of oxygen in this manner: $\boxed{\mathrm{Ka} \mid \mathrm{O}}$ Their *inter-penetration* is impossible, because matter does not admit of penetration. One substance can by no means be closely wrapped round the other, in the form either of a ring or of a sphere, for in that case the enclosing sphere could not be regarded as an indivisible particle. It is impossible that the one should be distributed in particles round the other, for it is *one* molecule. The only theory then which remains for adoption, is that of an arrangement of the opposite particles *beside* and *near* to each other. If we suppose that each particle of potassium and oxygen is wholly and every where supplied in the same degree, with the forces (K) and (O), the effect of these forces will be to produce an approximation of the molecules, because the forces are opposite to each other and the strongest attraction will take place at the point

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* See Harting in Bulletin de Neêrlande, 1840, p. 287.

of approximation; in other words, the attracting forces may be supposed to act in the axis of two spheres.*

Such a composite molecule can be united with molecules of the same kind, only by means of the general principle of attraction. Potash in mass is bound together not chemically but physically, that is, by the universal force of attraction or cohesion. For the mass may be divided into smaller parts without disturbing the chemical equilibrium.

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* It is considered a legitimate deduction of science, that the crystals of bodies indicate the forms of their molecules. The perfect symmetry and the constancy in every angle, exhibited not only in the crystal as a whole, but in the minutest particle into which it can be broken, must proceed from as perfect a symmetry and constancy of form in the constituent molecules of the crystal.

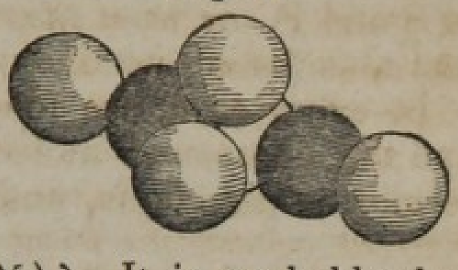
On these grounds it is inferred that the form of the molecule of lead is a *sphere*, the crystalline form being one of the tesseral solids, having, like the sphere, equal axes. The same conclusion is arrived at with regard to the molecules of gold, silver, mercury, and many other metals. In like manner we learn from the crystal of sulphur—a rhombic octahedron having *three unequal axes*—that its molecule must be an ellipsoid with unequal axes. The form of tellurium being a six-sided prism, (in which the vertical axis differs in length from the lateral,) the molecule is an ellipsoid of like axes with the prism.

No aggregation of spheres could produce the crystals of sulphur or tellurium. Or supposing it possible to make the *form* by means of spheres, the crystal would not present a difference of lustre, cleavage, and optical properties in the vertical and lateral directions—differences observed in all crystals except the tesseral solids, and often extending also to color and hardness. These peculiarities show a dissimilarity in the nature of the molecule in different directions, or in other words, indicate that the vertical axis is unlike the lateral, and consequently that the molecule is, as stated, an ellipsoid corresponding in its relative dimensions with the form of the primary. The optical phenomena of crystals as long ago as Huygens, were explained on these principles, and to the present day they give not only a satisfactory explanation, but the only one that accords with the facts. In farther explanation, we state that the axes of attraction in these ellipsoidal or spherical molecules, correspond with their conjugate axes or conjugate diameters, and by action in their directions the various forms of crystals may be produced. The ellipticity of the molecule will depend of course on the attraction in the several directions, the length of the axes being inversely as the strength of the attraction.†

If the inference with regard to the molecules of simple elements is correct, it will be no less so with reference to those of compound bodies, however complex their composition. The hexagonal prism of phosphate of lead indicates as much that the molecule is an ellipsoid,

† This subject will be found farther illustrated in the Treatise on Mineralogy, by J. D. Dana, to whom we are indebted for these views: also in an article by the same, in Vol. xxx, p. 225, of the American Journal of Science.

Fig. 1.



If polarity really exists in the simple molecules, so must it in the composite molecules. We can easily imagine this, if the substances, composed of one atom of each element, produce a binary combination, as in the case of potash; but it is difficult to form a conception of the nature of the combination, when two, three or more molecules of one element are combined with one or two molecules of another. How, for instance, can we form an idea of the polarity of sulphuric acid (SO^3) and of phosphoric acid (P^2O^5)? It is probable that

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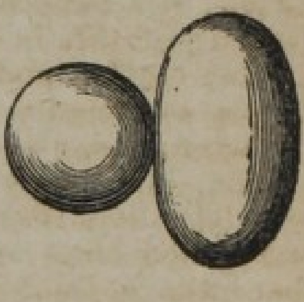
as that of tellurium; and the rhombic octahedron of tungstate of lime leads to the same conclusion with that of sulphur.

It is hence necessary in a *compound*, that the molecules of the elements combined should be so united together, as to produce the results that would proceed from spherical and ellipsoidal molecules; or rather, they must actually *constitute* molecules of these forms, as only thus could the results be produced. Axial attractions in fixed directions are required to produce solids of perfect symmetry and unvarying constancy in the angles, and a uniformity in the texture of the molecule, (varied only by those unequal attractions in different directions that occasion the ellipticity,) in order to account for the optical effects.

In view of the above considerations, we may well question whether the theory of *juxtaposition* is fully satisfactory. Take a sphere of lead and an ellipsoid of sulphur, (see annexed figure,) and by what process can a sphere (the molecule of sulphuret of lead) be made from the two? or how can axes exist in these unequal solids, juxtaposed, that will produce the *effect* of a sphere—a cubical form of crystal, and a cubic cleavage? The more complex compounds in chemistry, would if possible, be a greater puzzle to the *atomic* philosopher.

Fig. 2.



We are thus led to the conclusion that molecules are not *atoms*, *indivisible* particles; that in forming compounds they admit of an intimate union into spheres and ellipsoids. Adopting the mode of expression of our author, the *forces* which constitute molecules are capable of mutual action, and they produce, as a resultant, the molecule of the compound—as neat a sphere or ellipsoid as the molecule of an element, similarly governed by axial attractions (at least when entering the solid state) on which depend the form of the crystal, and its optical and other physical characters.

By the principles of *dimorphism*, the same substance may present two distinct forms, the one or the other being assumed according to the temperature at which crystallization takes place. This is true of *sul-*

the molecules of oxygen, being here the more numerous, are arranged *round* the molecules of sulphur and phosphorus (S and P), and that the force (K) of the latter element is neutralized by a part of the (O) of the former. But we cannot conceive how by any probable means (K) can be distributed in S and P, or what may remain of (O), capable of acting and manifesting itself externally.

In every case, we may deem it probable that the simple and the compound molecules are combined together in determinate directions, and that their character is fixed by the

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phur, one of the elements, as well as of some compounds. Thus the molecule of an *element* even, is not constant in its figure. The form produced at a high temperature, often changes in the cold to the other form, every particle altering its character throughout the solid crystal. We can easily understand dimorphism if we suppose it a simple change in the molecular axes, depending on temperature. In *carbonate of lime* (one of the dimorphous substances) some theorists would say that there is a different arrangement of the juxtaposed atoms; but how is it with sulphur, where there is but one molecule concerned? And with carbonate of lime there would be some difficulty in arranging the atoms of carbon, oxygen, and calcium, to make either one form or the other.

In *isomorphism* the substitution of one element for another, without a change of form, accords well with these views. The principles of isomerism also seem to find here their only explanation. The compound represented by the formula CH, results from the union of a molecule of each carbon and hydrogen into a simple molecule. In C^2H^2, *two* molecules of each are united into a simple molecule, condensed probably in a different degree from that of CH; so also with C^4H^4, C^8H^8, and other cases similar. Juxtaposition gives no satisfactory explanation of these singular compounds.

These views also elucidate the condition of gases absorbed by spongy platina, and many other analogous phenomena. According to the principles here illustrated, we have the obvious explanation, that this and similar cases are instances of simple cohesive attraction, without that intimate combination of molecules which takes place in forming a chemical compound. The *surface action* theory of Liebig may therefore be less objectionable than is urged by our author.

The controversy among some chemical writers as to whether the molecules in a compound have one mode of arrangement or another —whether sulphate of lime consists of a compound molecule of sulphuric acid alongside of a molecule of lime, or whether it is made up of a molecule of calcium united to a molecule of quadroxyd of sulphur, as Graham suggests—appears to be of little value to science, if the views here stated be correct. It seems important to the chemist, only to distinguish what are the constituents between which the affinities were exerted that gave origin to the chemical compound, carbonate of lime; and this action of affinities it is well to express in the name and in the manner generally adopted.—S.

form which the compound molecules assume. We see, then, a determinate relation between the arrangement of molecules and isomorphism, between the number of atoms and the form of the crystals. For if the atoms of sulphuric acid and selenic acid are arranged in the same manner, we can conceive that when these acids combine with the same base to form salts, the same form of crystals may be produced, although we cannot, *à priori*, determine from that arrangement of the molecules what the form of the crystals may be.

The difficulty we have noticed, as to the combination of several molecules into one whole, is greatly increased, if we endeavor to form an idea of that state of polarization which exists in every compound organic molecule. We cannot explain how the atoms of sugar are combined together; and so with every other organic compound. It is, however, certain that here also polarization exists; because in crystallized sugar, $C^{12}H^{11}O^{11}$, two equivalents of water are contained, for which two equivalents of oxide of lead (PbO) may be substituted. Hence it is evident that a constant proportion exists between the 2 of oxygen in 2HO and 2PbO, and the 9 of oxygen in $C^{12}H^{9}O^{9}$.

It thus appears that the oxygen of the sugar, after combining with carbon and hydrogen, and after having several times neutralized their forces (K), has forces (O) still remaining to oppose to water or to oxide of lead, these in their turn possessing (K), by which they are enabled to combine with the sugar. The other elements of the sugar leave to the 9 atoms of oxygen, after subtraction of the quantity applied to the neutralization of the carbon and hydrogen, as much force as enables it to combine with the same quantity of oxide of lead as can be attracted by two of sulphuric acid ($2SO^{3}$), thus:—

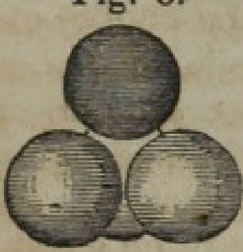
$C^{12}H^{5}O^{9}$, require 2PbO.
$2SO^{3}$, " 2PbO.

If, then, we assume a state of polarization in the elements of sulphuric acid and oxide of lead, and if we imagine, that resultants of all the forces which reside respectively in oxygen and lead, and in oxygen and sulphur, are developed—resultants which influence each other, though co-operating as a whole—we cannot form any other idea, than that a similar resultant proceeds from the elements of sugar, directly the opposite of that which proceeds from the atoms of the oxide of lead.

We cannot, however, determine, with any probability, how this resultant may be obtained.

There is, however, a class of organic substances, in which this division into groups is obvious, namely, those substances of which we know the radicals, acetyl, formyl, æthyl, methyl, &c. We attempt in vain to form an idea of the various substances, of which the radicals are still unknown; as, for instance, sugar. If a simple substance can combine, with but one atom of another, such a substance is probably unipolar, if with two, bipolar, &c. And so with more compound substances. It is therefore likely that the molecules of bi, tri, quadri, quintibasic acids are just as much polaric; and that in a tribasic acid, for instance, the three atoms of base are arranged *round* the acid in the form either of 3 of oxide or of water ($3RO$ or $3HO$),* or 2 of oxide and one of water ($2RO+HO$), or one of oxide and 2 of water ($RO+2HO$).

Fig. 3.



C. *The Influence of Circumstances upon Chemical Forces.*

We may employ the quantities of different substances, which can combine with the same element, to express the measures of the chemical forces which reside in them. Whether one substance can separate another from its combinations, may be ascertained by experiment. Now, experiment informs us that in the same circumstances different bodies possess different quantities of chemical force. For instance, sulphuretted hydrogen is decomposed by iodine, and sulphur separated; hydriodic acid by bromine; hydrobromic acid by chlorine. These simple substances, therefore, stand to each other in this order of affinity, chlorine, bromine, iodine, sulphur. So with the metals, silver, mercury, copper, lead and zinc. Each is precipitated from its solution by that which follows it in this order of succession. There is thus more force of affinity in each of the subsequent, than in each of the preceding metals. In alkalies the affinity for sulphuric acid diminishes in this order—baryta, strontia, potash, soda, lime, magnesia, ammonia.

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* R is used in chemical formulas as a general expression for the bases.

The chemical forces, however, emanating from bodies, are modified by so many particular circumstances, that it is as yet impossible to lay down determinate principles.

1. If, for instance, any substance is volatile, it is easily liberated from its combinations. Carbonic acid, therefore, passes off very quickly; and even hydrochloric acid, though much more powerful, does so, because it is volatile. Phosphoric acid expels even sulphuric acid, because it is unaffected by fire. Silicic acid, though possessed of but little power, expels many other acids when heat is applied, because it is not volatile.

2. If any substance has a tendency to produce an insoluble combination, then its force of affinity is considerably increased. Of this we have a striking example in carbonate and acetate of potash. If carbonate of potash is dissolved in water, the carbonic acid is expelled by acetic acid; but acetate of potash, if dissolved in alcohol, is decomposed by a stream of carbonic acid, because carbonate of potash is insoluble in alcohol. If a double decomposition take place, the bases and acids are always arranged and combined together in that order, in which the least soluble salts are produced.

3. It is a remarkable peculiarity in the modification of affinity by the influence of circumstances, that many combinations are much more easily effected, if some other substances must first be separated, than if the substances are brought into mutual contact in an uncombined state. Lime, if quite dry, does not absorb carbonic acid, though hydrate of lime does so very easily. Oxide of ethyl does not combine directly with acids; but it does combine if the acid be made first to separate water (HO) from alcohol, and thus to form the ethyl with which it is to combine. If a metal is dissolved in hydrochloric acid, the metal (M) is substituted for the hydrogen (H) of the acid, for $MCl+H$ is produced by $M+ClH$. In this case Cl and M are easily combined, because M is substituted for H, though it is often very difficult to unite M directly to Cl. It is probable that the double decomposition is very much promoted by the double substitution which then takes place.* In Graham's opinion, the power which the hydrates of silica and alumina have of forming combinations, ought also to be ascribed to

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* Graham.

substitution, since the same substances, after being subjected to a red heat, scarcely combine with other bodies at all.

4. Mutual decomposition of two salts takes place, not only when one or both of them become insoluble, but also when one of the two new products, or both, are less soluble than those which were originally employed. Such is the case when solutions of sulphate of soda and nitrate of potash are mixed together. If sulphate of copper be mixed with chloride of sodium, the blue color is changed to green, which proves the formation of chloride of copper. It is possible, however, that this may result from mere affinity, because sulphate of copper can be decomposed by hydrochloric acid, and chloride of sodium by sulphuric acid.

5. Pressure is another circumstance which influences chemical forces. If it be very great, no hydrogen is disengaged from diluted sulphuric acid and zinc. If the vessel be closed, the evolution of gas is diminished and finally stopped; but it begins again whenever the vessel is opened.

6. If carbonate of lime is heated in a close vessel, none of the carbonic acid is disengaged; but it is otherwise when carbonate of lime is heated in the air, at least in the uppermost layers of heated air. But if atmospheric air or steam be conveyed through a tube, which contains carbonate of lime, then all the carbonic acid passes off. If hydrogen pass over red-hot oxide of iron, water and iron are produced; and if steam pass over red-hot iron, hydrogen and oxide of iron result. In this case the affinity is modified by the atmospheric air which surrounds the substance; and this phenomenon is thus related to the diffusion of gases.

It appears, then, that a considerable part of what we see as to the inclination of substances to combine or to separate is to be ascribed to the influence of circumstances. To effect a combination, it is necessary that the chemical forces included in the substance should be either excited or elevated to a determinate degree. It is only thus that we can conceive how a molecule can acquire the power to combine with 1, 2, 3, 4, &c. molecules of another substance, so as to produce well-defined chemical compounds. The quantities of chemical forces are thus graduated, as it were, and substances are combined in proportions, which depend on the quantity of those forces; such combinations, however, do not occur until two opposite forces are excited to a certain degree by the influence of determinate circumstances. If, for instance, iron be slightly heated in the air, the protoxide (FeO) is produced; if it be heated to a greater degree, the peroxide (Fe^2O^3). Why do the same iron and oxygen combine together in two different proportions by means of the same agent, heat?

If we suppose, that at the ordinary temperature iron has a tendency to combine with oxygen, and *vice versa*, but that there exists no proportion at all between the quantities of the forces (K) and (O) which reside in them respectively, then the iron would not enter into combination. This is what we observe in dry air. If the iron be heated, its force (K) is excited, and so is the force (O) in the oxygen, when in contact with the heated iron. A combination of the opposite forces, and consequently a combination of the iron and the oxygen, (Fe and O,) occurs only in the case where both forces increase to such a degree that they both reach an equally high maximum, with reference to the circumstances in which they exist. A dull red heat makes these forces increase to a limited maximum only. If we heat FeO and O to a still greater degree, these forces get a new increase, and Fe^2O^3 is formed only when the forces of Fe and O have attained a new maximum.

As to the production of some other compounds, we must adopt a different principle. If, for instance, sulphur is to be oxidized into SO^2 and SO^3—sulphurous and sulphuric acid—then the sulphur must in each case be placed in peculiar circumstances. When sulphur is burned in the air, the elevated temperature affects S with (K), and oxygen with (O); in other words, the forces resident in sulphur and oxygen, must be excited in such a manner that S is combined with O^2. The oxidation into sulphuric acid (SO^3) is effected in a different way. Sulphurous acid (SO^2) is brought into contact with a substance possessing energy, and which is known to have the power of exciting action in other substances, and even of itself giving off 1 equiv. of oxygen, namely, with hyponitrous acid (NO^3). SO^2 is thus predisposed to take up O again; NO^3 excites new forces in SO^2, and the combination of O with SO^2 is effected in the same manner, as that of gold with chlorine, by the contact of the gold with chloronitrous acid (aqua regia). This result is attained because 1 equiv. of oxygen very easily escapes from the hyponitrous acid NO^3, which it contains, and this oxygen, being in the *nascent state*, retains that force by which it was previously kept in combination with NO^2. As regards the gold, it is NO^3 also which excites the force in this metal, producing its combination with Cl, or with a substance which possesses the (O) force.

Phosphorus may be combined with O^3 at the ordinary temperature, and the product is phosphorous acid. To form PO^5, phosphoric acid, however, a more elevated temperature than that necessary for combustion is required.

The predisposition either of simple or of compound substances to form new combinations, the excitation of the forces resident in them, and which were neutralized so as to be wholly or partly imperceptible externally, is produced sometimes by one, sometimes by another circumstance, often by the influence either of a different substance or of a certain temperature, or of light, or of electricity. We learn from experiment that the excitation of forces takes place in such a manner, that determinate and constant combinations are produced. It is, therefore, necessary that the measure of the opposite forces, which are excited, should be a constant one also; at least a maximum of both the opposite forces must be produced, before any combination can result, though the forces may increase with the increasing influence of circumstances. This maximum may be superseded again by other circumstances, producing a new combination of the elements.

D. *Catalysis: Molecules in Motion.*

Berzelius has directed our attention to a power, which some substances possess of exciting chemical action by their presence, though they themselves are exempt from the effects of such action. This power he calls Catalysis.* It is distinguished from ordinary chemical force, in so far as the latter, while it is exerted by one substance upon another, yet generally reacts upon both. If sulphuric acid acts upon soda, an action is effected by both, which reacts upon both. If oxygen come in contact with phosphorus, at an elevated temperature,

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* Jahrbuch für 1836, von Schumacher, p. 88.

then they are mutually combined. Though the action might have proceeded from the oxygen to the phosphorus, the oxygen nevertheless is drawn within the circle of action.

The effect of catalyzing substances is entirely different. Spongy platinum condenses hydrogen; and so soon as oxygen comes in contact with it, water is produced, while the spongy platinum undergoes no change. Hundreds of pounds of hydrogen and oxygen may be combined together by means of a small piece of spongy platinum. Thus the platinum produces a force, which influences at once the hydrogen and the oxygen, and causes an action, from which the platinum itself is exempted. Such is the force which Berzelius calls *catalysis.*

The greater part of the substances, which excite chemical action in other bodies, and are themselves involved in the reaction, are undoubtedly affected by this catalysis. Possibly catalysis may always be present among chemical causes, so that, if SO^3 and NaO—sulphuric acid and soda—for instance, are combined together, a force proceeds both from SO^3 and from NaO, each of which is similar to that proceeding from platinum, when in contact with certain gases. Catalysis might be defined as the *exciting* cause of chemical action, and this excitation may take place whether the exciting substance be contained in the circle of action or not. We reckon, however, as pure catalytic phenomena, only those in which the substances provoking the combination do not enter into that circle. Those bodies thus possess the power of exciting, but have not the property of sharing in the combination which is the result of their action.

This force is possessed, not only by spongy platinum, but by platinum in substance; for if a piece of platinum foil be placed in a mixture of hydrogen and oxygen, the gases as they pass along its surface, form small quantities of water, so that in a few hours all the gas has disappeared, and water has taken its place.

Nor is platinum the only metal which has this property. Every substance which is porous, is possessed of it in a greater or less degree. Thenard and Dulong have detailed a great many experiments on the subject, and have demonstrated, that this property belongs even to glass when pulverized, but only at a somewhat elevated temperature—namely, at

572° F., and to gold and silver at a lower temperature. It had previously been discovered by Sir Humphry Davy, that platinum, if placed in the vapor either of alcohol or of ether, began to glow, and caused a combination between the vapor and the oxygen of the air. Spongy platinum was afterwards discovered by Edmund Davy, who observed that it possessed this property in so high a degree, that if the platinum was moistened with alcohol, acetic acid was produced from the alcohol while the platinum was glowing. Before the discovery of Thenard and Dulong, it had been remarked by Döbereiner that hydrogen and oxygen could be combined together by means of spongy platinum. This discovery was extended by the two former to several other substances.

The effect of deutoxide of hydrogen, (HO^2), when in contact with various substances, has been classed by Berzelius with the same series of phenomena. It explodes, if brought in contact with platinum, silver, peroxide of manganese, and even with organic substances, such as fibrin. Oxygen is disengaged, and water (HO) remains.* In every case, where the solid substance can combine with the whole quantity of oxygen, there is of course only an ordinary chemical action; but if this combination does not take place, and if the action occurs on contact simply, the phenomenon is that which Berzelius calls catalysis.

This term ought further to be used with reference to the change of alcohol into ether, by means of acids. Hydrate of sulphuric acid—the common oil of vitriol of the shops—into which alcohol is dropped at an elevated temperature, is not diluted by the water produced, but a mixture of oxide of ethyl and water distills off. Sulphuric acid, therefore, catalyzes at that temperature the elements of alcohol into oxide of ethyl and water, without itself combining with either. The same effect is produced by other acids, especially if they are powerful. To the same class we refer the changes, produced on starch by sulphuric acid, transforming it either into dextrine or into sugar—the changes which are produced by acids on starch, gum, sugar, forming humic acid, ulmic acid, and for-

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* It is now known that at the same time part of the oxygen is combined with the fibrin, and oxy-protein produced. (Scheikundige Onderzoekingen, by Mülder, D. 1.)

mic acid—and also the action of emulsine upon amygdaline. Several other phenomena, besides, are referred by Berzelius to the same class—phenomena ascribed to organic chemistry—as for instance, the transformation of starch into gum and sugar by diastase, the transformation of sugar into carbonic acid and alcohol by yeast, and also the changes which take place in the bodies of animals and plants. Transformation by diastase ought doubtless to be classed with these phenomena. An exceedingly small quantity of this substance changes a large quantity of starch into gum and sugar; but it is also possible that the diastase itself is at the same time acted upon, and that thus we have in this instance, no pure catalysis. This is the case especially with yeast, which, during fermentation, changes sugar into carbonic acid and alcohol, and probably it is much more so in the animal secretions.

In view of these considerations, Liebig has been led to reject catalysis entirely,* and to give a totally different explanation of facts. He has *assumed*, that chemical forces are in action in those substances, which, according to the supposition of Berzelius, are capable of exciting action, though without taking part in that action; and he thinks that by such chemical action, another may be excited in other substances. He adopts the principle, indicated by Laplace and Berthollet, that a molecule, being put in motion, can communicate its motion to others, if in contact with them. He applies this principle to yeast especially. The opinion of Berzelius is that sugar is changed into carbonic acid and alcohol by this substance, just in the same manner as alcohol is changed into ether and water by sulphuric acid; and as water is produced from hydrogen and oxygen by platinum. Liebig, however, assumes that yeast is continually in a state of decomposition; that it thus undergoes a change in its own elements, and that if put in contact with sugar and water, it disturbs the chemical forces, by which the elements of sugar are combined together, and so produces alcohol and carbonic acid;—this disturbance being caused by the change in the elements of the yeast, which follows the disturbance of its chemical equilibrium.

Though it seems to be proved that yeast is really changed during the alcoholic fermentation, and cannot therefore be

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* Chimie Organique, Introduction.

said to act by catalysis, yet this series of chemical phenomena is not reducible to any class of ordinary phenomena, and we are consequently obliged to assume three different forms of chemical action.

1. That which is effected by a substance, without any reaction, but which is transferred to other substances, (*catalysis.*)

2. That which is effected by certain substances and transferred to others; the primary substances being at the same time decomposed, though they do not communicate any of their elements to the new products, (*fermentation.*)

3. That which is effected by certain bodies, but which produces a complete reaction upon the bodies themselves, so that common products result from both the active or influencing substances, and those which are acted upon, (*ordinary chemical action.*)

We have already treated sufficiently of the third cause of action; we must dwell, however, more particularly on the first and second.

Catalysis.—In our opinion it is not to be denied that a particular action must proceed from spongy platinum, or from platinum in mass, when hydrogen and oxygen combine to form water—from sulphuric or any other acid, when oxide of ethyl is produced—in the transformation of starch into gum and sugar by sulphuric acid—in the change of sugar into humin by diluted acids. This action differs in character from ordinary chemical action. In the latter case the substance, from which the action proceeds, is always itself comprised within the circle of effects, and generally enters into new combinations. There are, however, a great many similar actions, which are erroneously referred to ordinary chemical action. If, for instance, gold or platinum be dissolved in aqua-regia, hyponitrous acid (NO^3) takes no part in the combination. Either NO^3 or some other powerfully acting substance, however, is indispensably necessary to produce the combination of chlorine with gold or platinum. A still more striking example is afforded in what has already been mentioned, namely, that the presence of a third substance is often required for the production of a combination, though it be separated after the combination has taken place—as in lime, water, and carbonic acid, (see above, p. 25.) The water in this case, is required for effecting the union between carbonic acid and lime, and will, notwithstanding, soon be separated. It does not enter into the combination which results.

Whatever name we may give to this acting cause, it cannot be denied, that there are a great many substances which predispose others to combination, enabling the latter thus to enter into combinations, which without their agency could not take place. The action which Berzelius has distinguished by the name of catalysis, is thus a peculiar mode of exciting a chemical action.

What conception ought we to form of this catalyzing action ?

Some molecular forces are hidden in the elements. One of these forces we know to possess the great power of producing combinations between dissimilar substances. Such forces generally proceed from the very substances on which they react. Catalysis is precisely the same force, without the reaction, however, on the substances, whence it proceeds.

If we transmit a small electric spark through a mixture of hydrogen and oxygen, in a gaseous state, the whole is immediately combined. Two molecules—one of each—first combine, and from these the action is communicated to the whole. They have been called by Laplace and Berthollet, *molecules in motion.* We perceive, however, in this example, an action proceeding from two molecules of hydrogen and oxygen, and transferring itself to thousands of molecules of the same elements; but the particles originally affected by the electrical spark are not involved in the subsequent action.

Something of a similar kind we observe in catalysis. Spongy platinum does not enter into the combination of hydrogen and oxygen. We see, however, this difference between the case in which combination is effected by means of platinum, and that in which it is effected by an electrical spark—the particles of platinum are in the state of moving molecules, no influence apparently being exercised by external causes.

It would be an interesting experiment, to expose spongy platinum to a mixture of hydrogen and oxygen, reduced to a very low temperature, with the view of ascertaining whether platinum would then possess the same power. It is probable that the metal would not retain this property at every temperature. Nay, it is certain that pulverized glass produces the combination of these elements, but not below 572° F.—thus acquiring at this temperature, the same power which platinum possesses at the ordinary temperatures. A neutral substance may therefore be made equal to platinum, by an elevation of temperature. It is further known, that a determinate temperature is required to convert alcohol into oxide of ethyl and water, by means of sulphuric acid; that humin is formed from sugar by means of an acid, but not at every temperature; that the power which sulphuric acid possesses, of converting starch into gum and sugar, is not unlimited, but that a determinate temperature is required for that purpose.

If in this manner, we go over the series of catalytic phenomena, we observe that the influence of temperature is almost always indispensable.

Now it is known, from abundant experience, that heat has the power, greatly to modify the chemical forces, resident in substances. This is very clearly shown by the innumerable products, obtained by dry distillation at different temperatures. If then, the influence of heat on the substances, said to be catalyzed, be communicated to them by the catalyzing substance, (if the heat, for instance, which causes oxide of ethyl and water to be produced from alcohol, be communicated to the elements of alcohol by means of an acid—should the heat in this case prefer such a medium,) the idea of catalysis contains nothing repugnant to acknowledged principles.

However this may be, it cannot be denied that there are many cases in which chemical action proceeds from a substance, which is not itself comprehended within the circle of such action. Although this be a deviation from ordinary chemical action, the idea seems not to be opposed to any sound principle, and creates no greater difficulty than occurs in the case where all the substances, which excite any action, enter into the combination.

The peculiar property of spongy platinum has been called by some philosophers, *surface action*. To this action they have ascribed every phenomenon, similar to that produced by the peculiar influence of spongy platinum. I must confess, that I understand the meaning of surface action as little as I do that of contact action. A surface cannot produce an action; that must necessarily be effected by matter—by the forces imparted to matter, which manifest themselves under certain circumstances, especially when the matter is minutely divided,—though under other conditions, the same forces are quiescent. We should, I think, approach nearer the truth, by inverting our conception of the subject, and assuming, not that substances obtain a new power by minute division, but on the contrary, that by their accumulation into masses they become powerless,—that the forces present in molecules are prevented from acting, being reduced to a state of quiescence. When iron is in mass, it shows but a slight tendency to oxidation; but when minutely divided, it cannot possibly be brought even in contact with atmospheric air, at a low temperature, without becoming red hot, and at the same time becoming converted into an oxide. Cobalt, nickel, and uranium, possess the same property.* It is true that in these spongy bodies, obtained by reducing their oxides by means of hydrogen at the lowest possible temperature, the oxygen from the atmosphere is apt quickly to condense; but is this condensation an effect, produced by the iron in the metallic state, or by something else—by a power dwelling in the matter, (the iron,) or by a power which is without? If it be absurd to suppose that this power is present in any thing but the iron, then the power coincides with chemical attraction. It verifies the proverb, *corpora non agunt nisi soluta*, but in a more definite form, *corpora non agunt nisi divisa.* Chemical action operates by molecules, not by masses. In the masses the chemical forces are rendered powerless and quiescent. If we could isolate the molecules of all the elements, these forces would show their potency.

I see no reason why, with regard to spongy platinum, that is, platinum so minutely divided as to approach the molecular state, I should assume that any thing else takes place, than with regard to iron, cobalt, nickel and uranium in the same spongy state. On the contrary, spongy platinum wants something, which the others possess. Their molecules condense gases around themselves, and if the gas be oxygen, this condensation is almost contemporaneous with the oxidation of the metal. Thus one molecular action is succeeded by another, and so determinate quantities of the two substances become and remain united. This power is not exercised by platinum, and thus it possesses one power less than iron. This mani-

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* Magnus.

festation of molecular forces, without the intervention of external circumstances, may be observed in every element, provided it can be minutely enough divided. There is a whole series of metals which, if pulverized, burn away in chlorine at the common temperature. The power of exciting a red heat, and of combining chemically, exist both in the chlorine and in the metal; they only need to be placed in proximity, and forthwith this power is exhibited. If tartrate of lead be heated to a proper degree, it yields lead, in a state of very minute division, ($C^4H^2O^5+PbO=C^4O^4+H^2O^2+Pb.$) Lead in this state is an exceedingly good phosphoric substance; when it comes in contact with the atmosphere, it is instantaneously oxidized, even though previously saturated, either with carbonic acid or with nitrogen.

From the whole series of pyrophoric substances, we learn still more clearly, that all the elements manifest their properties energetically, if, when in a state of minute division, they are only brought into contact. Phosphorus and liquid bromine cannot be brought into contact, without entering vehemently into combination. If a solution of phosphorus in bisulphuret of carbon, be poured upon paper, and exposed to the air, the sulphuret evaporates, and the phosphorus remains in a state of minute division. Whenever this operation is completed, the phosphorus absorbs oxygen from the atmosphere, evolves heat, produces phosphoric acid, (PO^5), and the paper burns.

In all these phenomena, nothing is visible but molecular action, which, however, has been called chemical. This action cannot proceed from masses, because the molecules, placed in close juxtaposition, counterbalance each other. Chemical bodies, therefore, in a chemical point of view, are entirely different from what they appear to be when in mass.

There is another substance, also, which deserves particular notice, to wit, finely powdered charcoal. Its well known power of condensing gases and retaining metallic salts, coloring matter, &c., is ascribed to a surface action. There are, however, in regard to this substance, so many cases in which we perceive a real chemical action, that we can have no doubt of the proper cause. Thus, we find that when a mass of charcoal, recently made red hot, and allowed to cool in vacuo, is exposed to the air, it takes fire; so when sulphuretted hydrogen and oxygen are absorbed together by charcoal, water is produced, and sulphur separated; and when a solution of acetate of lead is filtered through charcoal, metallic lead, combined with the charcoal, remains behind.

We may therefore assume, that these well known properties of charcoal correspond with the chemical tendencies of the molecules of carbon in the porous charcoal, the molecules not being rendered inefficient by aggregation.

Platinum possesses chemical tendency in a high degree, but it is of such a kind, that it does not react upon the platinum. When in mass, the metal is no more devoid of that tendency than the iron in a similar state is, of the power of attracting and combining with oxygen.

Hence it may be inferred, that we have good reason for distinguishing by a peculiar name such actions as proceed from certain substances without reacting upon themselves; and we have to acknowledge that to the introduction, by Berzelius, of the peculiar term *catalysis*, we are indebted for a more correct idea of the nature of ordinary chemical action.

What is called the *nascent state* of substances, is that condition of the elements in which they exhibit both analytic and catalytic phenomena; in which, being free and unconstrained, not rendered powerless, either by being agglomerated into masses, or by combination into compounds, they show themselves in their proper chemical condition—that is, an active one, in which they can operate upon others, excite a slumbering energy, and cause combinations and decompositions, in which they themselves may either participate or not.

This *nascent* is the real *chemical state* of bodies. In that state both the elements and the compounds exhibit themselves in their true character. In the organic kingdom the greater number of substances are actually in that condition; and to this *nascent state* we ought to ascribe the numerous peculiar phenomena apparent in organic substances.

It seems to me that we ought to take what has been called by Liebig *motion of molecules*, in a sense corresponding with the view now stated. Activity, in a chemical sense, indeed, cannot be excited by mere motion; but one chemical energy is awakened by another; the chemical equilibrium is disturbed, the influence of cohesion is broken, and the elements are brought back to their free and proper chemical and molecular condition.

Disturbance of chemical equilibrium.—It is a property of the chemical forces, when active in any substance, to excite analogous forces in others. We notice this especially in organic nature, and it is no where more strikingly illustrated, than in the nutrition of animals. Blood, a homogeneous fluid, circulates through very different parts of the body. In the muscles it sustains muscles, in the liver it supplies the component parts of the liver, and from it the gall is there secreted; in the kidneys it maintains their various parts, and secretes the urine, &c. None of these secretions appear in the blood with their peculiar qualities; of some of them not even a trace is found. But the four organic elements of the whole are to be found in protein and its combinations, in the coloring matter of the blood, &c. The elements of protein might, no doubt, be transposed in the liver, &c., by means of catalysis, and so the component parts of the liver and gall be produced from it. It would only be necessary, then, that the constituent parts of the liver should be put into contact with the component parts of the blood, and the forces of affinity resident in the substance of the liver would not require to influence those in the protein, or to produce any chemical alteration in its component parts.

Other causes, however, ought undoubtedly to be considered. For instance, a change of its component parts takes place in the liver itself, and, from the first, chemical forces actively operate therein. For the continual change of its component parts is a chief characteristic of every living organic substance. These forces may disturb the chemical equilibrium of other substances, and cause the formation of new products. If the constituents of the blood—the combinations of protein, the coloring matter, &c.—enter the liver when it is in a state of action, and are there put in contact with the gall during its secretion, and with the substance of the liver itself, which is in a state of continual alteration, then the result will be, that this change of their component parts having taken place, the action will be transferred to the elements of the blood, and will maintain the secretion. If, on the other hand, the constituents of the blood are in a state of continual change, then the circle of action in which they are involved, will extend to the mass of the liver; and so with every organ.

We have, however, no more knowledge of the manner in which this secretion originally commences—whether it proceeds from the blood or from the secreting organ, or whether each of these contributes its part—than with the manner in which the first germ of the whole organ, the liver, is produced, or in which the germ of the animal is converted into an animal. But the continuance of the action—the duration of secretion—entirely corresponds with some other phenomena, which we may observe separately, and which therefore throw light upon these animal actions. This is the case especially with fermentation, from which Liebig has drawn many illustrations, for the purpose of clearly exhibiting his ideas; and with the same view we shall also avail ourselves of this process.

Yeast changes sugar into carbonic acid and alcohol, and is at the same time changed itself. The latter change causes the former, and is only transferred to the sugar. If we substitute blood for yeast, and the liver for sugar, we may form an idea, more or less distinct, of the secretion of the gall. The component parts of the blood are continually undergoing change. This constant change of the component parts in organic bodies is a chief cause of the continuation of their existence. The liver without intermission assumes new parts and loses others. This process we call nutrition. At the same time that the parts of the blood in the substance of the liver are thus undergoing change, chemical forces are excited; these forces are transferred to the elements of the blood, and so are enabled to produce from them the gall. This takes place the more easily, as the blood itself is also in a state of continual alteration, and thus readily yields to the impulse which, in some way or other, is communicated to it. As the impulse varies, so does the effect. Hence that great diversity in the secretion of very dissimilar substances, which are in a state of alteration, from the same fluid—that is, the blood, which is itself at the same time in a state of decomposition.

From the nutrition of the cellular texture, however, which must be produced from the component parts of blood, and from the nutrition of all the secreting organs—which, besides producing the secretion, maintain themselves by separating what they require from the constituents of blood—we learn that catalysis cannot be left out of consideration in the mere process of nutrition. Further, we must apply the same principle to all the solid parts of the body, which are compounds of protein. The muscles, for instance, have the property of secreting protein from blood, and converting it into fibrin; on the other hand, when protein is deficient in the blood, this fibrin is taken from the muscles and converted into blood-protein, as in diseases of long continuance and in emaciation. Muscles have thus the property of forming muscle—fibrin by simple contact, if protein abounds in the blood, and this result can be ascribed only to a cause similar to that by which crystals gradually accumulate from solutions of salts. It is at least a peculiar action, different from ordinary chemical action, which takes place when the plasma of blood is transformed into muscles, which in composition do not essentially differ from the plasma. The same is the case with the production of hair, nails, and permanent horns.

Let us now proceed to inquire into the influence by which chemical forces in action excite new forces in other substances generally.

In the inorganic part of chemistry we perceive some phenomena which demand particular notice. For instance, platinum is not dissolved by nitric acid, but if previously alloyed with silver, it is dissolved by that acid, as well as the silver. The oxidation of the silver thus becomes transferred to the platinum, which, by itself, could not be brought into that condition.* If deutoxide of hydrogen be put in contact either with oxide of silver or with peroxide of lead, oxygen is lost not only by the deutoxide of hydrogen, but also by the metallic oxides. The disturbance of the chemical equilibrium in the one compound transfers itself to the other; the motion in which the molecules of the one substance are involved, is communicated to the molecules of the other.

Some chemical compounds have a very slight internal cohesion. Their elements are in a state of unstable equilibrium; they are either decomposed by a slight external disturbance, or they enter into new compounds. To this series belong oxide of chlorine, iodide of nitrogen, the fulminates, &c. It is easy to conceive that such substances, when in contact with others, also in a state of action, must immediately

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* Liebig.

disturb the chemical equilibrium of the latter. Deutoxide of hydrogen belongs also to this series of compounds. But the greater part of chemical substances do not disturb this combination—this state of neutrality or of equilibrium, among the forces in other substances—unless they themselves can combine with one or more of the elements of those substances. Sulphuric acid readily separates oxygen from peroxide of manganese; but it does so only because it can combine with the protoxide. Heat, light, electricity, &c., may put the molecules in motion, and cause the production of combinations which are different in kind, according as these agents are more or less intense in their action; but in organic substances we perceive that a slight disturbance of chemical action in a part of the substance extends through the mass, or passes from the one to the other. If, for instance, a single spot of an organic substance is put into a state of putrefaction, the putrefaction forthwith spreads through the whole mass. If a piece of rotten wood be united with a sound piece, the latter will quickly become rotten also. Thus the disturbed action of organic forces disturbs others in their turn. What we perceive in crystallization and in the explosion of gunpowder, is connected with this principle. A fluid may long remain uncrystallized; but when one crystal is formed, a great many others often succeed. If a grain of gunpowder in the midst of a large quantity is inflamed, the action spreads through the whole mass. For the same reason we perceive in organic digestion the appearance of biline, as a principal substance from which a chemical action, affecting the assimilation, proceeds. It is very easily transformed and changed into bili-fellinic acid and cholic acid. This is very strikingly illustrated in every kind of fermentation.

Fermentation.—A great many organic substances, if exposed in a fluid state to a determinate temperature, exhibit an internal motion, produce bubbles of gas, and at the same time are chemically changed. Such is the case with all kinds of sap from plants, especially those which contain sugar. This change is caused by organic substances entirely different from each other, but yet very complex. In proportion as an organic substance consists of a more complicated group of other compounds, formed of variously arranged elements, all combined into one whole,—the more easily are these elements transformed, the less powerful are the uniting forces, and the more readily are new combinations produced. Among such substances are to be reckoned albumen, fibrin, animal gelatine, vegetable albumen, gluten, and all the substances in which these are contained. When one of them is mixed with saccharine matter, the phenomena above mentioned soon manifest themselves, and what we call *fermentation* commences. According to Liebig, the sugar is changed into carbonic acid and alcohol, by the distribution of the chemical forces, which previously kept the atoms of the sugar together. This disturbance is an effect of decomposition in one of the said complex substances; which decomposition is continuous, and, so long as it lasts, disturbs all the organic chemical forces around. If this opinion be correct, then either the albumen must always be in a state of decomposition, or the fermentation does not begin until these complex substances enter into decomposition themselves; and the decomposition of albumen must therefore depend upon something else. The former view is not confirmed by observation, because it is impossible that these complex substances should be produced and decomposed at the same time. They could not be formed *into* the organic substance, and exist at the same time in a state of decomposition. Moreover it is also indicated by observation, that they may be kept for some time out of the organic substance, which produces them, without the manifestation of any phenomena of decomposition. If, for instance, they be dried, they may be preserved for an indefinite time. It is not determined, whence the decomposition in these complex substances proceeds. The forces which keep them united, have a chemical character, and they cannot be disturbed by any other than chemical forces. Thus the enigma still remains without a solution. A cause still requires to be indicated, by which the first motion of the molecules in these complex substances is originated—as, for instance, when, after being dried or preserved for a long time, they are put into sugar and water, and produce a fermentation. According to Liebig, yeast is always in a state of decomposition, and this decomposition is transferred to other substances, comprehended in the circle of action, more especially sugar; but still the question remains, how does yeast enter into the state of decomposition? Why does the same change among its elements take place in yeast, as yeast communicates to sugar? Is there still another substance which causes the decomposition of yeast, in the same manner as yeast causes that of sugar? If we effect the change of sugar into carbonic acid and alcohol, by means of gelatine, which has for years been preserved unaltered and in a state of non-decomposition, then the question is, how does the decomposition of gelatine commence, whenever by its agency the formation of alcohol—that is, fermentation—is effected? By what cause is it brought into that state? Here we must pause, for we can give no sure explanation. We may however assume, with Leibig, that very complex bodies contain atoms, loosely combined, which are decomposed by external causes, as easily as the fulminates.* A determinate temperature is, no doubt, to be reckoned among these external causes; a temperature which need not exceed the average temperature of the atmosphere, and so may be what we call a low temperature, but which, nevertheless, is as capable of changing complex combinations, as one more elevated is of transforming all the organic bodies into a large series of pyrochemical products, whose characters entirely depend on the temperature. If we observe, that the elements of organic substances are brought into different chemical states by different temperatures, so as to unite into new combinations, we may ascribe a catalytic influence to heat. If this be applied in reference to those plants, the functions of which are suspended in winter, and which are revived by the warmth of spring, and if it be extended to all the substances, which are more or less dependent on the influence of temperature, then we should seem entitled to assume heat as the primary source of chemical change in the component parts of complex organic substances; a change which, once originated, may be transferred to other substances. To heat, then, we ascribe catalytic action; and thus the commencement of decomposition in yeast is attributable to a determinate catalyzing temperature.

Complex organic substances are easily transformed by a change of temperature, and this transformation is easily com-

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* Scheerer has proved, that fibrin, if placed in oxygen, absorbs it, and produces carbonic acid. (Ann. der Chem. und Pharmacie, 1841.)

municated to other organic substances, with which they are in contact. We are entitled to hold this as positively proved. According to our observation, therefore, we place the primary source of chemical action,—proceeding from complex organic substances, and transferred to others,—not in those substances themselves, but in the temperature. We call the temperature catalyzing, then, in the same sense with Berzelius, as having the power of modifying the chemical forces which are hidden in the elements, and which unite them into one whole—strengthening those forces in some cases, and weakening them in others, so as to disturb the equilibrium, and produce new substances,—just in the same manner as spongy platinum excites hydrogen and oxygen to enter into combination, as sulphuric acid converts the elements of alcohol into water and oxide of ethyl, and as the same acid converts sugar into the humic and formic acids.

The chemical forces which can be excited in inorganic substances by this decomposition of organic bodies, are sometimes governed by laws, different from those which usually obtain in mineral substances. If, for instance, sulphate of soda, of which the elements are firmly combined, be exposed to the influence of a putrefying substance, carbonate of soda and sulphuretted hydrogen are the results. The carbonic acid is produced by the fermentation of the substances in putrefaction, but contrary to all ordinary chemical laws, the sulphuric acid is decomposed; it loses its oxygen; and at the same time the water is decomposed, its hydrogen combining with the sulphur. The decomposing action of organic substances is thus transferred to those which are inorganic, and even alters their ordinary chemical forces.*

If we see such a transformation taking place among strongly combined atoms, then the atoms of organic substances, loosely combined, may, by the same means, be still more easily transformed. This remark applies especially to such as are so feebly combined as to be immediately separated from each other, and made to assume a new arrangement by the slightest action in which they are involved. This transformation takes place the more easily, because the organic chemical forces act upon others of a similar kind. Hence the easy

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* Treatise on the Waters of Amsterdam, 1826.

conversion of sugar into alcohol and carbonic acid, or, in other circumstances, of sugar into lactic acid and into mannite, of alcohol into acetic acid, &c.

It appears from the variety of changes to which sugar is subjected by different agents (converting it into alcohol, ulmic, oxalic, and saccharic acids), that its elements are very loosely combined—more loosely, indeed, than the elements of many other substances. We perceive something similar in oil of cinnamon. New products are continually formed in this oil by the influence either of the air or of different acids—namely, hydruret of cinnamyl, cinnamic acid, and a great many resinous substances. In every case, the elements of sugar persist in their combination till decomposed by some force. Thus in the decomposition of sugar a force must be subdued. In the alcoholic fermentation, the force by which this is effected proceeds from the yeast, but is undoubtedly to be ascribed originally to heat. Heat is the pulse of life in the chemical changes of bodies, and has thus an unlimited influence upon their chemical combination.

Substances containing nitrogen are most liable to that kind of decomposition, during which the decomposing action is communicated to others also. Nitrogen has a strong tendency to extricate itself from combination, owing to its character of indifference.* Explosive bodies contain nitrogen—for example, the iodide of nitrogen, and the fulminates. It is only with hydrogen that it easily combines, forming ammonia. The chemical equilibrium of the elements is disturbed from the very moment that the production of ammonia commences, and then the action may be transferred to other substances—the fulminates, and hence their rapid decomposition. Organic substances containing nitrogen, if in contact with water, produce ammonia, and in consequence of the formation of ammonia, the carbon and oxygen combine into carbonic acid.

Thus yeast, as well as other substances containing nitrogen, requires water to produce fermentation—that is, first, to produce ammonia and carbonic acid, and afterwards to excite thereby a new disturbance of the chemical forces in other substances. The decomposing forces arise from the decom-

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* Liebig.

position of water and of organic matter—from the formation of ammonia and carbonic acid. Liebig gives an interesting proof, that those substances which can be wholly changed into ammonia and carbonic acid, may also be decomposed with great facility. The cyanic acid belongs to that class. When dissolved in water, it is suddenly decomposed into carbonic acid and ammonia.

1 cyanic acid + 3 water = 1 ammonia + 2 carbonic acid.
$NC^2O + 3HO = NH^3 + 2CO^2$

One equivalent of carbonic acid (CO^2), passes off with effervescence, and the water retains carbonate of ammonia (CO^2 and NH^3) in solution. Complex organic substances are decomposed the more easily the nearer they approach to a combination, which on decomposition can produce ammonia and carbonic acid. Such, according to Liebig, should be the case with substances which produce fermentation. The action of alkalies upon them proves, that they either contain or easily produce ammonia, for the alkalies all liberate ammonia from those substances, viz. from albumen, fibrin, and the like. But the composition of these latter substances differs remarkably from that of bodies in which the carbonic acid represents the principal part, after the ammonia is abstracted.

For instance, if from 1 equiv. of protein, $C^{40}H^{31}N^5O^{12}$
We take . . 5 equiv. of ammonia, $H^{15}N^5$

There remains, ... $C^{40}H^{16}\ O^{12}$

The composition of this remainder is very different from that of carbonic acid.

These substances, however, absorb oxygen very easily on decomposition, a fact which has recently been proved of fibrin and albumen.*

When sugar is brought into a state of fermentation by the influence of yeast and a moderate temperature, (59°—67° Fahr.) alcohol and carbonic acid are always the product: and so with many saps containing sugar; for instance, the sap of fruits, beet-root, carrots, onions. But if these are made to ferment at a temperature between 97° and 104° Fahr., other products are formed. The albumen and gluten of the sap are then wholly decomposed, so that all the nitro-

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* Scheikundige Onderzoekingen, Deel I.

gen remains in the liquid in the form of ammonia. With this alteration in the influence, lactic acid, mannite, and a gum-like substance are produced from the sugar, instead of alcohol and carbonic acid; gases at the same time being evolved. Thus it is evident, that the decomposition of the sugar entirely depends upon the state of the gluten and albumen in the sap of plants, which bodies are both changed into the chief constituent of yeast during the alcoholic fermentation. It is also evident that yeast, if subjected to a decomposition different from the ordinary kind, forms entirely new products which are not at all analogous to those formed by the alcoholic fermentation. Hence it is clearly proved, that the general idea of the molecules being put in motion, is not sufficient to explain the formation of alcohol and carbonic acid from sugar. That motion on the contrary must be of a peculiar nature, and such as to affect the molecules of sugar in one determinate mode for the formation of alcohol and carbonic acid. The alcoholic fermentation can be produced only by the most simple transformation of yeast. This transformation consists in the production, first of acetic acid, then of carbonic acid, and probably at the same time with the latter, of ammonia. If this transformation be checked, yeast has not the power either to excite or to maintain fermentation. The power of yeast is destroyed or paralyzed, by drying it highly, by chloride of mercury, nitrate of silver, sulphurous acid, and creosote. Yeast is also incapable of producing, or at least of originating, fermentation, without the aid of the oxygen of the air; for if the air be completely excluded, no fermentation takes place.

Very incorrect ideas have been formed as to the peculiar character of yeast. From several analyses which I have recently made, I am quite convinced that it is a minute cellular plant consisting of isolated cells. These little plants are utricles of a substance nearly approaching to cellulose—woody fibre—in its properties and composition, though in some respects it is different. Its composition is $C^{12}H^{10}O^{10}$.[*]

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[*] Scheikundige Onderzoekingen, Deel II.

	Found.	Atoms.	Calculated.
C	45·00	12	44·92
H	6·11	10	6·11
O	48·88	10	48·97

It contains no nitrogen.

It is insoluble both in cold and in boiling water; it is not converted into xyloidine by nitric acid, but is readily changed into humic acid by hydrochloric acid, and is easily soluble by strong caustic potash at the ordinary temperature. Its composition cannot by any means be reduced to that of cellulose.

These utricles contain a protein-like substance, which is neither gluten, for it is insoluble in boiling alcohol; nor albumen, for it is with great difficulty soluble in acetic acid. In boiling water it may be pretty easily obtained in such a state, that it may be regarded as a highly oxidized protein. Thus—

$$\left.\begin{array}{l}\text{Substance separa-}\\ \text{ted from yeast,}\end{array}\right\} = \text{1 protein} + \text{8 oxygen} + \text{6 water.}$$

$$C^{40}H^{37}N^{5}O^{26} = C^{40}H^{31}N^{5}O^{12} + O^{8} + 6HO.$$

The protein in these utricles, however, exists in such a state that its composition approaches to that of fibrin, albumen, and casein;* that is to say, when it was extracted by acetic acid and precipitated by carbonate of ammonia, its composition appeared to be analogous to that of these substances.†

The substance approaching to cellulose, which forms the bag or utricle of the yeast plant, does not assist fermentation. During that action, the protein compound penetrates exosmotically through this membrane, the utricles decrease in bulk, contract, and at last remain behind in the form of collapsed, wrinkled globules, much smaller than they originally were. The protein compound when expelled, soon undergoes decomposition, to which at a certain temperature it is exceedingly liable. It leaves nothing behind, but ammonia and a

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* Scheikundige Onderzoekingen, Deel II.

	Found.	Atoms.	Calculated.
C . .	43·35 . .	40 . .	43·65
H . .	6·56 . .	37 . .	6·50
N . .	12·68 . .	5 . .	12·64
O . .	37·41 . .	26 . .	37·12

† Scheikundige Onderzoekingen, Deel II.

	Found.
C	54·35
H	7·04
N	16·03
O	22·58

The sulphur and phosphorus have not been determined.

quantity of extractive matter which has not yet been sufficiently analyzed. Thus—

From protein, . . . $C^{40}H^{31}N^{5}O^{12}$
Take ammonia, . . . $H^{15}N^{5}$

There remain, . . . $C^{40}H^{16}\ O^{12}$

Thus it is evident, that heat is the primary cause of the phenomena of fermentation. The protein compound in yeast, a very complex body in common with many other substances, such as hydrate of deutoxide of copper under water, &c., has a temperature which forbids its permanence under water, and induces decomposition. This decomposition is transferred to the sugar, and resolves it into carbonic acid and alcohol. During this decomposition, especially at the commencement, a small quantity of oxygen is absorbed. This absorption is not the cause, but the first effect resulting from the decomposition of the protein compound which exists in yeast. Thus all that has been stated as to the chief constituent of yeast, holds good also with respect to yeast itself, provided we regard the cellular membranes of the yeast globules as having no influence whatsoever upon fermentation, but as being only the vessels to contain the protein compound. They are left behind insoluble when fermentation is finished.

During the fermentation of sugar by means of yeast, part of the latter is decomposed, though its component parts contribute nothing to the formation of alcohol; neither do they to any perceptible extent add to the quantity of carbonic acid produced. For Thenard has found that 100 parts of sugar yield 51·27 of carbonic acid, and 52·62 of absolute alcohol, making together 103·89. One equivalent of water, however, is combined with sugar when crystallized, $C^{12}H^{11}O^{11}$, which thus gives nearly the same amount. In my experiments, 20 parts of yeast which had caused the fermentation of 100 parts of sugar, left behind 13·7 parts of insoluble matter, which being again put in contact with sugar, left behind 10 parts of insoluble matter, which had no further power of producing fermentation. It has been elsewhere stated, that the yeast is also decomposed during fermentation. But a very small quantity of yeast cannot bring a large quantity of sugar into fermentation; while on the other hand, the decomposition of the yeast still continues after the transformation of a small quantity of sugar into alcohol and carbonic acid.[*]

This power, either of yeast or animal matter, to change sugar into alcohol and carbonic acid, has been justly traced by Liebig to the same principle with many other decompositions. If, for instance, the fresh urine of the horse be evaporated and saturated with an acid, hippuric acid is produced; but if the urine be kept for some days, the product is not hippuric, but benzoic acid. If fresh human urine be saturated with nitric acid, we get nitrate of urea; if the urine be putrescent, we have carbonate of ammonia. Amygdaline is changed by yeast and sugar into prussic acid.[†] If mallows be macerated in lime-water, we get asparagine after evaporation; but if the solution be put in contact with yeast, we get aspartic acid, combined with ammonia.

A great many organic substances, when exposed to a fixed temperature and to moisture, are decomposed into new products, which also can be formed by ordinary chemical means. For instance, the natural change of woody fibre into humic acid and other substances, may be produced also, if sulphuric acid be made to act upon woody fibre. It is not a real fermentation, but a transposition of the elements, analogous to that which takes place in yeast. If wood undergo decay while lying in water containing salts of sulphuric acid and iron, sulphuret of iron is deposited upon the solid substances, whilst the rotting wood is converted into humic acid. This sulphuret of iron is produced from the sulphur of the sulphates, and from the iron of the iron salts. Some substances very rapidly undergo the alteration, which causes the production of humic acid from woody fibre. Tannic acid, for instance, if exposed to the air, is very quickly converted into apotheme of tannin; and in like manner extractive matter is converted into apotheme, by the influence of the oxygen of the air and a more elevated temperature. It is a similar transformation to that which takes place in substances containing nitrogen, such as yeast, &c., but of course it is inca-

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[*] Liebig.

[†] We must persist in calling the action of emulsine upon amygdaline, catalysis, till it be ascertained that emulsine is in a state of decomposition, and immediately communicates that to the amygdaline.

pable of producing any ammonia if they contain no nitrogen. During this transformation, oxygen is always absorbed, and sometimes only one or two new substances are produced; such as when acetic acid and water are formed from alcohol by the agency of the oxygen of the air. Thus—

1 acetic acid + 3 water = 1 alcohol + 4 oxygen.

$$C^4H^6O^2 + 3HO = C^4H^6O^2 + O^4.$$

By the oxidation either of tannin or of extractive matter, however, carbonic acid is also produced, and equal in volume to that of the oxygen absorbed.* The elements in such substances are very loosely combined, and tend to produce other substances, which combine more intimately. They have thus a tendency to act externally, and eagerly attract all the oxygen with which they are in contact. This state, which is like that of hydrate of protoxide of iron, hydrate of protoxide of manganese, sulphuret of potassium, and many other inorganic substances,—we indicate by the too limited expression of *tendency to oxidation*. The greater number of organic chemical substances are transformed in consequence of this tendency. Such is the case with the solutions of vegetable acids in water, which, if exposed to a certain temperature, can produce a series of new substances, such as citric acid, tartaric acid, &c., and others even of an organic nature, such as mouldy plants. If the substances be of a complex character, they are still more easily transformed. Such is the case, for example, with wood, which in certain circumstances, is subject to very rapid decay—dry rot—caused by the albumen which it contains. The alkalies, especially, are capable of promoting in some substances this conversion of elements. Gallic acid, for instance, when in contact with an alkali, is rapidly changed into a brown matter; so salicylite of potash is changed into acetic and melanic acids, by absorbing three of oxygen (O^3).

Fat oils and other fatty matters in this manner produce neither a mixture of different substances, nor carbonic acid, but a fatty acid. Almost all the volatile oils form resins, the products of oxidation by the air. Other examples are afforded in the transformations of orcine, phloridzine, &c., when in contact with air and ammonia, producing blue colors from

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* De Saussure.

white substances. So in the transformation of protein with 4 of oxygen into humic acid and ammonia:

One of protein, with four of oxygen, } $C^{40}H^{31}N^{5}O^{12}+O^{4}$
Are equal to 1 of humic acid, $C^{40}H^{15}\quad O^{15}+HO$
And five of ammonia, $H^{15}N^{5}$

I repeat, that all these transformations correspond to such ordinary phenomena in inorganic chemistry, as the oxidation of iron, potassium, &c., in the air.

This transformation has been compared to *combustion;* and whether hydrogen only, or carbon only, or both, be combined with oxygen, it has been called combustion. It does indeed resemble combustion. But there is this difference between combustion and such a transformation of substances, that the former is a complete conversion, effected by a more elevated temperature, while the other phenomena are produced by a mere disturbance in the equilibrium of chemical forces. These forces are modified, while the vital functions of the animals or plants, to which the substances belong, are in action; they are still present in certain circumstances, in which they are not sensible—as when the body is dry, and is kept at a low temperature; but they are disturbed by heat and moisture, especially the former, so as to make room for other forces. Among these new forces, the tendency of hydrogen and carbon to oxidation then appears. These forces come into operation as soon as the others are at rest. They come into full operation if a great disturbance is effected by powerful causes, such as when a burning substance is brought near the organic one; they are, however, but partially brought into operation, if a different set of atoms of carbon, hydrogen or oxygen meet each other in such a proportion as to produce a new and intimate combination. This is clearly illustrated by the change of sugar into alcohol and carbonic acid.

It must not be thought, however, that this power of affecting substances resides peculiarly in oxygen. If our atmosphere consisted either of chlorine, or of vapors of bromine only, the power of these substances to disturb a chemical equilibrium, (or to form promptly, in case of a disturbed equilibrium, a combination with substances present,) would be much greater than that which we now perceive in oxygen. All these phenomena of oxidation, either in organic or inorganic substances, ought not therefore to be classed as a determinate and peculiar series. They must be referred to ordinary chemical action, dependent in a great measure on the *influence* of the circumstances in which a substance is placed. This action is always terminated by the operation of the chemical tendency, the production of a state of equilibrium.

The peculiar forces of the elements must, therefore, be classed among the principal causes of the conversion of organic substances into others, accompanied by the attraction, for instance, of oxygen. This tendency to combine with oxygen is not exhibited by free carbon and hydrogen at the ordinary temperature, but may be excited in both by heat, and in hydrogen also by spongy platinum. We see these forces very active in potassium and sodium, in phosphorus and many other substances. Hence it appears, that such substances act in the same manner (*i. e.* attract oxygen), without the aid of any new external circumstances, as carbon and hydrogen do when under combustion, or when accompanied by the conversion of organic matters. As soon, therefore, as carbon and hydrogen cease to be influenced by those chemical forces which modify them in the organic kingdom, they yield to what is originally their most powerful tendency; they combine with oxygen in the same way as the nitrogen of yeast combines with hydrogen and forms ammonia. So far, therefore, as the arrangement of the organic molecules is changed, when bodies begin to decay or undergo any similar transformation, the change depends partly on that primary tendency of the elements, partly on the possibility of forming such new and intimate combinations of the elements, when otherwise arranged, as cannot be again disturbed in these circumstances, but can be decomposed only by more powerful causes.

The alteration in wood, which is called mouldering, does not essentially differ from putrefaction. So far, however, it is different, that during putrefaction, hydrogen combined with carbon is given off in the form of gas, while in the former case only oxidation, either of carbon only, or of carbon and hydrogen, takes place. Hence it appears that, properly speaking, in mouldering, the elements slowly obey their most powerful tendency, yielding to the strongest forces which they possess; and on the other hand, that the formation of wood is the effect of a chemical action in an opposite direction.

The question is, whether during decomposition the organic forces grow weaker of themselves, permitting the elements to obey their primary tendency,—or whether causes must exist by which these organic forces are made weaker? Neither is improbable. Every thing which ceases to be subject to the vital principle, becomes incapable of being stimulated by the vital forces;—it is placed in other circumstances; and as the products of the vital functions are different from the products of inorganic nature, in consequence of the very difference of the circumstances in which the elements are placed, so the products of substances, deprived of vital influence, must also greatly vary with circumstances. Hence it may happen, that the forces present in organic substances, when deprived of the vital influence, may disappear of themselves. The impression they had at first received is changed, modified, obliterated, and therefore the effects can no longer be the same. A substance persists in the state into which it was first put, according to the law of inertia; but the maxim, *sublata causa tollitur effectus*, is of equal value. The vital action, which we express by the collective name of circumstances, confers a certain tendency upon the molecules, which in many substances disappears whenever the molecules are withdrawn from its influence.

If but a small disturbance of chemical equilibrium has occurred, that is to be regarded as a focus or centre, from which the action extends. A small piece of mouldy wood infects a whole mass, acting in the same manner as yeast in fermentation.

What is the cause to which this disturbance is attributable? There is proof that it is caused by temperature; neither fermentation, nor putrefaction, nor chemical action, taking place without a determinate temperature. But though this temperature be present, another substance is required to excite such actions in a certain degree. In every kind of fermentation, this disturbing property, as has been proved, is possessed by oxygen. The first phenomenon observed either in a fermenting or in a putrefying substance, is the absorption of oxygen. Without oxygen no putrefaction, no fermentation takes place. This has been ascertained by Gay-Lussac. He kept the juice of grapes for some days over mercury; it did not ferment, but the introduction of one bubble of oxygen was enough to originate fermentation, which then proceeded spontaneously. A single bubble is thus required to bring a force to the juice of grapes, capable of disturbing in a small part of it the organic forces, excited by a certain temperature. In the other parts, disturbance is effected by the new products in their turn, and is transferred through the whole mass, so that a decomposition of sugar and water into alcohol and carbonic acid takes place.

Upon this principle the preservation of meat, vegetables, &c., in vessels exhausted of air—generally by ebullition—is founded; so is the method introduced by Appert, of boiling vegetable saps in bottles, well corked, for the purpose of taking away the oxygen of the small quantity of air left behind, and of uniting it with part of the substances; and also for the purpose of disturbing by the ebullition, part of the chemical forces, especially those in the dissolved albumen, which becomes coagulated when boiled. On the same principle depends the sulphuration of sweet wines or of juices of fruits, by the application of sulphite of potash, the sulphurous acid (SO^2) being easily changed into sulphuric acid (SO^3).

This attraction of oxygen is very much promoted by alkalies, though we know not how. But it is perceived in orcine, phloridzine, and salicylous acid. Alcohol, if it retain any alkali in solution, produces acetic and formic acids, besides a brown substance, absorption of oxygen being a uniform accompaniment. A substance which is easily decomposed, also readily changes alcohol into acetic acid, with absorption of oxygen. Hence alcohol, when exposed to the air, is in like manner changed into acetic acid by a little honey, malt beer or acid wine. On this principle depends the method of preparing vinegar by the quick process now practiced in Germany. The substances added begin first to decompose, and when in that state communicate to the elements of alcohol the tendency to transpose themselves also, and to assume a new order in connection with the oxygen of the air.* Some organic substances, however, if merely present, can act here also by the forces which proceed from them, without being themselves altered; and a real catalysis may thus take place. This appears from what occurs, when vapors of alcohol are brought

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* Liebig.

in contact with spongy platinum, the supply of air being imperfect. The spongy platinum then becomes hot; water and aldehyde are produced, with absorption of oxygen—the spongy platinum, however, taking no part in this process. If free access be given to the air, acetic acid and water are produced. Thus the same, or some similar force, resides in the spongy platinum, as in the substances by which alcohol may be changed into acetic acid, according to the method of Schuzenbach, when these substances are decomposed after being mixed with the alcohol.

The formation of saltpetre is regarded by Liebig as an analogous process. It is a known fact, that organic substances containing nitrogen, can in certain circumstances produce nitric acid, which forms a nitrate with any base that is present. Ammonia results from the putrefaction of organic substances containing nitrogen, and passes off in the form of a carbonate. The nitrogen combines by preference with hydrogen, and never directly with oxygen. It may, therefore, be a question, how it happens that nitric acid is in this instance formed from the combination of nitrogen and oxygen.

The presence of a base, especially of some alkali, is indispensable to the formation of saltpetre. From the nitrogen, ammonia is first obtained by combination with hydrogen, and this is afterwards changed into nitric acid,—the hydrogen of the ammonia combining with the oxygen of the air to form water, and the nitrogen with the oxygen to form nitric acid, which is united with the base into a nitrate. When organic substances are decomposed by oxide of copper, deutoxide of nitrogen (if the organic substance contain the nitrogen in the state of ammonia) is always formed; but if a compound of cyanogen be burned in oxygen, the carbon only is oxidized, and the nitrogen is liberated without the production of nitric oxide. Thus nitrogen, when alone, is not combined with oxygen, but only when present in the state of ammonia.[*] During the nitrification, therefore, nitric acid is formed, because the oxygen of the air produces water and nitric acid at the same time from the ammonia, and because these two substances mutually promote the production of each other, while *in the nascent state.* Hence it happens, that during nitrification,

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[*] Liebig.

the animal substances contribute but the smaller part of the nitrogen contained in the nitric acid produced, while the greater part is absorbed from the atmosphere, and so the organic substances are the chief means, whereby the nitrogen of the atmosphere is changed into ammonia, which is afterwards decomposed with absorption of oxygen into water and nitric acid. This is fully proved by the nitrification which takes place, without organic substances in putrefaction. A great deal of nitrate of lime is found upon old walls, and in all porous substances, which have been long exposed to the atmosphere. In such porous substances ammonia is not only condensed, but produced from the air, and afterwards converted into water and nitric acid. (See *Arable Soil*, below.)

On these principles, relative to molecules in motion, for which we are indebted chiefly to Liebig, several interesting questions in science are explained.

The primary cause, however, of that motion may thus be briefly described. Every chemical molecule possesses the property of combining with others; such combination is an effect of molecular tendency elevated to a determinate degree. Tendency, producing combination, arises from various circumstances. The presence of a third substance, electricity, light, heat and vital force, give to the combination a determinate direction—the last producing, for the most part, complex substances, which are of a peculiar character, because it is generally difficult to obtain an artificial imitation of those circumstances. Ordinary chemical operations are almost uniformly more simple. The substances produced, differ because the circumstances differ. Temperature is a powerful exciting cause of the chemical tendency, which effects combination. To that tendency, we must look for the primary and principal cause of what may be called molecules in motion, or, in other words, molecules in the act of transposition, possessing a capacity for chemical combination, both of which qualities are indicated by the expression chemical tendency.

By spongy platinum,—glass at a temperature of 572° Fahr. —sulphuric acid,—any burning substance,—yeast,—a piece of rotting wood, actions are produced in other substances, attended with consequences which are characterized as chemical, that is, with combination or decomposition.

Whatever is affected by one of these substances, must be susceptible of such influence. This is what we have called chemical tendency. The excitation of that susceptibility is equivalent to the elevation of this tendency to a determinate degree.

The object of science is to determine the influence of each circumstance. The knowledge of this influence, in the science under consideration, is the basis, on which all other knowledge of the cause of combination and decomposition in substances is founded. The term *circumstance* is as yet only a collective one, comprehending very different things. The reduction of all these to their proper place in science we can expect only from future times.

§ 2. ORGANIC FORCES.

A. *Connection between Organic and Molecular Forces.*

All vegetable and animal substances are composed of those bodies, which in chemistry are called elements, and which combine with each other in very different ways. The question now to be considered is, whether the organic forces, which operate in the organic kingdom, depend either in whole or in part on the molecular forces of the elements. This is indeed a question difficult of solution. We shall see how far science in its present state, enables us to reach a satisfactory result.

If we assume, that an organic whole is governed by a general force called vital force, then we ascribe to that whole something which is not learned from observation. We perceive an aggregation of phenomena, which we comprehend in a general idea, expressed by the term *life*, but that idea is a concrete. It consists of a multitude of parts. The function of every organ, though a function of life, has an individual existence, in some respects separate from the aggregation, in others not. The function of the liver is not dependent, and yet it is dependent, on that of the kidneys;—not dependent, because the liver has within itself the power of secreting the bile, with the requisite organs;—dependent, because any great disturbance of the function of the kidneys, influences, and may even prevent the secretion of the bile. The idea of health implies, as the principal condition, an undisturbed function of each organ and of the whole. The idea of life implies, as the principal condition, the exhibition of the chief phenomena, the subsistence of the chief actions, proper to this whole.

The entire organism, and consequently each organ, each part of any organ, consists of elementary substances, which not only are individually supplied with indestructible forces, but may possess these under very different modifications. Oxygen, hydrogen, carbon, nitrogen, iron, sulphur, phosphorus, and iodine, are the substances which by mutual combination produce organic bodies; but to these are added a great many other substances, which are seldom wanting in living organic bodies. A great many acids, bases, and salts, are there present, which are just as indispensable to the existence of organic substances, as the eight elements above mentioned. Albumen, for instance, is an albuminate of soda; casein is a combination of protein with sulphur and phosphate of lime;—in a word, the intermixture of substances in the organs, and so in the organism, is not a simple but a complex one.

All these elements and compounds are severally accompanied by forces of their own. Their materiality is by no means to be called their chief characteristic, but that by which matter is governed, *i. e.* its peculiar force. They all manifest themselves as adapted for mutual combination, and appear after such combination as new substances, of which the forces are again modified, and applied by the chemist to produce new combinations.

If we pass in review the substances present in the organic kingdom, we perceive an endless series of combinations from either two or three or four elements only. This is enough to show that there is an unlimited capacity for modification in the primary forces which operate in the elements. The influence of one element upon another is thus unlimited also. A slight difference in the state of an element is sufficient to give it the appearance of a new and entirely peculiar substance, as compared with the other elements. Let us take, for example, starch, gum, sugar, acetic acid, glucic acid, inuline. All these are composed of the same elements, taken in the same proportions. Thus they consist severally in equivalents of

	Carbon.	Hydrogen.	Oxygen.		Water.
Starch, . .	12	9	9	+	HO
Gum, . .	12	9	9	+	HO
Sugar, . .	12	9	9		
Acetic acid,	$\frac{1}{3} \times 12$	9	9		
Glucic acid,	$\frac{2}{3} \times 12$	9	9	—	$1\frac{1}{2}$HO
Inuline, .	2×12	9	9	+	2HO

The carbon of one of these substances is no doubt equal to the carbon of any of the others, in so far as it exhibits the same properties if separated from its combination. But it is incorrect to suppose that the carbon, hydrogen, and oxygen in sugar, are identical with those in acetic acid; for there is a great difference between sugar and acetic acid, and we cannot attribute this difference to any thing but to the difference of the forces by which the same substance is governed. Thus the carbon, hydrogen, or oxygen, is not in any two cases supplied with the same properties. They assume in each substance a peculiar form. The general idea, comprehending carbon, hydrogen, or oxygen, in sugar and acetic acid, must therefore be modified, because the forces peculiar to matter must necessarily be modified, as matter is itself unalterable.

This will appear clearly, if we consider the combinations of carbon with hydrogen. If we supposed the carbon and the hydrogen in $C^{5}H^{4}$, $C^{10}H^{8}$, $C^{15}H^{12}$, $C^{20}H^{16}$, to be always the same, we should be constrained to assume the identity of the substances, and any distinction would be impossible.* Among the elements we know a considerable

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* The term *impossible* here used, appears to me to be too strong. It restricts more than is necessary the powers of the elementary bodies to form compounds possessed of different properties. If into the simple combination CH, one of the elements, say C, enters in two several allotropic states, C_a and C_b, we can readily understand that C_aH and C_bH would or might be different substances, the peculiar properties of which arose from the peculiar state in which the C existed in each. This is Mülder's view, generalized from the very interesting facts contained in Berzelius' paper upon the combinations of sulphur with phosphorus, to which he subsequently refers. The idea is very simple and very beautiful, and throws a new light upon the combinations of the organic kingdom.

But how do the allotropic states of the elementary bodies themselves arise? It is the effect of circumstances, which are special for each number which, without entering into any combination, present an entirely different appearance in consequence of but a slight difference in the circumstances under which they are placed. For example, phosphorus becomes black when heated and then suddenly cooled; and by means of a red heat merely, silica is so modified, that the substance after and before the application of such heat, might be taken for two different substances if we looked to its properties only. The interesting experiments recently made by Berzelius as to the allotropic character of phosphorus, have opened a new path for scientific investigations. If the *simple* substances can assume the permanent appearance of unlike bodies with-

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state, upon the forces of *cohesion* which reside within the similar molecules. Of course, we cannot describe the way in which different circumstances act upon the molecules so as to produce these different states. It may be, that under certain conditions the forces become stronger in a given direction, and cause the molecules to unite in that direction rather than in another. And that such an arrangement, by different sides or at different distances, does sometimes take place among the elementary molecules, is shown, I think, by the fact, that in their several allotropic states, carbon and sulphur crystallize in different forms.

Now, if a new and different arrangement of the molecules cause or accompany a new allotropic state in the elementary body, may it not be so also in the compound body? If C_aH and C_bH be different substances, because in each the elementary *molecules* of C are in a different state of arrangement, may not $C_a^5H^5$ and $C_b^5H^5$ be different respectively from C_aH and C_bH, because of (or in connection with) a new arrangement of the *equivalents* of which they severally consist?

We thus recognize two causes of diversity among isomeric and polymeric bodies.

1. The different allotropic states of the elementary bodies, these being probably caused by a change in the relative positions or distances of their molecules.

2. A new arrangement, in distance or position, among the *equivalents*, whether of simple or compound bodies, the allotropic states of the elements remaining the same.

3. Both of these causes may operate together. Some of the equivalents of C or H may be in one state, some in another, and they may arrange themselves in many different ways, so as, in a complex body like protein, to produce numberless diversities or modifications in appearance and properties, the ultimate chemical composition remaining the same.

In other words, we may have an *allotrope* of the elementary molecules, an allotrope of the compound equivalents, or a combination of the two.—J.

out forming any combination, their compounds can do so much more. And such an assumption of other characters must take place in all cases, in which no other mode remains of explaining the diversity of the compounds, than in the supposition of a real difference in the component elements themselves.

If we apply these principles to the known compounds, a field of boundless extent is opened to our view. What we call protein in animal chemistry, is a substance which we know is composed of $C^{40}H^{31}N^{5}O^{12}$, which is insoluble in water, alcohol, or ether, but soluble in alkalies, whence it can be precipitated by acids; and which produces ammonia by means of powerful bases, &c. But what meaning do we attach to all this? What conception do we form from these considerations of the substance itself? We have a mere idea of distinction in comparison with other substances which have another atomic composition, and are soluble in water, alcohol, or ether, which in other words, possess different properties. But as little ground have we for supposing, that protein is the same in the very different modifications to which it is subjected in the body of animals, as we have for saying that the carbon in sugar and in acetic acid is governed by the same forces. The carbon in these two substances cannot therefore be comprehended under the same idea.

It is said in physiology, that in the embryo of the egg there is nothing but a shapeless mass, which by decomposition produces always the same substance—that is, a compound of protein. From this embryo, however, is gradually evolved, during the growth of the egg, a series of germs of organs, which are soon developed as entire organs, together composing the chicken. A general force is assumed—influencing that shapeless mass, the embryo, originally existing as a whole—and represented as the same with that which the complete animal possesses. Müller says: "The simple embryo, which consists of a granular and shapeless substance, is to be regarded as the potential whole of the future animal, supplied with the essential and specific force of the future animal itself."*

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* So muss man die einfache, aus körnigem formlosen Stoff bestehende Keimscheibe, als das potentielle ganze des Spätern Thieres betrachten, begabt mit der wesentlichen und specifischen Kraft des Spätern Thieres. (Physiologie, I, p. 23.)

No idea can be less distinct than this. According to Müller, the forces which will afterwards govern the organs of the chicken, should be present before the existence of those organs themselves—before the production of an organism from the granular and shapeless substance of the embryo.

If we recur to what we have stated as to the idea of force, then we see that Müller has deviated far from the true method of physical investigation. In physiology, the existence of a similar general force governing the whole, is assumed in the fully formed organism. Respiration, the circulation of the blood, the function of the nerves, &c., are effected by one force, which is called *vital force.* This vital force causes respiration here, digestion there, the secretion of the saliva and of the pancreatic juice in other parts of the body. It maintains at once the substance of the bones, of the muscles, and of the brain. It is supposed that this same force is modified with reference to the different organs which it influences. This idea is also inconsistent with a sound method. What would remain of the primary idea of force, if we saw force here causing motion, there effecting a chemical alteration, elsewhere producing feelings or sensations? It seems to me, that in its ordinary signification, vital force expresses an idea as incorrect as if we supposed that one single force, differently modified, operated in a battle fought by thousands—a force which acted so as to fire cannons and muskets, cut with swords, transfix with lances, sound trumpets, and keep men and horses in constant agitation. The army appears as a substantial whole, and produces phenomena. The organism, composed of the most different organs, also appears as a substantial whole, and produces phenomena. If we assume for the latter a single force, differently modified as the organs vary—a single *vital force* by which the whole is animated—then, to be consistent, we should assume a *fighting force* in a battle. The existence of such a vital force has by some writers been maintained, by way of distinguishing animate from inanimate nature; for in a stone there is no appearance of a general force capable of assuming new powers depending on the nature of the organ. A prejudice in favor of living nature, as peculiarly directed and sustained by the Almighty hand, has caused every opinion which conceived of these forces as residing in the molecules themselves, to be looked upon as savoring of materialism. It was not borne in mind, that, in adhering to an intricate and obscure idea of vital force, we do not at all approach to an acquaintance with the manner in which the organic world is maintained by that Almighty Being, who with unlimited wisdom created and still sustains every animate and inanimate substance. Let us then proceed to inquire, what forces we must regard as existing in organic substances, and where we must commence in order to arrive at a sound conclusion.

Let us ascend from the simple to the complex. It has been ascertained from observed facts, especially from the application of them by Liebig, that some plants* will grow, when supplied with carbonic acid, ammonia, and water, provided the bases and acids (that is, the salts) be added to these, which are necessary to every kind of plant. Now, it must be supposed, either that the plants are nourished by carbonic acid, water, and ammonia; that with new materials the plants receive new forces from those bodies; or that the plants can themselves *communicate* forces to the elements of carbonic acid, water, and ammonia. The idea of *communication of forces* is unsound; it is only what is substantial that we can communicate. Forces may be *excited*, they cannot be *communicated.*

This is fully explained by the phenomena produced by the magnet. A piece of steel possesses magnetic forces, though not magnetized. These forces are slumbering, that is, such an equilibrium exists between them, that they cannot be externally perceived. They nevertheless exist. They reside in the molecules of the iron. Three elementary substances are known, to which they are peculiar: iron, nickel, and cobalt. Every particle of these metals is possessed of the same forces, and these forces can produce that series of magnetic phenomena which science has observed. But these forces cannot be communicated to tin, lead, or silver. When we appear to communicate them to a piece of steel, we merely excite what previously was hidden in it—we separate what was

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* By saying, that *some* plants *will* grow, it is not implied that plants in general do not extract soluble organic substances from the soil, viz. humate of ammonia, crenic acid, apocrenic acid, &c. It has, however, been ascertained, that many plants can produce organic compounds from carbonic acid, water, and ammonia. (See infra, *Arable Soil.*)

united. In the same way, plants excite forces in the elements of carbonic acid, water, and ammonia, whenever these are absorbed, and their elements are combined in different modes, so as to form acids, bases, neutral compounds, resins, fats, volatile substances, and the like. If there be only excitation from the plants, then the forces originally existed in the elements of carbonic acid, water, and ammonia: that is, though slumbering, they *are* present. Hence it results, that every transformation in plants is effected by the molecular forces of carbon, hydrogen, oxygen, and nitrogen,—the elements of carbonic acid, water, and ammonia,—the forces being excited in these elements by the plants themselves.

By the plants themselves? What does this mean? Does *the entire plant* excite slumbering forces in carbonic acid at the very moment the acid enters the plant? Or is such excitation produced by some one *part* of the plant? It is produced by the part of the plant, with which the carbonic acid is in contact, at the moment it becomes changed, producing new and indeed organic substances by the assistance of water, or of water and ammonia. Let us take starch as an example. It is not the entire plant which produces a grain of starch from carbonic acid and water, with separation of oxygen, but a small organ of the plant. By this organ a force is exercised, exciting forces which slumbered in the carbon, oxygen, and hydrogen, or rather *modifying* the forces existing in these, so that 12 equiv. of carbon (C^{12}) combine with 10 equiv. of hydrogen (H^{10}), and 10 of oxygen (O^{10}), and from 12 equiv. of carbonic acid ($12CO^2$) and 10 of water ($10HO$) starch is produced—24 of oxygen (O^{24}) passing off.[*] Any one who imagines that there is any thing else in action than a molecular force, than a chemical force, sees more than exists. Such a phenomenon is common, and it is one of a chemical nature, produced as new combinations are in the inorganic kingdom. It is only the circumstances which differ.

Are those small organs, however, necessary to the manifestation of such forces? and are those forces to be found only in plants? Certainly the different organs, which produce different substances in plants, exert peculiar forces; yet these

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[*] We do not mean that starch is formed directly from $CO2$ and HO; we have merely taken an example from a familiar substance.

are not entirely peculiar to those organs. Gum and sugar can be formed without the intervention of the plant, as well as in its interior; and the same is the case with the benzoic, the cinnamic, and the valerianic acids. The chemical forces, therefore, which proceed either from the minute organs of plants, when they form new compounds out of carbonic acid, water and ammonia, or from these substances themselves, after they are combined in some manner, may be excited in a common chemical way also; and so far as this cannot be effected, an accidental, not a real difference is the cause. Every compound substance requires peculiar circumstances for its formation; that is, the forces in the elements of the compound must be excited by the influence of peculiar circumstances. Starch and cellulose have not as yet been produced, except in the living vegetable, and may never be so; but neither is sulphuric acid produced in plants from sulphurous acid and oxygen, nor hyper-manganic acid, nor chloride of iron, nor deutoxide of hydrogen, nor peroxide of potassium. The forces excited in the elements vary with the influence which certain agents—temperature, moisture, light, &c.—exert. By the aid of crucibles and retorts, therefore, compounds can be formed which differ from those produced by the organs of plants; while from carbonic acid and water plants can produce cellulose and oxygen, a result which cannot yet be attained by art.

Of what do these small organs, producing cellulose and starch in plants, consist? They have originally been produced in a similar way with the grains of starch itself, that is, from carbonic acid, water and ammonia, by the operation of organs previously existing. On their production they received peculiar forces, as the grain of starch does. The difference between the organ producing starch, and the grain of starch produced, is not that the former can alone excite force, and that the latter is passive;—both are active in their turn. If starch be put in contact with nitric acid or sulphuric acid, the acid is powerfully decomposed by the starch, which itself at the same time is altered. Though starch be formed from carbon, hydrogen, and oxygen, it still exhibits, under different circumstances, a great variety of chemical tendency in its elements, inducing the production of new compounds. Starch yields gum and sugar by means of diastase; sugar may be changed into carbonic acid and alcohol by means of yeast. Alcohol is changed into oxide of ethyl be means of acids, and into haloid compounds of ethyl by means of hydracids; when brought into contact with the air, and either an organic substance or spongy platinum, it produces acetic acid; with a more elevated temperature, it produces aldehyde; by means of chlorine, chloral; and lastly, by combustion in the air, carbonic acid and water. At this point the primary elements of starch reassume the same form in which they were originally presented to the plants, part of the carbonic acid, however, being separated during fermentation. By the combustion all the elements become fitted again for nourishing plants, and a small organ, similar to that which produced the grain of starch, may again produce starch from this carbonic acid and water.

To express briefly what we have now endeavored to explain—no excitation of the forces of carbonic acid and water could be effected in the plant by its organs, unless those forces already existed, any more than chloral could be produced without alcohol and chlorine.

To whatever organ of plants we direct our attention, all, without exception, are formed in the same manner as the grain of starch, and all have received peculiar molecular forces at the moment they were formed from chemical molecules. The notion that heterogeneous forces can excite each other, is opposed to the primary idea of force. The force of gravitation cannot excite the magnetic force. It is only homogeneous forces that can set each other in action. Every decomposition, every formation of new compounds, the products of molecular forces, can therefore be effected by molecular forces alone; in other words, the small organs, which form a new compound from substances supplied to them, and which disturb the existing chemical equilibrium, can do so only through chemical forces possessed by them—through the chemical tendency possessed by their elements. This is the source of every excitation of new forces giving rise to a new combination. Further, these exciting forces proceed not from masses, but from molecules; they are molecular forces, and have therefore nothing in common with what proceeds from the whole individual. Starch is not formed by the plant, but by the molecules of the organ in which it is produced, because those molecules modify the chemical equilibrium.

This may be explained by an example. During the transformation of starch into gum by sulphuric acid, each molecule of the acid influences each molecule of starch, the latter thereby becoming gum;—the mode in which the elements of starch are combined is changed by the sulphuric acid, the alteration proceeding from molecule to molecule. The production of gum from starch in the organs of plants is similarly effected.

Wherever forces are found in organic nature, there are substances which are all supplied with molecular chemical forces. Even those singular structures, the nerves, consist of the same elements as the ordinary substances of the organic kingdom. It is thus undeniable, that the molecular forces act a chief part in the organism, so far as a change of substances takes place therein; and that no general, no vital force, should be assumed as the source of those molecular forces. Such a vital force is irreconcilable with the true principles of science, which require that nothing should be *assumed* as existing, but that every thing should be *sought for* in nature; which teach us to ascend only from an unprejudiced consideration of the phenomena to their causes, and to assign those causes only as we deduce them from the observed phenomena.

B. *The Development of a Germ.*

If we review the phenomena of life, caused by change of materials, we must go back to the original formation of organs—to the growth of an individual from a germ. We perceive no greater trace of the future oak in the acorn, than of the chicken in the embryo of the egg. Should we say that the acorn is governed by an oak-forming force, the embryo by a chicken-forming force? Does there exist a *general* force, which governs in particular all the molecules of tannic acid, starch, cellulose, &c., in the acorn, and all the particles of protein in the embryo of the egg? A *particular* or *peculiar* force is the active cause of *peculiar* effects; a *general* force is the active cause of *general* effects. Nobody can form any other idea of the terms. Though it cannot be denied, that in the embryo the rudiments of the future organs of the chicken are not to be found; yet we do find the materials from which the first rudiments of organs will be produced, that is, we find rudiments of rudiments. The forces which are inseparable from matter, their molecular forces, are present as well as the materials. If in these molecules there exists no capacity of becoming the germ of organs, and if in the germ of organs there exists no capacity of ultimately becoming organs, no chicken at all is produced. The capacity, this predisposition, must be present in the molecules, otherwise the heat necessary for hatching would be insufficient to produce germs of organs in the first place, and organs afterwards. This is the only reason why the embryo of the egg will not produce an oak, nor an acorn a chicken.

As the materials differ, so do their forces. Some who concur in this conclusion are of opinion, that the granular shapeless mass, which they suppose exists in a passive state, is acted upon by a power that can only be described as a chicken-forming force in the embryo. This mass is, according to Müller, "possessed of the real and specific force of the future animal."* This animal, however, does not as yet exist, and not even a single organ, nor the germ of a single organ; and are we to suppose that in that shapeless mass the *peculiar forces* of the animal exist, though that animal itself does not yet exist? I must acknowledge that I can scarcely imagine a gall-secreting force in the perfect liver; and I believe that no human being can possibly conceive of a gall-secreting force in the embryo of the egg, which does not yet possess even the rudiment of a liver. This idea is also unphysical. In the science of nature, we infer that forces exist whenever phenomena are observed; but if the non-existence of the organs, by which they are produced, render such phenomena impossible, no question can arise as to such forces. No forces peculiar to the future animal, therefore, can exist in the embryo.

Let us take an example from the inorganic kingdom. If we evaporate a solution of sulphate of soda in water, we get prisms. In what form must we suppose that the sulphate of soda exists in the solution? In that of minute prisms? By no means. In that of molecules supplied with a prism-forming force? We must reject this supposition too. There ex-

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"Begabt mit der wesentlichen und specifischen Kraft des spätern Thieres."

ists only a force of molecular attraction in a determinate direction, the formation of the prism being *the last result.* Between the first attraction of the molecules in a determinate direction, and that last result, a great variety of states of the particles intervenes,—a great many forces come into action, which are present, and excited *only when* the molecules, by the position they have already obtained, cause them so to be excited in and by each other. According to the doctrine of isomorphism, the arrangement of the molecules causes the formation of the prism; for every substance composed, for instance, of MO and RO^3, assumes forms, among which a crystallographic connection exists.* But as we have no reason for imagining a prism-forming force in each of these isomorphic substances, in sulphates, seleniates, &c.; so have we none for holding, that this primary force, dependent on the position of the chemical molecules, is the only cause of all the phenomena, perceptible during the formation of prisms.

Let us apply this to the substances present in the embryo. Whoever perceives in them nothing but protein and certain salts, examines that shapeless mass in a very cursory manner. Our object should be to mark what we see evolved from it, namely, compounds, which, in chemical composition, differ either slightly, or not at all, from protein; but which, nevertheless, do differ from it.

The shapeless mass begins to exhibit, here and there, very small points, which are arranged particles. These are produced from the existing materials—their forces being excited by the increase of temperature. Without elevation of temperature, such new arrangement of particles cannot be effected; but at the same time the molecules must possess a capability of being arranged, just as those of the sulphate of soda. The first crystals of this salt cannot be formed without the evaporation of the water, &c., and without a power in the molecules of attracting each other in a determinate direction.

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* MO denotes the protoxide of any metal M, or a combination of one equivalent of oxygen (O), with one of metal. RO^3 represents an acid composed of one equivalent of any radical R—such as sulphur or selenium—with 3 equivalents of oxygen (O^3). All compound sulphates, seleniates, &c., represented by ($MO+RO^3$), in which M may be any one of several metals, and R any one of several radicals, crystallize in forms, which are either identical, or are closely related to each other.—J.

In the embryo, this arrangement of the particles increases more and more, so as to produce a greater complication. This does not result from the primary molecular forces, till after they are modified by those other forces, which the substances received on their first arrangement. That first arrangement of the particles in the embryo, as well as the subsequent, must, of course, differ from that of sulphate of soda, because protein differs from sulphate of soda. But neither is the protein, in each of its particles, *the same protein in a chemical sense*, that is to say, yielding on analysis no other results than $C^{40}H^{31}N^{5}O^{12}$; the protein, therefore, does not always possess the same primary *arranging forces*. A minute difference of condition causes the deposition of sulphate of soda in very different forms, either with 10 equiv. of water of crystallization, or without any; the former are produced at a temperature below, the latter at a temperature above, 91° Fahr. The molecules of the substances which occur in the organic kingdom—those of carbon, hodrogen, oxygen, and nitrogen—seem to possess an unlimited power of forming mutual combinations. The number of compounds which they form, indeed, is incalculably great. That power is *inherent* in these elements; neither in the animal, nor in the vegetable kingdom do they acquire it; it is only excited therein. The diversities of form which the elements of sulphate of soda may give rise to, are very limited; but, on the other hand, the elements of protein, by their unlimited power of chemical arrangement, can originate endless diversities of combination. If subjected to chemical examination, each particle of the embryo in the egg would appear to be protein; but by such examination we could not discover the peculiar condition which makes one particle differ from another. We can no more explain this than we can the real difference between the transparent and the milky arsenious acid, between the yellow and the red biniodide of mercury. We perceive the differences, however, and therefore admit their existence; and so when we perceive them in reference to albumen, fibrin, casein, we are equally constrained to admit them.

Undoubtedly the differences which exist between the particles of the same organic substances are not chemical, in the ordinary gross signification, but are of the nature of those which are connected with polymorphism. The chemist gives us but a rude result—the composition in a hundred parts, frequently not affording us any insight into either the real characters of substances, or into their real differences. Whenever such dissimilar particles come together, a compound must be produced, possessing peculiar forces, which, though dependent upon the molecular forces of the elements, are yet not determined by these alone. The new arrangement causes a modification of those primary forces. Whenever it takes place, they appear modified, and therefore indicate their presence by producing new effects. In sulphate of soda, the whole collected forces of its constituent molecules—those of sulphur, sodium and oxygen—are still existent; and upon these alone depend its qualities, composition, and crystalline form. Sulphate of soda cannot possess other qualities—cannot become other in property—than what results from its elements, and exclusively originates in these.

Thus, then, we suppose that the molecules of the substances in the embryo are arranged, in the first place, simply, and afterwards more complexly. Not a trace of any organ is as yet perceptible, however; nor of any force, therefore, by which these organs will be governed. By the new arrangement of the particles, the molecular forces are modified anew, and this process is continuous. Although the primary forces, once united with the materials, remain the source of every action, of every manifestation of phenomena, of every chemical and organic, that is, physical, combination; they must, nevertheless, produce different effects, as the combinations become more complex. Each existing particle is the germ of a subsequent one, which is more complex; and, while the temperature necessary for hatching keeps the primary forces always excited, there is originated in the new arrangement of the particles, and also in the forces proceeding from the groups recently formed, a modification of these primary forces, which is constantly on the increase.

The whole material of the embryo in the egg is gradually brought in this manner within the circle of action. Then the circle is still more extended, and in its action are comprehended the elements of the yolk, and also of the albumen. These are erroneously called the food of the newly formed chicken, or its rudiments. In these elements there are forces also conjoined with the materials—chemical forces, analogous to those which exist in the embryo, and contributing to the production of the whole. These forces differ from those found in the embryo, not in nature, but only in direction, or in the mode of manifestation.

Thus we do not at all suppose that the molecules of the heart in the complete chicken existed in the germ as heart molecules, or the molecules of the intestinal canal as intestinal molecules. A series of successive transformations proceeds in the embryo—the production of the heart, of the intestines, of the whole chicken, being the final result. Neither do we suppose, therefore, either a heart or intestine-forming force in the germ, but a gradual evolution of new series of forces, resulting from the same primary forces of the molecules of carbon, hydrogen, oxygen and nitrogen, and which are to be considered as so many exhibitions of new groups, produced in their turn by the causes previously in operation.

In this way, therefore, neither does a gall-secreting force exist previously to the production of a liver, nor the force which effects the circulation of the blood previously to the production of the heart and blood-vessels.

It is an impenetrable mystery how the particles of substances, both organic and inorganic, mutually combine in different modes; and after they have so combined, again form new compounds. This mystery, as regards organic substances, is not, however, greater than that which surrounds the inorganic. If any one fancies that it is more easy to conceive of the production of a crystal, than of a texture composed of fibres, globules and cells, in other words, any animal or vegetable organ;—of the origin of a precipitate, than of a primary fibre;—of the state in which crystallized sugar exists in solution, than of the first rudiments of organs in the embryo,—he greatly errs. To penetrate into either is not as yet permitted to man.

To express our idea in a few words,—the elements of the organic kingdom, carbon, hydrogen, oxygen, and nitrogen, are susceptible of endless modifications of their primary forces. For that reason they can form, with minute changes, a great diversity of products; and, by the operation of the same primary forces, they stand towards each other in entirely different relations from those assumed by all the other elements; so that they can produce a peculiar series of bodies, which are called organic substances.

C. *Equivocal Generation.*

Upon the principles which have been stated above, no room is left for the dispute as to *equivocal generation* and *epigenesis.* The doctrine of epigenesis has originated in the idea, that every living thing is produced from ova alone; because in these only can all the forces and germs of organs exist, which are found in the future plants or animals. The dictum of Harvey, *Omne vivus ex ovo*, has been strongly defended, and has still many supporters. On a sound view of organic nature, and of the essence of organic beings, this doctrine appears to be perfectly reconcilable with that of equivocal generation. If we consider an *ovum* as an organic molecule, or an organic body, made up of the four organic elements, combined in various groups, then the conclusion of Harvey is no doubt true. It is still true, if by an ovum we mean a molecule of a determinate kind; for this is also proved by observation. The mites of cheese are peculiar to cheese; and from certain parts of plants—fruits, for instance—peculiar fungi are produced also. It is a general rule, that from organic molecules of a given and determinate kind, only specific compounds—specific or peculiar forms, can be produced.

The term *ovum*, however, has been taken in a limited sense, to signify the germ of an individual, produced by peculiar organs only;—a germ in which every thing belonging to the future animal is concentrated. Such ova, we have seen, do not exist. There is a *development*, an ascension from the simple to the complex. According to the supporters of epigenesis, an egg is such a germ as, in favorable circumstances, always produces the same species. And in reality, the supporters of equivocal generation do not entertain any different idea. In their opinion, there exist certain organic substances,—organic molecules,—which are capable of evolving and forming something new, whence individual plants or animals may also finally proceed. Why may not cheese be an agglomeration of ova, that is, of molecules, from which an individual being may be produced, as from the ovum of an insect? It cannot be denied that the existence of the spermatic animalcules proves, that animals, or at least their germs, gradually growing, by merely floating in a fluid, may be secreted. What we know of the Acarus Scabiei, the Filaria aracunculus, the Echino-cocci, and a great many other entozoa, shows that they may be produced from ordinary organic molecules in the animal body, as every small organic globule of mucus, for instance, or of milk, or of pus, &c., is formed. As the germs of the spermatic animalcules are secreted animal germs, so may the molecules of casein also be the *ova* of mites, though these remain molecules of casein. The one idea is not excluded by the other:—an egg consists of the white and the yolk; both, however, constitute the germ of a chicken. In the very same manner the ergot of rye (Secale cornutum) is produced. From the top of this same fruit, under different circumstances, a different plant arises—a fungus instead of a grass.

The idea of an ovum, therefore, coincides exactly with that of an *organic molecule;* that is, of such a molecule as consists of elements which may exhibit themselves under a change of circumstances in infinite modifications, may form new combinations, attract other elements, incorporate them, unite into definite compounds, and thus separate from other bodies with which they were originally combined. Among species of this nature, formed from organic molecules, are the mites in cheese, and the mould upon rotting fruits,—resulting from the molecular forces of the elements, like the spermatic animalcules.

Finally, the ordinary ova of plants and animals consist of nothing but organic molecules, such as those of which all organic substances are composed. They are products of organic bodies, and therefore differ neither in composition nor in character from the germs of those substances which are said to originate through equivocal generation. Nay, it is a peculiarity of organic molecules that they produce organic molecules. As regards this leading characteristic, ova and organic molecules resemble each other. Of this the vegetable kingdom exhibits an endless variety of striking examples. The stem of a tree produces not leaves, but branches; these branches produce not leaves, but petioles, and the leaves grow from the extremities of these. From the end of the footstalk, a flower grows, in the same manner as a stem from the seed deposited in the soil. No other part can produce a flower. And in the flower itself every separate portion derives its nutriment from the spot to which it adheres. The extreme cells found there, are the feeding cells of entirely peculiar parts, which no other kind of cells can produce.

Each cell, therefore, is, as it were, the ovum of peculiar parts of plants; as, for instance, the cells at the very extremity of the petiole are the ova of the evolving leaf; the cells at the very extremity of the foot-stalk are the ova of the beautifully shaped flower, with all its parts. This is proved in the clearest manner by grafting.

The idea of an ovum is thus reduced, in truth, to that of an organic molecule; and the dispute as to equivocal generation and epigenesis is at an end. In the same way, however, the general vital force is reduced to molecular forces. The effects of the vital force are effects produced by the cells, which are so very diversified, and which exhibit phenomena that vary with their own differences. We must in a single plant divide this one vital force into thousands,—into as many forces as there are series of cells, producing different substances. In other words, we must reduce them to what is effected by the cells themselves; and thus we find that the idea of vital force coincides with that of molecular force.

D. *Transference of Vital Force.*

The idea of transferring vital force is opposed to the idea of force. A slumbering force is awakened, a weak force is strengthened; but it is impossible to imagine the transfer of a force from one material mass to another. We must first refer to this point in pausing to consider the manner in which we must conceive of the transition, into a new organic whole, of life originating in another. If animals impart vital forces to their offspring, then such forces must, no doubt, be lost by themselves. We do not perceive, however, that this takes place; on the contrary, they retain their strength, sometimes for many years, after having produced new beings, completely formed, of the same species. The tree which, for a great many years, produces fruit, and the seeds of which have, in great numbers, become full-grown trees around the parent stem, nevertheless lives as at first. A single poppy plant produces thousands of small seeds, each of which grows up to a poppy plant equally perfect. Hence we are not entitled to admit the idea of transference of vital force, even where it is not opposed to the idea of force itself. With our own eyes we perceive the evolution of that force from its phenomena.

What part then bears the germ of that vital force which is afterwards to be developed? and at what point does the development commence? It is the poppy seed which bears the germ,—a small quantity of organic molecules, different in nature from all others,—some carbon, hydrogen, nitrogen and oxygen, combined in a certain manner into substances, which are peculiar in respect of their composition and arrangement. The peculiar quality, which distinguishes these substances from amorphous precipitates and crystals, they owe to their origin. Their elements were brought into a state of peculiar tendency by the forces residing in the organic molecules of the plant, whose influence had previously governed them. They do not possess more than they exhibit, and they exhibit nothing but a change of their chemical composition. The seed changes its starch into gum and sugar, and so chemical forces forthwith appear, which seem to be intimately connected with the development of new forms. Another phenomenon soon succeeds, namely, the absorption of substances from without. These bring something with them: they are not merely *substances*, but the residence also of peculiar active forces to which they owe their composition. Of these forces, some portions combine with those which are derived from the seed itself. And now, the previously existing molecule, and that which is formed from external matter, both live—the former through what it received from the parent plant, the latter through its having assumed the form of the other. This conformity arises from matter, and from the property which matter possesses, of obeying the action of forces, proceeding from the first molecule; in other words, the second molecule must necessarily be endowed with the capacity of becoming similar to the first, through the influence of the first. Thus, the second molecule did not receive its peculiarities, but these were excited in it; and so this molecule also lives as well as the first, and in its turn can take up new substances from without, and entirely assimilate them. So again, the third lives also, and thus is life gradually extended. The molecules, after being once arranged in a certain manner, give birth to new arrangements, to new forces, as we endeavored before to explain.

From what has been stated, it will sufficiently appear, that the oak, when losing its acorns, loses none of its vital force; that an animal loses none by generation; but that, in both cases, the generating substances leave only certain quantities of matter, endowed with the power, first of somewhat increasing, then of taking up other substances, and with these just so much of life as *they* afterwards manifest. Organic substances, whether called germs or food, possess properties of a peculiar kind, existing in the four elements of which they are all constituted.

CHAPTER II.

INORGANIC, ORGANIC, AND ORGANIZED BODIES: PLANTS AND ANIMALS.

All bodies divide themselves naturally into two principal classes, namely, those possessed of peculiar organs, by means of which certain acts are performed, and those which are destitute of such organs. The former are called *organized*, the latter *unorganized*. Those substances, which are either themselves organized, or which are derived from such as are so, are called *organic* substances; those which contribute to the composition of unorganized bodies, are called *inorganic* substances.

It is not difficult to indicate the organs of an organized being, if it have them either in great number, or very much developed. Such organs, in the classes of the so called higher animals, are the eye, the stomach, the liver. It needs no lengthened demonstration to show what is meant by such organs as these. There is no room for doubt, indeed, as to the application of the term, in even the least developed condition of organized beings; for, in general, an organ signifies an instrument by which a certain act is performed; it may be either a very complicated, or a very simple one. A mere cell, therefore, is such an organ; the only function necessary to constitute it such, being the capability of producing cells similar to itself.

This power of forming new substances is peculiar to a certain class of natural products. Such as are endowed with the requisite instruments are called organized. Each organ has its peculiar office assigned to it. But all the organs are, besides, united into one whole: they act in combination to maintain the whole, to give it a substantive existence, to make it perform certain actions;—in a word, they form by their union what we call living beings. Living beings, therefore, are organized. Organized beings and substances either have lived, or are still living. In every thing that either has not lived or does not live, we miss those organs, which are destined either to produce new substances, or to perform certain actions; and, from the absence of those organs, their actions also are wanting in such as are unorganized.

This is the case with all minerals. Their composition, however regular, as regards their form and the proportions of their elements, is such that, without the intervention of forces acting from without, the mass persists in the state in which it has once been placed. The whole is composed, in a regular manner, of parts, which are quiescent till their forces are excited by external causes. But all plants and animals have an exactly opposite character. Every thing belonging to them is in a state of continual motion, till causes come into operation, which convert that motion into rest. This motion is accompanied by a constant change in the substance of their parts, which continues even when the mutual harmony of these parts is disturbed,—the substantive existence of the individual destroyed. The animal and vegetable worlds are made up of an endless multitude of structures, which are in a state of almost uninterrupted activity;—an activity, the first indication of which is a change in their constituents, while its farther manifestations are characterized by a great variety of phenomena, all of which we include under the general name, *phenomena of life.* The regular recurrence of these phenomena, we call *health;* their disturbance, *sickness;* their entire suspension, *death;* their harmonious co-operation for a common end, that is, primarily, for the maintenance of the whole, we designate *life.*

The minutest portions of an organized being consist, for the most part, of very small organs, which unite in vast numbers to constitute a substantive whole, which we call an instrument or organ. Such is the liver or the spleen. Thus as an organized individual consists of organs, so a larger organ consists of smaller ones; and as the actions of an individual result from the combined actions of all its organs, so again the actions of any larger organ are nothing but the combined actions of the smaller organs, by which the larger is made to appear as a substantive whole. So also in most organs, the function of the whole is made up of all the functions of all its parts combined. Thus, the simplest form of a lung, is an air-cell, covered with a vascular net of arteries and veins;

the smallest form of a submaxillary gland, is a small grain, into which, on one side, arterial blood enters, while the secreted saliva flows from it on another. In the same manner, the simplest form of a plant is a cell, because, if numbers of these are taken and placed together, in various orders, they produce a plant.

The size of the organs, then, by no means determines whether natural products are either organized at all, or more or less organized. The very smallest of them are still organs—manifesting themselves by certain actions, and originating phenomena, not wholly, but partly dependent on external conditions. Any substance, however, which possesses a greater variety of these organs—each of which, by themselves, or with their respective groups, perform several actions—is properly said to be *more* organized. There exists in nature an astonishing variety of such substances. Some are of exceeding simplicity, as in the lower orders of plants. Others are of a very complicated structure, possessing a variety of smaller organs, united either singly or in groups; and thus acting in a variety of ways. These latter abound in the higher classes of animals.

It need scarcely be remarked, that each organ, or each of its constituent organs, differs in substance from such as act or manifest themselves differently from them. And this difference appears not only in their substance, but also in their form—the component parts of each being arranged in conformity with the functions they are intended to perform in different classes of individuals. Hence an infinite diversity of products. They can present a new arrangement to the substances supplied to the individual from without; and hence their products are innumerable. The substances, thus produced by the organs, are called *organic.* They are called organized, if they are either organs themselves, or if they contain organs; but generally organic if they are the products of organs. Organized substances, therefore, are organic substances; but organic are not always organized.

Organic unorganized substances do not at all differ from inorganic, as to the nature of the substances themselves. But they materially differ as to the arrangement of their constituents. The elements of the organic kingdom are to be met with in substances which are not organic, but wherever we find them, they are the same, and exhibit the same properties. If, however, these elements are placed in certain circumstances, they form combinations dependent on these circumstances. This tendency to combination, which exists in the elements, and which is to be looked for *within*, and not *without* —being dependent on nothing but the elementary forces, concealed, as it were, in the molecules of carbon, hydrogen, nitrogen, and oxygen,—this tendency being excited to a determinate degree under certain conditions, produces new substances. This general law, of which chemistry gives innumerable examples, is obvious in organic nature. Slight differences of temperature are quite sufficient to produce, in the chemical laboratory, entirely different combinations from the same elements. In common chemical experiments, numerous minute circumstances influence the nature of the product which results from the combination of two or more elements.

Looking at the subject in this general point of view, new combinations, entirely different from each other, must be produced by different organs from the same materials, supplied from without. And if we add to the endless multitude of different organs in plants and animals the diversity of materials afforded from without, then we shall understand, how that endless series of new combinations must necessarily arise, which is formed in plants and animals, out of two, three, or four elements, and which chemistry makes known to us. In a word, every change of materials in the organic kingdom, as in the inorganic, is the result of the primary forces of the elements, and cannot be ascribed to any other source.

By the nature of those products, therefore, the nature of the actions of the said organs is more or less determined. But there are several other effects of these peculiar instruments, which go far beyond a simple change of materials. A great many living creatures are endowed with the power of changing their position at will, and possess for this purpose peculiar organs, in which the change of materials is limited to their own support exclusively—such are the muscles. They have a complete system of organs, by which they are enabled to absorb substances from without, to retain them for some time, to expend them gradually, and to employ them in the formation of new organic substances—such are the organs of digestion. They have peculiar instruments, the organs of sensation, by which certain impressions from the external world may be conveyed to a spiritual being, endowed with a power of observation, will, and even consciousness;—a being which chooses according to fixed rules, forms judgments, and draws conclusions; remembers former situations in which it has been placed; imagines new situations as if they really existed;—a being which is itself conscious, why, what, and for what purpose it exists;—a being which can investigate more or less, and admire the Cause of the universe; which recognizes in itself a faint image of the Divinity who governs both worlds and atoms;—a being which may acquire moral worth, and has a clear idea of the distinction between good and evil;—a being conscious that it was created for immortality.

How surpassingly beautiful is the visible world! At one extreme of organic nature spiritual man is placed, dwelling for a season in a godlike house, formed by a Master-hand, suited to his moral elevation, making him familiar with all nature, and with many of its beauties:—at the other extreme, the minute fungus, scarcely visible, as simple in composition as it is humble in appearance—as ill furnished with organs as the human body is rich in them.

It is easy to distinguish between these extremes in the series of organized beings—their difference, indeed, being so obvious that we can scarcely perceive any conformity. But whether we descend from the one extreme, or ascend from the other—it is exceedingly difficult to draw the line of demarkation between animals and plants. The result of all the endeavors to determine this line of separation has been, that the structures of the individuals which constitute the transition class between animals and plants, and which partake in an equal degree of the nature of both, do not enable us to reduce them to either class. They may with equal propriety be called either plants or animals.

There exists a mutual approach between the materials of which animals and plants consist, in certain determinate conditions—an approach which is really remarkable. Miguel* has described an epizootical fungus, the Isaria cycadæ; and Virey† has made us acquainted with a minute moss upon the

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* Bulletin, 1838, p. 85.

† Journal de Pharmacie, 1838, p. 83.

silk-worm. He has lately* recorded further observations, by which the Tinea lupinosa of Guy de Chanliac is reduced to a kind of Mucor of the genus Mycodermata. The sporules of these kinds of plants find a fertile soil in the *scales* with which the hairy part of the head of children, &c. is covered: they penetrate into the epidermis, and in this way sustain and feed themselves. To these plants also belong the bran-like moulds, mucors, &c., which have been placed in the order of the Coniomycetes, of Nees von Esenbeck. A great many dartrous pimples belong to the class of the fungus-like mosses. The warts of the human body are classed with the gynosporanges? by Meynier of Ornans. It is difficult to make out, if the tubercle of the lungs be really a Cycoperdon, and the cancer a Uredo caries.

Though there is no uncertainty as to the characteristics proper to oaks and lions, each of them respectively producing a complete impression on the mind, so as to afford a standard whereby plants and animals may be examined and determined; nature has, nevertheless, established forms of transition which do not admit of a fixed classification.

The attempt will, therefore, be always made in vain to draw a distinct line of demarkation between animals and plants. Dumas is one of the last who has tried to do so.† He thinks that the following table of distinctive properties establishes a new system, and gives a clear idea of the difference, which we have more than once stated:—

PLANTS	ANIMALS
Produce indifferent substances containing nitrogen;	Consume indifferent substances containing nitrogen;
" fats;	" fats;
" several varieties of sugar, starch, and gum.	" sugar, starch, and gum.
Decompose carbonic acid;	Produce carbonic acid;
" water;	" water;
" ammoniacal salts.	" ammoniacal salts.
Give off oxygen.	Absorb oxygen.
Absorb warmth;	Produce warmth;
" electricity.	" electricity.
Are apparatus of reduction.	Are apparatus of oxidation.
Are immovable.	Change their place.

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* Journal de Pharmacie, 1841, p. 703.

† Comptes Rendus, Nov. 28, 1842.

He to whom this detail is new, or appears to embody the truth, is unacquainted with the actual state of science. It is universally known, and will appear from what follows, that not one of these so-called distinctive characteristics will stand the test of examination.

As we are not able to draw a clear and just line of demarkation between plants and animals, neither can we between unorganized and organized substances. As soon as the functions of the organs have reached a minimum, we approach the limits of those series of substances, the most complicated of which may easily be distinguished from mineral matter—but of which the least complicated opens the way to the knowledge of another series of substances, which, being wholly dependent on circumstances, do not possess the power to represent any thing but the usual properties which are inseparable from matter.

1. The general characteristics of organized and living beings are, increase and growth, generation and death. Besides these properties, common to animals and plants, the former are endowed with the power of perceiving external impressions and of moving themselves at will. Schleiden* justly characterizes animals as having a tendency in their organism, to develope their life to the utmost degree of individual separation, and thus to conceal internally their principal organs; that which is shown externally being as much as possible a uniform surface. The plant, on the contrary, bears its chief organs without, increases very much externally, and shows its beauties all on the surface.

2. If any substance is deprived of the properties common to animals and plants, then it is either an inorganic or a dead organic substance. The latter are characterized by the absence of the effects of organs, which are themselves present; the former by the total want of any organs, which either can now, or formerly could, perform any action in any circumstance whatsoever.

From the articulations of the Gallionella ferruginea of Ehrenberg† being made up almost wholly of oxide of iron, it appears that the transition from organic to inorganic sub-

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* Schleiden, Grundzüge Wissentschaft; Botanik I, p. 29.

† Ibid, p. 34.

stances is almost as imperceptible as that from animals to plants.*

3. *Binary and ternary combinations.*—It has been thought that a clear line of distinction might be drawn between organic and inorganic substances, by stating that, among the former, ternary and quaternary combinations occur, but in the latter, only binary ones. This limit being quite arbitrary, is at the same time entirely unchemical. Every one but partially acquainted with the chemistry of organic nature, is aware that a great number of radicals have already been discovered, and that the terms ternary and quaternary, as applied to combination, were of no use after the first radical was indicated. Ether does not consist of C^4H^5O, but of C^4H^5+O. The oxygen can be separated from it, and sulphur, chlorine, bromine, iodine, or cyanogen substituted. Thus we have ethyl (C^4H^5), a binary combination. This unites with oxygen, sulphur, &c., and forms another binary combination.† All organic substances are no doubt built up in a similar way, but the radicals of many of them are not yet known. A few years ago not one was known. Science is gradually discovering more of them, and encourages the hope, that in process of time every organic substance will be reduced to its own radical.

4. If any distinction is to be made between organized and unorganized chemical substances, it should be stated thus:—that in the former, compound radicals exist; and in the latter, elementary ones. But is this distinction founded upon their belonging to no different provinces of nature, or upon a

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* The following work may be consulted on the difference between plants and animals:—Kutorga, Naturgeschichte der Infusiores-thiere, St. Petersburg und Karlsruhe, 1839 and 1841, S. 30.

† The meaning of this passage is, that ether consists of 4 equivalents of carbon, 5 of hydrogen, and 1 of oxygen; but the three elements are not united together all at once, as is represented by the juxtaposition of the several symbols in this way, C^4H^5O, forming a *ternary* compound, from which no part can be taken away without breaking the whole up. But first, the carbon and hydrogen are united together to form a binary compound, represented by C^4H^5, to which the name of ethyl is given. This afterwards combines with oxygen and forms ether, which is *rationally* expressed, therefore, by C^4H^5+O. And the proof of this is, that the oxygen can be separated from it, and chlorine (Cl) made to take its place, forming C^4H^5+Cl, and so on.

peculiarity in the nature of the carbon, hydrogen, and nitrogen, of which organized substances consist? The answer is obvious, for the organic kingdom is built up out of the four elements—the elements themselves being wholly independent of organic nature. It is, moreover, doubtful, whether all organic substances contain compound radicals. On the contrary, it is probable that cellulose, starch, gum, sugar, &c., consist of carbon and water. The transformation of tannic into gallic acid (see *Tannic Acid*) affords strong grounds, for adopting this supposition.

5. *Juxtaposition.*—Another real difference is assumed as to the way, in which organized and unorganized substances are formed. In the latter, a juxtaposition is supposed; in the former, a growth, an increase of solid matter in some of its parts. First, this distinction is not quite accurate; for horns, nails, and hair, which are all produced from protein compounds, are formed by juxtaposition. Of hair, this is proved by Dr. Van Laer beyond dispute.

But let us consider this juxtaposition in the unorganized kingdom. When burned gypsum after being mixed with water changes into a solid mass, we look in vain for any juxtaposition. Does any thing else happen in the deposition of the materials of bone, within the cells of the bones? Does not the bony matter of the skull extend itself from a centre in the form of rays? Let us take an example from the vegetable kingdom. How does the formation of wood take place? Is it not a real superposition, when layers of woody fibre are deposited against the walls of a cell? But the very same happens also in the ordinary growth of an organ. Matter does not *penetrate* into matter. If the germ of an organ, produced by simple juxtaposition, once exist, then the organ cannot increase in bulk without one particle placing itself *next* to another, and so shifting its place—and this is a real juxtaposition. This is fully confirmed by the way in which cells are produced—a subject with which, of late, we have become somewhat better acquainted.* There exists, however, a difference between crystals and many organic substances. The

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* See Schwann, Microscopische Untersuchungen über die Uebereinstimmung in der Structur und dem Wachsthum der Thiere und Pflanzen. Berlin, 1839, S. 191.

cellular and fibrous primary forms which are present in the latter, are wanting in the former; while the symmetrical forms of the crystal are not found in organic nature. The latter is just as averse to symmetrical forms, as inorganic nature is to cells and fibres. We seldom find crystallized compounds in the bodies, either of plants or animals; and the substances contained in them, which are susceptible of regular crystallization, exist there usually in a state of very fine division, or of solution. In regard to theine, which is so beautifully crystallizable, we do not find a trace of it crystallized either in coffee or in tea.*

If we add to this, that many organic substances, provided they are placed in favorable conditions, assume juxtaposition —for instance, tartaric acid, citric acid, &c.; morphine, narcotine, many resins, camphor, &c. which are all organic substances,—then the positive distinction between organic and inorganic nature, grounded on this peculiarity, disappears. We may, however, state, as distinctions between organized and unorganized substances, that, generally, the former are in a cellular, the latter in a crystalline state; that the one class performs a function of which the other is not capable.

After what has been said, we must necessarily conclude that the causes of this diversity are reducible to the forces which primarily exist in the organic molecules, carbon, hydrogen, nitrogen, and oxygen, and in those of all the other elements. The four organic elements have the peculiarities, which are indicated in organic nature by their almost innumerable mutual reactions and combinations. To these elements a peculiar potency is imparted, if such an expression ought to be retained in science.

6. Finally, between plants and animals, which are both characterized by the cellular form of the component organs, there is this real difference, that cellulose, ($C^{24}H^{21}O^{21}$), forms the principal part of the cellular mass in plants; while in animals the primary material is gelatine ($C^{13}H^{10}N^{2}O^{5}$), or the matter which produces glue after ebullition; and to this rule no exception has yet been discovered, either among animals or plants.

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* For an important paper on the substances found naturally crystallized in plants, by Prof. Bailey, see American Journal of Science, Vol. XLVIII, p. 17.—S.

CHAPTER III.

THE ATMOSPHERE, IN ITS CONNECTION WITH ORGANIC NATURE.

Throughout all nature we perceive an intimate connection existing between different actions, one being disturbed as another is annihilated. Phenomena are united together by a chain, from which not a link can be taken without throwing the whole into disorder. If water were to lose its property of being converted into vapor, every living being on the earth would die; if the composition of the atmosphere were suddenly changed, thousands of living beings would instantly perish from the earth. In some instances, many causes coöperate to bring forth one phenomenon,—to produce one substance; in others, the destruction of one substance is the condition on which another exists.

On a cursory view, nothing is more surprising than the change of forms—the alteration of appearance—to which the same substance is subjected. On penetrating farther and farther into this law of nature, nothing excites greater astonishment, than the fact that the form alone perishes; that matter changes its appearance, but is itself imperishable. We think, observe, feel, speak to each other, by means of organs composed of a mass of elements, consisting of nitrogen, carbon, hydrogen, oxygen, phosphorus, sulphur, lime, magnesia, iron, chlorine, soda, potash, and many others, but the unchanged existence of these organs is of short duration. At every respiration they lose something, and they appropriate something again. This change is also promoted by perspiration, and by all kinds of secretion; and thus we shall not be the same to-morrow as we are to-day. Our body is no longer the same even after the lapse of a few moments.

The organic mass, which is called the human body—the animal body of man—is a texture of substances which are introduced into it by certain apertures. What now forms part of the human body, some days ago belonged to the body of an animal; and, again, some weeks ago it was a constituent of plants. Whatever our human body may be to-day, it will be changed into vegetable matter possibly after an interval of but a few months.

This body derives its origin, partly from the atmosphere, and partly from the earth's surface. From the latter it is separated but for a short space, soon to return to it again. Both plants and animals are then fed from our material part; and every man, doubtless, derives support from the dust of his ancestors.

Thus, by means of a small portion of matter, *once endowed* with certain forces, the Divinity, the Author of these forces, attains, in the course of ages, an infinite variety of ends, with which it is the endeavor of the natural philosopher to make himself acquainted.

1. It is a known fact, that nature, with singular economy, has formed the whole organic kingdom chiefly from four elements. Carbon, hydrogen, nitrogen, and oxygen, are the constituents of every thing that either has lived, or is still living. Besides these, there are some, so called, inorganic substances, which complete the organic whole; but it is of these four elements, that the greater part of organic matter has been formed by nature. It is of importance, therefore, to consider what alterations occur in the combinations of these four elements, after they have constituted, at one time, some part of a plant; at another, some part of an animal.

2. Further, it is known that animals are nourished by plants, and thus, that plants serve to connect animals with the earth's surface. Taking this point of view, the living substances by which the mere dead earth is invested with color and the air filled with odors, become of the very highest importance. Those which are employed as food by man, constitute, indeed, but a very small portion of the whole. Man makes use of scarce the hundredth part of the produce of the earth, and not one out of a thousand of the forms of vegetable life which grow upon it. It is, however, an indisputable truth, that without plants no animals, except the infusoria, could exist.

3. In the third place, it is known, that what we usually call putrefaction is nothing but a change of form. A substance, which has formed part of a living being, is endowed with

forces modified in a peculiar manner, which have been excited during life, but must necessarily become again quiescent so soon as the life of the being ceases.

According to a general chemical law, those substances have been arranged and influenced in a peculiar manner by the peculiar circumstances in which they have been placed. Whenever, therefore, they are withdrawn from the influence of those circumstances, a great many gaseous, liquid and solid substances appear, which taken together represent *just as many* substances, and those *the very same*, as were formerly contained in the living part. This is a new effect of the forces by which the organic world is maintained. Its destruction is its very source of life; its life, again, the cause of its destruction. When we perceive in an organic whole, that the component parts cease to coöperate for a common object, its existence as a whole—its life is at an end; a new life begins immediately to appear. It may be that the new products appear to us disgusting. Those revolting substances, however, contain the germ of the most beautiful combinations. The most splendid plant has been produced only from such substances, and can derive its support only from what has been such.

4. We may regard a fourth peculiarity as also known, namely, the value of that black layer of soil which surrounds the globe we inhabit, in many places to a thickness of several feet. If this black crust were taken off our planet, much of what lives upon it would be destroyed or prepared for destruction. Where this covering exists, plants readily spring up; where it is wanting, many of them are either not found at all, or are found in an unhealthy condition. It is the standing place of the organic beings which are bound to the earth. How far it is their source of nourishment, we shall presently endeavor to explain.

5. Besides these four points, I must advert to a fifth, now sufficiently ascertained—the value, namely, of the gaseous veil of the earth, which is extended to a considerable distance from the globe; of that air-ocean which, in its fury, turns palaces into ruins, and crumbles rocks to dust in its calmest moments;—which is constantly achieving the destruction of every dead substance on the earth's surface; but, at the same time, maintains every thing that lives upon it. Every living

being requires the support of that mobile fluid. It affords nourishment to animals and plants; it not only supplies substances, but carries force into organic beings; it is a real source of life to every living thing on our planet.

One of the most beautiful contrivances of the material world, is that which is exhibited in the innumerable changes undergone by the same substances, which, among their various forms, at one time constitute parts either of the atmosphere, or of the black soil—at another, the component parts of living plants and of animals.

We have acknowledged, as a general law, that the same elements may assume thousands of forms, and produce new combinations, though they cannot change their essential character; and that by means of the same substances, in various instances, nature attains entirely different ends. The substances, which, in an organized form, adorn the earth, will, ere long, be decomposed. Their constituents, combined in a different manner, will soon assume a new shape, but will present themselves in the interval as component parts of the black soil and of the atmosphere. Thus the same substances, at one time float in the atmosphere which envelopes the earth, and at another are component parts of plants and animals.

For these purposes, nature employs a small portion of matter only, compared with the large mass of the earth. Though apparently so very liberal in maintaining life, she is at the same time economical in applying the material means by which that object is effected. The number of animals and plants, which may at any time have existed on the earth, could scarcely be greater than it is now, because there would be a want of materials requisite for sustaining their existence. With the increase of the number of animals, that of plants must diminish, because the former are composed of parts of the latter. In the thin, black layer of soil, the constituents of animals and plants, and a little intermixture of the atmosphere, we have the whole store, which exists on the earth, of the materials necessary for the existence and support of living, of organized beings.

Let us now consider the atmosphere in its connection with organized nature. Unknown in ancient times, it is at present acknowledged to be a main source of life to every living being upon the earth.

Accordingly we must bear in mind what the atmosphere is composed of; what influence it now exerts on the life of plants and animals; what influence is exercised by these in their turn upon the atmosphere; what its probable state has been in former times, and what influence it then exerted;—and finally, we shall have to consider what causes actually exist, having power to modify the nature of the atmosphere; and to inquire what is likely to be its future state, so that we may form some idea of its influence on what will hereafter be living.

The atmosphere, we know, is an invisible, very mobile veil of our planet, extended upwards to a great distance, and tending to occupy every space not occupied by other substances. Being kept in continual motion by general and special causes, it forms a uniform mixture of a few principal ingredients; at the same time, it is the receptacle of all the volatile particles, of all the vapors from the earth's surface. The causes, which produce its motion, are among the most beautiful which investigation has observed in nature. Without that motion, every disturbance of the composition of the atmosphere would necessarily be pernicious to the life of plants and animals; every organized substance would become surrounded by an atmosphere of its own, expending what is useful, and leaving what is useless, so as soon to be deprived of every thing not belonging to that by which it is immediately encompassed. Were the atmosphere a motionless mass—from which something is taken, and into which something is discharged, and in a different way by every organized being—then all things now alive on the earth's surface would in a few days be destroyed. It is, therefore, a wise and most excellent contrivance, that thousands of causes are at work, to keep the atmosphere in ceaseless motion. What may be pernicious to one organism, is indispensable to another;—what is left from the abundance of one, is usefully applied by another;—what in one place is copiously produced, and might be detrimental, is rendered innoxious by being widely diffused through the ever-moving atmosphere.

I have purposely drawn attention, in the first place, to the continual motion maintained in the atmosphere, by the action of varying temperature and other causes; because in this lies the chief argument in favor of the opinion, that the atmosphere—however it may be composed, and whatsoever may be either discharged into it or taken from it—must be a uniform mixture; and that every where, over the whole earth's surface, and at every height, it must contain the same constituents. As a direct consequence of this beautiful contrivance of nature, all the organized beings on the earth's surface, wherever they may be, are, as regards the atmosphere, exposed to the same influences.

The chief constituents of the atmosphere are four in number—oxygen, nitrogen, carbonic acid, and aqueous vapor. The proportions of the two latter vary with many circumstances, in a way which we can detect by observation—the way in which the proportions of the two former vary has hitherto escaped us. The received proportions of oxygen and nitrogen are, 21 of the former, and 79 of the latter, by volume—the carbonic acid averages nearly half a thousandth part, the quantity of watery vapor is very variable.

To these principal constituents of the atmosphere thousands of others are added. Volatile exhalations from the organized matter of the soil,—products of the volcanoes on the earth's surface, and of the artificial burning of fuel,—gaseous fluids escaping from mines,—vapors of volatile solid substances,—hundreds of volatile oils from odoriferous plants,—putrid volatile products of animal and vegetable decomposition,—the muriatic acid arising from salt water in shallow lakes and lagoons,*—exhalations of men and animals,—an innumerable multitude of substances ascending in vapor from manufactures and chemical processes,—and finally, the volatile products of animal excrements;—all these are sources of pollution to the atmosphere, which thereby undergoes innumerable alterations in its composition.

The accumulation of these multifarious substances in the atmosphere is prevented by one single cause, which is among the most remarkable we know;—a cause, which is the same for the whole earth, which originates in the same source, and acts for the same purpose;—a cause as sublime in its effects, as it is simple in its nature;—a cause only to be brought into

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* Mülder found free muriatic acid in the rain-water of Amsterdam, which he ascribes to the decomposition of the chloride of magnesium, contained in the waters of the Lake of Haarlem, by the action of the sun's rays.—*J.*

operation by the Supreme Wisdom, which can attain innumerable ends by one means. It is the rain, which, in falling, carries with it every thing that floats in the atmosphere, and which is not essential to its constitution; which brings back to the earth, what came from the earth; and which, whilst it thus purifies the atmosphere from noxious immixtures, carries the thousands of volatile substances into the soil, in which they have abundant opportunities of forming innoxious combinations with the substances which the soil contains.

The atmosphere, thus purified by means of rains from all heterogeneous mixtures, and kept in constant motion by currents of air, is a mixture of four substances. Let us briefly consider, how we may accurately investigate them.

1. To determine the composition of the atmospheric air, it is necessary to ascertain accurately the amount of nitrogen and oxygen, its two chief constituents, and also that of the carbonic acid and aqueous vapor.

The first experiments for determining the amount of oxygen and nitrogen are comparatively recent; for it is not long since weights and measures began to be employed in the science of chemistry. Lavoisier was the first who used the balance, and he but rarely. When in the latter part of the last century, the kilogramme was introduced, it was noticed as a singular circumstance by the committee, assembled at Paris for the purpose of considering the subject, that the mechanician, Fortin, had made a balance, which sensibly indicated one millegramme. The whole science of measuring and weighing is scarcely sixty years old. The just determination of the composition of the atmosphere cannot, therefore, be older.

Besides some older experiments by Scheele, Priestley, Cavendish, and Horace Benedict de Saussure, those of Volta, De Marti, Spallanzani, Berger, Configliachi, Dalton, Humphrey and Edmund Davy, Biot, Gay Lussac, von Humboldt, Brunner, Theodore de Saussure, Verver and Dumas, have been mainly useful, in determining the composition of the atmosphere.

At first this composition was thought to be variable. Instruments were invented to determine the amount of oxygen in the air. According as the proportion of oxygen was large, the air was thought better adapted for respiration. Hence these instruments were called *eudiometers*, that is, measures of the degree of the air's adaptation for that specific purpose.

The invariableness of the mixture was first stated in the year 1804, by von Humboldt and Gay Lussac, who, during the months of November and December, in dry as well as in moist or rainy weather, and during various states of the wind, collected the air of Paris, above the Seine, and subjected it to eudiometrical examination. In 29 experiments, made on 29 different days, the largest quantity of oxygen they found was 21·2, the smallest 20·9. The difference between these two numbers lies within the limits of the ordinary errors of experiment.

Since a constant composition, namely, 21 of oxygen to 79 of nitrogen, was thus assigned to the atmosphere by men of so high reputation as von Humboldt and Gay Lussac, it has scarcely ever been questioned. Their results have been confirmed by those of most succeeding experimenters.

Thirty years later, the air round and within Geneva was examined in an entirely different way by Theodore de Saussure. For this purpose he employed finely divided lead, which diffused through water, he agitated with the air under examination; a method which was followed in London, a few years ago, for manufacturing white lead.

By thus agitating air with moistened lead, de Saussure combined its oxygen with the metal, and thus nitrogen only remained. From his experiments made with air, collected over the Lake of Geneva, and at Chambeisy, it appears, that during very various winds and states of the weather, the minimum of oxygen was 20·98, and the maximum 21·15—the average of a great many experiments being 21·05.

The same results were obtained by Gay Lussac, who, on his ascent in a balloon, brought with him air from a height of 21,430 feet; by von Humboldt, who analyzed air from the Antisana, a mountain of 16,640 feet high; by Gay Lussac and von Humboldt, with air from Mont Cenis, at a height of 6,170 feet; and by Configliachi, from the Legnone, a mountain 8,130 feet high. Finally, Dumas has recently found the same results confirmed, when air is passed over red-hot copper, and the nitrogen is collected.

Not only pure, but impure air also, has been found to give, after the foreign ingredients were separated and subtracted, 21 to 79 as the proportions of the two gases, in the remaining mixture of oxygen and nitrogen. For example, Configliachi examined the air collected over rice fields,—Seguin, Gay Lussac, and von Humboldt, that which was collected in a theatre at Paris, filled with people,—E. Davy, that from hospitals,—Theodore de Saussure, that from a bed-room in the morning. All these specimens of air showed no variation whatever in the amount of oxygen and nitrogen, provided the foreign mixtures were previously separated.

But, according to Levy, this composition is not invariable. He found, for instance, in the air of Guadaloupe, collected by Deville from different places, the following per centage of oxygen by weight:—

November	28,	1842,	22·68	oxygen.
"	23,	"	22·85	"
"	29,	"	23·00	"
"	20,	"	23·03	"
"	27,	"	23·04	"
"	21,	"	23·05	"
"	23,	"	23·14	"

The air at Copenhagen gave, from the 17th of November to the 22d of December, 1841, 23 per cent. of oxygen by weight. At Elsineur, close to the sea, he found, in February, 1842, 23·037.

During a journey from Havre to Copenhagen, he collected air, which, on the 2d, 3d, and 4th of August, gave 22·6 of oxygen.

Levy ascribes this difference to oxygen, given off by Infusoria, which are occasionally found in sea-water, (see below.) But it may be asked, if that difference ought not to be ascribed rather to error in his experiments?* It is safer, therefore, at

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* See Journal de Chemie et de Pharmacie, May, 1844, p. 212.—Morren, however, has lately, to a certain extent, confirmed the results of Levy. He found that air, collected on the immediate surface of large ponds of sea-water covering many sea-weeds, in the middle of a clear and very calm, sunny day in April, contained 23 per cent. of its bulk of oxygen. This excess of oxygen he attributes to the rapid escape of bubbles of oxygen gas from the surface of the water, and of the green plants beneath it under the influence of the sun's rays. Of course, this gas will soon mix with the surrounding air, and at a very small distance from, or height above, the water, all sensible difference in the per centage of oxygen should disappear. See Annales de Chem. et de Phys., xii, p. 34.—J.

present to consider the composition of the atmosphere to be constant in so far as regards the relative proportions of the oxygen and nitrogen.

Yet we ought not to conclude positively, that the proportion of oxygen and nitrogen never changes. All we are warranted to infer is, that the existing variation lies beyond the reach of observation; that the causes of disturbance are not greater than those by which the difference is made up; that in walled rooms the disturbed equilibrium is much too quickly restored by the draught of air, to admit of its being observed; that in open air the winds quickly supply whatever portion of the oxygen may, by various circumstances, be abstracted.

The quantity of this oxygen is indeed astonishing. If we assume the height of the atmosphere to be a geographical mile, that is, 22,843 feet;—if we bear in mind, that the radius of the earth is 860 of these miles, then the bulk of the air amounts to 9,307,500 cubic miles, that is, a cube of which the side is 210 miles; so that, there being 21 per cent. of oxygen, the earth is surrounded by a quantity of this gas, equal to a cube of which the side is 125 miles;*—an astonishing quantity, indeed, in which small disturbing causes must necessarily escape our observation.†

2. The amount of carbonic acid in the air is pretty constant. It has been determined in various ways. Dalton agitated a known volume of air with lime water, and weighed the quantity of carbonate of lime he got. Thenard employed baryta water for the same purpose. Theodore de Saussure took a small bottle containing baryta water, and suspended it in a balloon filled with air. Brunner transmitted air, by means of an aspirator, through sulphuric acid, moistened lime, and again through sulphuric acid, and weighed the two latter substances, contained in a proper apparatus.

In 1827 and 1829, de Saussure made 225 experiments, to determine the proportion of carbonic acid in the air. He found, by 104 experiments with the air of Chambeisy, a small village near Geneva, that the quantity of carbonic acid in

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[*] Of the miles here spoken of, there are 16 to a degree; each is equal nearly to 4½ English miles.—J. [The side of the cube of oxygen in English statute miles, will be 540½ miles.—S.]

[†] Poggendorff, in Handwörterbuch, I, S. 562.

10,000 parts of air was, on the average, 4·15, the minimum being 3·15, the maximum 5·74. This difference is too great to be ascribed to errors of observation. De Saussure further found, that during the day the air contained less carbonic acid, than during the night. He found, during the day, an average of 3·38, during the night, of 4·32; the maximum during the day was 5·4, during the night, 5·74. With slight winds at mid-day he found a smaller quantity of carbonic acid than when the wind was violent;—in the former case, 3·76, in the latter, 3·98. The quantity of carbonic acid was diminished less by violent showers, than by continued gentle rains. The quantity was greater over cultivated grounds, than over the Lake of Geneva; at Chambeisy, he found 4·60, when the air above the Lake of Geneva gave him 4·39. In 30 observations, which he made simultaneously at Chambeisy, and in a street of Geneva, he found the proportion in the air in the neighborhood of Geneva, 4·37; in that of the town itself, 4·68, showing a larger quantity of carbonic acid in the latter place. Finally, he found that on mountains the air contained somewhat more carbonic acid, than in the lower regions of the atmosphere; the difference, however, was very small.

The same experiments were repeated by Verver, after the method of Brunner, and his results confirmed those of De Saussure.*

3. We must here advert to the quantity of ammonia in the atmosphere, which is considered by Liebig† of such great importance to the growth of plants. It frequently happens, that traces of ammonia are found in rain-water; but its quantity is so very small, that Liebig himself could obtain only a trace from many hundreds of pounds of rain-water. In another

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* Verver's results, obtained at Groningen, give 4·2 parts in 10,000, his maximum being 5·1, and his minimum 3·5. Since these were published, an elaborate series of observations has been published by Boussingault. The mean for nine months, according to his observations made in Paris, was 4 parts in 10,000, the minimum being 2·2, and the maximum 6·7. A series of 16 experiments, made on the same successive days in September and October, 1843, and at the same hours, by Boussingault in Paris, and Levy at Andilly, near Montmorency, gave for the carbonic acid in the air of the city 3·19, and in that of the country, 2·989. This is in accordance with the result of de Saussure.—Ann. de Chem. et de Phys., x, 66, 462, and 472.—J.

† Organic Chemistry applied to Agriculture.

work* I have shown it to be impossible that plants should obtain their nitrogen from that source—that the quantity of ammonia in the atmosphere is exceedingly small—and that, in fact, it should not take any higher rank as regards organic nature, than the many other substances accidentally mixed in minute quantity with the atmosphere, and which are really innumerable. I shall recur to this point, however, in treating of arable soil. For the present, it may be enough to remark, that the atmosphere contains a quantity of ammonia which as yet it has not been found possible to weigh; and which to organized nature, is but of secondary importance.

4. The quantity of water in the atmosphere varies considerably, at different times and in different places. It is, besides, dependent on the temperature of the air, and of the water evaporating from the earth's surface. The air being in contact in one place with large collections of water, which are continually evaporating, and in another with dry, arid ground, this variation must be considerable. The continual rising of currents of air, causes the vapors which are diffused through the atmosphere, to form clouds, that is, utricular vapors, which float in the atmosphere at a height of from 5,000 to 20,000 feet, according to the latitude of the place. By the ascent of these, the lower parts of the atmosphere are deprived of their aqueous vapor, the quantity of which is thus dependent on the source and temperature of the evaporating fluid, on the temperature of the air, the velocity of the wind, and many other causes. Atmospheric air is never quite dry, as it is never quite free from carbonic acid. To some substances this moisture obstinately adheres; others absorb it gradually and become liquid; while others again are changed in their nature through its influence. For instance, the rusting of metals is a combined effect of the moisture of the atmosphere, of its carbonic acid, and of its oxygen. In a word, an acquaintance with the quantity of aqueous vapor in the atmosphere is of the greatest importance to a right knowledge of its peculiar properties.

The proportion of aqueous vapor has been determined by Verver for the Netherlands. In 1,000 volumes of air he found the minimum 5·8; the maximum 10·18; the former on the

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* Scheikundige Onderzoekingen, Deel II, p. 78.

24th of August at 10 o'clock, A. M.; the latter on the 4th of May, at 11½ A. M. The average of 50 observations, during May, August, and September, was 8·47. From an early hour in the morning to 10 o'clock, A. M., it was 7·97—from 10 to 2 o'clock, P. M., 8·58—and from 2 o'clock till the evening, 8·85.*

5. Finally, Boussingault, Verver, and others, have shown the presence in the atmosphere of other substances, which contain hydrogen and carbon. Boussingault and Verver passed atmospheric air, *freed from carbonic acid*, over red-hot copper, and obtained small quantities of water and carbonic acid. By means of the oxygen of the air, the hydrogen and the carbon—no matter in what state they existed in it—would be changed into water and carbonic acid, while passing together over red-hot copper.

We cannot determine in what state this hydrogen and carbon are contained in the atmosphere; they may be so, in the form of hydrogen gas, carburetted hydrogen, and carbonic oxide, or possibly in that of volatile organic substances. As to this point, nothing has yet been ascertained, nor can it be determined by such experiments as these. It is certain, however, that, before the constituents of organized bodies are reduced to their most intimate combinations, they can assume a great many intermediate states—supplying the atmosphere with either solid, liquid or gaseous products. Thus, in every kind of putrefaction, peculiar volatile substances are diffused through the air, which may contain the four organic elements combined in various ways. Further, in a great many diseases—such, for example, as cause eruptions on the skin—volatile compounds escape from the patients, and are diffused through the atmosphere.† Many substances, also, which, both at ordinary and at more elevated temperatures, are regarded as fixed and not volatile, are constantly emitting particles in a state of vapor, and diffusing them through the atmostphere

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* Bulletin, 1840, p. 191.

† See on this subject the elaborate treatise of Dr. J. Van Geuns, Natuur-en Geneeskundige Beschouwingen van moerassen en moerasziekten. Amsterdam, 1839. (Physical and Medical Considerations on Marshes and Marsh Diseases. Amsterdam, 1839.) Mülder's Verhandeling over de Wateren en de Lucht van Amsterdam, (Treatise on the Waters and the Air of Amsterdam,) p. 163, may also be consulted on this subject.

—such for instance are potash, soda, and even iron, when smelted in blast furnaces. Thus, the atmosphere must contain not only substances consisting of carbon, hydrogen, nitrogen, and oxygen, but a great many others besides, which it would really be of importance to investigate, but on which it is unnecessary for our present purpose to dwell.

We are therefore entitled to state, as a general result of this brief enumeration of the component parts of the atmosphere, that besides a countless number of accidental ingredients which are continually carried down again to the earth by the rain, the chief constituents of the atmosphere are a mixture—nearly constant, so far as we are able to observe—of 21 parts of oxygen and 79 of nitrogen by volume, a variable proportion of aqueous vapor and a quantity of carbonic acid, which amounts on an average to something less than half a thousandth part.

Two great causes of disturbance are continually at work to diminish the quantity of oxygen in the atmosphere, namely, the respiration of animals and combustion. By these processes, vast quantities of oxygen are consumed and combined with carbon into carbonic acid. We shall afterwards inquire, how far these causes may tend to change the composition of the atmosphere ; at present we only remark, that those two disturbing causes are opposed by a third, which, if the equilibrium be disturbed, may restore it again, namely, the decomposition of the carbonic acid by plants, and the separation of oxygen by their green parts. This decomposition is one of great importance. While the larger animals by their respiration continually extract oxygen from the atmosphere and give off carbonic acid, plants on the other hand absorb carbonic acid and give off oxygen ; this evolution of oxygen being their action during the transformation of the nutritive substances which they have absorbed, and among which carbonic acid is one of the most important—into other compounds, either containing little oxygen, or altogether destitute of it. In relation to the atmosphere, therefore, the larger animals and plants are directly opposed to each other, and we shall afterwards treat of their several functions in this respect.

To this generally acting cause, tending to restore the equilibrium previously disturbed by respiration and combustion, a second remains to be added which is of no less importance, though of less extensive influence than the green parts of plants. I refer to the very remarkable observation made by Morren,* that not only plants but also some kinds of animals, very simple in their structure, give off oxygen when exposed to the rays of the sun. After a great many analyses of the air contained in different kinds of water from wells, from stagnant pools, and from marshes, it appeared to him, that such of the latter as contained a greenish minutely divided substance, gave off a considerable portion of oxygen—so that, according to his calculation, from a bulk of water of 8,000 cubic feet in favorable circumstances, 128 cubic feet of oxygen were given off into the atmosphere in a single day. This production of oxygen was dependent on the sunshine, and reached its maximum on a clear summer's day, about four or five o'clock in the afternoon. The quantity of gas, during its strongest evolution, was considerably diminished by the interposition of a piece of black cloth. He found the largest proportion of oxygen in 100 parts of air from the water, to be 61 ; the smallest, 16 to 17.† The green substance to which this disengagement of oxygen was to be ascribed, he found, when observed through the microscope, to consist for the most part, of the *Enchelis monadina virescens sulesphænea* of Bory de St. Vincent, occasionally mixed with the *Enchelis pulviscula viridis* of Müller, the *Monas bicolor* of Ehrenberg, &c., which are small monads—animalcules therefore performing the same functions which are usually performed by plants.

From the smaller proportion of oxygen obtained during the night than during the day, a deviation which always depended on the quantity of these green animalcules in the water, Morren drew the conclusion that they decompose the carbonic acid contained in the water, retaining and living on the carbon in the same manner as plants do ; whence it is to

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* Annales de Chemie et de Physique, Avril, 1841, and Biblioth. Univers. Novemb. 1841, p. 386.

† Morren states the very interesting fact, that when, in June, 1835, the air in the waters of the river Marne, a slow flowing river, contained only 18 per cent. of oxygen, great numbers of particular kinds of fish perished. How beautifully does this prove the wise purpose for which the air, in our rivers and seas, has been made to contain so large a proportion of oxygen !—J.

be presumed that their chemical constitution may nearly resemble that of plants.

Morren obtained the same result from other microscopical animalcules, which were not green, but red; the proportion however which they gave off, reached a maximum 47 per cent. only. These animalcules were the *Tracholomonas volvocina* of Ehrenberg, of a beautiful red purple color. The green color of the former, therefore, has no relation whatsoever to the quantity of oxygen evolved. The difference between the quantities of oxygen, produced by both kinds of animalcules, may be ascribed to accidental causes.

Wöhler has made the same observation. In the salt-water springs of Kur-Hesse, a green mucilaginous matter is formed during the summer's heat, in which great numbers of air-bubbles appear. These bubbles contain 51 per cent. of oxygen, and 49 of nitrogen. The green matter consists almost entirely of species of Navicula and Gallionella, mixed with fibres of Confervæ—in a word, for the most part, of Infusoria.*

In this, therefore, a new source of purification to the atmosphere has been discovered. Not only do plants decompose the carbonic acid, but the countless multitudes of Infusoria, which are to be found in stagnant waters, act as auxiliaries to the plants, in decomposing carbonic acid and extricating its oxygen.†

It is almost certain, that the atmosphere has always consisted of nearly the same constituents as at present. I do not here refer to what it might have been in another order of things; I allude only to the state in which it has existed since the last great geological revolution, and especially since the dispersion of man over the earth's surface. Much too

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* Annalen der Chemie und Pharmacie, 1842.

† Morren has more lately found that the air in *sea* water, which, when the sky is obscure, contains 33 per cent. of oxygen, contains more after some hours of bright sunshine, and varies between 31 and 39 per cent. It is least in the morning and in cloudy weather, and greatest after mid-day, and in prolonged bright weather. The whole sea, therefore, may be considered as a constant purifier of the air, removing its carbonic acid and renewing its oxygen. It does not appear, from Morren's researches, that *visible* infusorial animals are necessary to this action on sea-water, as, in the water he examined, the microscope showed the presence of very few Infusoria. Is the effect produced by animals too minute even for the microscope?—J.

short a period has intervened since eudiometrical experiments were first made, to admit of any positive conclusion being drawn; but there are other grounds which seem to warrant the inference, that the proportion of oxygen to the nitrogen of the atmosphere, as now known, is as old as the existing state of things, or, at least, may at first have but slightly differed from what we find it now;—it being probable, also, that previous to that time, the atmosphere was entirely different from what it is now.

It is not to be denied, that the carbonic acid, which is discharged into the air by animals and by combustion, is decomposed by plants. They decompose the amount supplied to them from these sources, and disengage its oxygen. They cannot decompose more. Thus vegetation, or the number of plants, depends on the quantity of carbonic acid in the air, and conversely upon the number of plants depends the quantity of oxygen which is liberated from the decomposed carbonic acid;—and thus the life of animals depends on the number of plants.

There are some plants which live entirely on what they receive from the atmosphere, without drawing any food from the soil, except some inorganic salts and bases. To these belong, among others, the lichens and mosses, with which the bare rocks are covered, and which grow in inaccessible places, where no change has ever been effected by the hand of man, and no natural deposit has ever been made. To these further belong many phanerogamic plants, the so-called fatty plants, (*plantes grasses*,) a great many Cacti, Euphorbias, Sempervivum, &c., and a great many of the false parasitical plants, which are fixed to trunks and branches of trees, by means of their own roots, and do not draw any of their food from them.*

It cannot be ascertained how the germs of the lichens and mosses have first been produced, or originally brought to their present place. It is sufficient for us that they do exist, and that they grow by means of the atmosphere.

A vegetation of this kind must necessarily have preceded the present one; for there was a time when no soil existed,

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* Miguel, Bulletin, 1838, p. 86, Pl. I, fig. B.

and its organic parts, together with those of animals and plants, were constituents of the atmosphere.

The first plants which grew upon the earth, but no longer exist in a living form—though they have been accurately determined by geology from their remains—could have found no humus, but must have derived their organic constituents from the atmosphere. Among them are found gigantic productions, which so resemble the existing vegetation in structure, that it may be assumed as certain, that the function of nourishment has never been subjected to other laws than those which we recognize in the existing vegetation. At that time, in the primitive world, the naked rocks must have been covered with gigantic Equisetaceæ, Lycopodiaceæ, arborescent ferns, and pines.*

Plants which now live on the atmosphere require carbonic acid, water, and nitrogen; the last of which, by the decomposition of water, gives rise to ammonia, under conditions of which we shall afterwards treat. (See *Arable Soil.*) In this manner they obtain carbonic acid, water, and ammonia, in which they find all their nourishment; the atmosphere cannot give them more; and as they live on nothing but carbonic acid, water, and nitrogen, in the form of ammonia, they must be able to prepare from these substances their several peculiar constituents.

If we suppose such plants as now grow upon bare rocks, to be planted in a stony soil within an enclosed space, and sur-

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* Bronn, Lethæa Geognostica, 1 Bd. Brongniart, Prodrome d'une Histoire des Vegetaux Fossiles, Paris, 1828.

It may reasonably, I think, be doubted, whether observed facts in geology bear out this opinion of Mülder in regard to the entire absence of a vegetable soil in those remote times when the trees referred to flourished on the earth's surface. The dirt-bed on the Isle of Portland, and other localities, which lies between the marine deposits of the Oolite and the fresh-water strata of the Wealden, is an ancient soil in which many trees grew, and the clays on which nearly all our beds of coal, without exception, rest, and in which so many roots are found, is no doubt the soil in which the vegetation of that epoch was fixed. Trees are known now, both in our own and in warmer and drier climates, to grow occasionally on naked rocks; but woods and forests grow only where a soil exists. In the absence of any facts to the contrary, therefore, it is safer to believe that, in the early geological epochs, when terrestrial vegetation prevailed, vegetable soils also were gradually produced.—J.

rounded by an atmosphere of carbonic acid, aqueous vapor and nitrogen, from which last, ammonia may be produced by the decomposition of the water—then these plants will decompose the carbonic acid, and give off the oxygen ; and from the ammonia, the carbon, and part of the carbonic acid left behind, as well as the water, several vegetable substances will be produced, which will adhere to the stony ground. The further the decomposition of carbonic acid and the condensation of nitrogen proceed, the better do plants grow—the greater is the amount of the four organic elements, which they fix to the stony ground ; and the greater also the amount of oxygen which is mixed with the surrounding nitrogen, carbonic acid, and aqueous vapor.

If the plants, after the seed is matured, die within this enclosed space, then they putrefy, and organic humus-like substances are left behind. The decomposition of these substances proceeds still farther, and the products are carbonic acid, which is diffused through the air, and ammonia, which remains intimately combined with the humic substances of the soil. In these decaying substances, the seed sprouts and grows to a small plant ; the carbonic acid from the air, and the ammonia formed from nitrogen and aqueous vapor, are decomposed by the young plant ; the latter thereby is advanced in its growth, gives off oxygen, and produces new organic substances, which again form constituents of plants. These plants putrefy in their turn, and so this rotation is continually going on. The production of plants cannot exceed the supply of the substances on which they live ; they can only rise to a height proportioned to the quantities of food afforded them, which existed originally in the air in the state of gas. The nitrogen which was in the enclosed space, along with carbonic acid and aqueous vapor, thus becomes mixed with oxygen on the first decomposition of the carbonic acid by the plants ; and this process is continued, till there is no more carbonic acid to be decomposed. Then the oxygen attains a maximum. When the dead plants decompose, their carbon at the same time takes up oxygen, and thus the quantity of the latter again falls towards a minimum, which is attained when putrefaction is completed, and young plants rise from the germinating seed. In such a limited space, the largest quantity of oxygen and the smallest of carbonic acid and nitrogen would exist, when the plants had attained the period of most luxuriant growth; on the contrary, the smallest quantity of oxygen and the largest of carbonic acid and nitrogen, would exist when the dead plants had reached the highest degree of putrefaction.

If we suppose that in the enclosed space, in which the stony ground is already covered with a layer of humic substances, and which contains ammonia and oxygen in the state of gas already mixed with the nitrogen, aqueous vapor, and carbonic acid—if we suppose that in this space the seeds of other plants are present, these will rise and attain a luxuriant growth, and will add to the condensation of carbon, hydrogen and nitrogen from the surrounding gases, and to the disengagement of oxygen into the air.

Suppose now that at this point we enclose certain animals along with the plants, in the same limited space in which the latter have already mixed the nitrogen with oxygen, then the former will inhale the oxygen, and will substitute for it nearly an equal bulk of carbonic acid. The amount of carbonic acid in the enclosed space being thus increased, is again given to the plants for decomposition, which thereby grow more luxuriantly, and restore again a large quantity of oxygen. If these animals eat of the plants thus enclosed with them, a portion of the latter will be deprived of the power to decompose carbonic acid: but these animals soon give off their excrements, which putrefy, and produce carbonic acid and ammonia from the vegetable nourishment carried through the animal body. These new products are again offered as nourishment to the plants, which thereby grow and may again serve as food for other animals.

Finally, if we kindle a fire in the enclosed space after the oxygen is introduced, then the carbon of the burning organic substance will be changed into carbonic acid by the combustion, and in this way also food will be prepared for the plants.

If the supposition above made be applied to the whole atmosphere, all the operations described remain the same. At the creation of the most ancient order of things, there might or might not be oxygen in the atmosphere. If there were carbonic acid, nitrogen, and aqueous vapor, then, at the very first traces of this peculiar vegetation, of which so many indications remain, the plants must necessarily have absorbed carbonic acid and ammonia—formed from nitrogen and aqueous vapor—and so oxygen must have been diffused through the atmosphere. With the increase of vegetation, the carbonic acid and the nitrogen would gradually lessen in the atmosphere. The quantity of both would fall towards a minimum, while that of the oxygen would rise towards a maximum—the constituents of the primitive atmosphere being more and more condensed into solid substances on the rocky earth.

Plants may preserve their existence, without the presence of either animals or combustion. By the putrefaction which one part of them undergoes, carbonic acid and ammonia are supplied to the other part. Except the Infusoria, all animals must have begun to live after the existence of plants, for without plants no animals could live upon the earth. The black layer of soil must have come into existence after the plants, for it can be produced by plants and animals only. Thus the substance of the organic parts of animals and plants, and of the black layer of soil, were formerly component parts of the atmosphere.

Animals must have vegetable food. As soon, therefore, as animals arose on the earth, the quantity of carbonic acid in the atmosphere, and that of ammonia in the black layer of soil, began to be increased by their respiration; and so the food for plants became more abundant. Thus vegetation must have been supported and promoted by the continual increase of animals on the earth; and the food supplied to plants from the atmosphere will still go on increasing with the increasing numbers of mankind.

At the beginning of the present condition of things, also, a very remarkable change must have been produced in the atmosphere, by the formation of the black layer of soil. The first plants, which lived upon and were nourished by carbonic acid and ammonia, either derived or prepared from the atmosphere, did not restore to the atmosphere on their decay all they received from it, but left on the earth's surface a black solid substance. As that layer increased, the atmosphere must necessarily have been deprived of the elements of carbonic acid—and of ammonia, either condensed or formed from the atmosphere by the decayed plants. And in proportion as this layer of humus increased, (as we see it at present doing on our moors and mosses,) the atmosphere would become poorer and poorer in carbonic acid and nitrogen.

That the production of a new vegetation upon arid tracts of land is now going on so slowly, is to be ascribed to the reduction of the quantity of carbonic acid to a minimum by the great number of plants which have existed. Every new vegetation fixes carbon to the ground. If drawn from the atmosphere exclusively, this carbon does not easily return, but is chiefly applied to the support of the plants which grow on the spot where the layer of humus has been deposited.

After the creation, and especially after the dispersion of the human race, a new source of transformation of the elements came into existence, in addition to what animals were already contributing to the support of vegetation. The fires employed for warmth, for cooking, &c., provided new nourishment, through which, places hitherto bare might become covered with plants, and existing vegetables might increase in growth. The coal, for instance, which lies concealed under the earth's surface, being changed into carbonic acid by combining with the oxygen of the air, continually supplies to plants a new portion of nourishment. The more coal is consumed, the more new vegetable products (viz. cellulose and other indifferent substances not containing nitrogen) may be produced.

From the nature of these reactions, it follows, that the black layer of soil is a product of the decomposition of animals and vegetables, and could not have existed before these; that the plants which existed before its formation could have no other source of food but the atmosphere;—that this food must necessarily have been carbonic acid and ammonia;—that, by the increase of plants, and of the black layer of soil, the composition of the atmosphere must have been changed, the proportion of carbonic acid and nitrogen being diminished, while oxygen took the place of the former,—that during this time the proportion of oxygen in the atmosphere must therefore have been always increasing;—that a great quantity of carbon and nitrogen, being condensed on the earth's surface, having passed into plants, into the state of humus, and into every kind of organic substance, the proportion of carbonic acid present in the atmosphere must have become very minute, and the increase and extension of plants over tracts of land, not yet cultivated, must have been thereby materially obstructed;—that then, not only the extension of vegetation had attained its highest point, but that without other and peculiar causes, by which carbonic acid was again returned to the atmosphere, it could not have been maintained at that highest point;—that, by the animals which came after the plants, the change in the constituents of the atmosphere has been considerably increased, a larger portion of carbonic acid and nitrogen being separated from the earth's surface, and brought into a state fit for being moved and transported over the earth;—that animals, by supplying new food to plants, namely, carbonic acid and ammonia, have again considerably supported vegetation;—and finally, that by the increase of the number of mankind, by their respiration, by the putrefaction of their dead bodies, and above all, by their fires, this effect has been again powerfully promoted.

Has the atmosphere, since the appearance of man on the earth, preserved the same composition as it had before? and will it at all times retain the same composition—the number of mankind being continually increasing, and that of forests diminishing?

It is not to be denied, that the quantity of carbonic acid must have become greater, and that of oxygen less, with the increase in the numbers of men, who respire and make fires, and whose dead bodies putrefy;—but, on the other hand, a great many animals, on the increase of mankind, have been expelled from the earth's surface. By the fires, however, which man has kindled, the quantity of carbonic acid has undoubtedly been increased, and that of oxygen diminished; but it is difficult to decide with certainty whether that increase in the carbonic acid would have ever become perceptible, even though the very first human beings had been able to make eudiometrical experiments. It is, however, probable, that in any given bulk of atmospheric air, they would have found a little more oxygen, and somewhat less carbonic acid, than in the present day, provided the method of investigation had been sufficiently accurate.

It is a consequence equally undeniable, that either the atmosphere will at last become infected by man, or that famine will arise on the earth. By the continual increase of man on the earth, the number of forests has been diminished. Man expels and destroys animals and plants which previously lived undisturbed. It is principally by the large forests that the great quantity of carbonic abid, resulting from combustion and respiration, must be decomposed. There must necessarily be a proportion between the number of plants and that of man and animals on the earth. The former must restore what the latter have taken from the atmosphere; the one must decompose what the other has imparted to the atmosphere. Wherever the equilibrium between the number of plants and animals is disturbed,—that is, when mankind increase and plants diminish,—then there will at last be no longer a sufficient quantity of carbonic acid decomposed, and the proportion between the oxygen and nitrogen, which we now assume to be invariable, will be altered.

It is true that a large portion of the earth, susceptible of cultivation, still remains uninhabited by man. But if, in imagination, we transfer ourselves into futurity; if we suppose the woods destroyed, the earth covered with edible plants, which reach but to a small height in the atmosphere; then we have, in imagination, reached a limit to the invariableness of the existing composition of the atmosphere, and at the same time to the existence of man upon our planet. The disappearance of the falls of Niagara and that of the human race belong to periods which, it may be, are still far distant, but which, notwithstanding, will certainly arrive, if nothing meanwhile interpose.

When will that period arrive? This is a question to which we may give an approximate answer. According to the experiments of Lavoisier and Davy, a man consumes 26·04 Paris cubic feet of oxygen in 24 hours; that is, 9,505 cubic feet a year. Let us suppose the number of men on the earth 1,000 millions, then these consume 9,505,000,000,000 cubic feet of oxygen every year, that is, nearly $\frac{8}{10}$ths of a cubic geographical mile. The whole amount of oxygen by which the earth is surrounded, is 1,953,570 cubic geographical miles.*

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* For this calculation of Poggendorff, the height of the atmosphere has been taken equal to one geographical mile, or 22,843 feet; the radius of the earth equal to 860 geographical miles, and thus the bulk of air, consisting of 21 of oxygen and 79 of nitrogen=9,307,500 cubic geographical miles. (See *ante*, p. 98, note.)

So that, if the number of mankind on the earth were always 1,000 millions, they would require 2,451,000 years to take away all the oxygen from the atmosphere. If, from the present moment, plants were to cease decomposing carbonic acid, all the oxygen of the atmosphere would be exhausted after two and a half millions of years.

By the operation of this cause, therefore, the human race will at some time be destroyed, if it should not happen to be so previously from other causes.

Whence has originated that admirable uniformity in the composition of the atmosphere, which has been observed wherever and whenever it has been investigated? First, we must not conceal, that our eudiometrical methods are not among the most accurate; so that slight differences in the composition of the air may easily escape notice. It must have been owing to an error in the mode of experimenting, for instance, that after separating the carbonic acid from the air in the pit of a theatre, where many people were breathing, the proportion of oxygen in the remainder was found the same as in the air outside of the building.* For, whence had the carbonic acid come, which is found in such air in so large a proportion? Whence could it be derived, except from the oxygen consumed? This cannot be restored immediately by the opening of doors, &c., since we should expect, that by the same cause the carbonic acid also ought to have been partially removed, though it be heavier. In such air, however, a great deal of carbonic acid was found, but no difference in the proportion of oxygen.

With the exception of these smaller errors of observation, the composition of the atmosphere is now every where constant, or nearly so.

The heavy rains, in the first place, carry to the earth many of the less important vapors. These vapors penetrate into it, either to be decomposed by plants, or to be converted into chemical compounds, in the substances of the earth's crust. Among the latter are the sulphuretted hydrogen given off by putrefaction, and many other substances, which combine with the metals of the salt-bases in the earth, and are gradually changed into salts by the influence of the oxygen of the air,

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* Gay Lussac and von Humboldt.

which is present every where. In this manner carbonic acid and the traces of ammonia, which exist in the air, are also conveyed to the small radicles of plants. And in like manner, after having remained in the ground for a longer period of time, those substances which are given off by the bodies of animals, &c., and are at first injurious to vegetation, must be decomposed and changed into new plants. (Ball, for instance,* having left the head of a Delphinus phocena to putrefy in a hot-house, found, after a time, a great many ferns, as well as other plants, in an unhealthy condition, withered, and discolored; viz. Osmunda regalis, Adianthum capillus veneris, many species of Aspidium; also Rubus corylifolius, Oxalis acetosella, &c.)

But in that air-ocean itself, another, and a much more powerful form of its uniform composition exists, namely, the motion imparted to it by so many various causes, by which, in the tropics, hot strata of air rise, direct themselves to the north and south poles, and thence extend themselves over the earth's surface, to supply carbonic acid to plants for decomposition, and the oxygen, thence produced, to man, to animals, and to the support of combustion. It is owing to this effect of the winds, which depend on the temperature, and to which a great many other causes might be added, that an intimate mixture of the constituents of the air is maintained, and plants and animals alternately receive what is indispensable to each.

It deserves particular notice, that the two chief constituents of the atmosphere—oxygen and nitrogen—are not combined chemically, but merely mixed together. If they were chemically combined, the respiration of animals would be impossible, the evolution of oxygen by plants would not restore the atmosphere to its proper state. The absorption, by the blood, of oxygen, which afterwards appears in the state of carbonic acid on the decomposition of the constituents of the blood, must be considered as a chief condition of the respiration of animals. This function would have been utterly impossible—the whole animal kingdom must have been entirely different from what it is at present, if the oxygen and nitrogen of the air had been chemically combined. During respiration, new compounds would in such a case have necessarily been formed

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* Biblioth. Univ., Nov. 1841, p. 412.

in the animal organism itself, not only from the oxygen, but also from the nitrogen, in consequence of its being in the nascent state. The whole of the nitrogen of the atmosphere would then have been included in this action, whereas it is now almost wholly excluded.

Further, plants which can now restore the disturbed equilibrium of the atmosphere by a simple separation of oxygen, would not be at all able to produce the necessary combination, were the atmosphere a chemical compound of oxygen and nitrogen. Where the combination was to take place, the quantity of nitrogen required might be deficient, and some other combination of oxygen and nitrogen might be produced; in other words, a higher degree of oxidation. In short, if the oxygen and nitrogen were chemically combined, then organic nature would require to be very differently constituted; but as it is, the operation of the winds is sufficient to make the mixture an intimate and uniform one.

Finally, the absolute quantity of oxygen and nitrogen which the atmosphere now contains, depends solely on the absence of substances from the earth, which either give to or take from this quantity, and upon the quantity originally appropriated to the formation of the atmosphere. This has not been determined after any chemical rule or natural law. But as the earth, once arid and rocky, and destitute of life, became covered with a peculiar vegetation—whose residue, coal, for instance, is astonishing—a vegetation possible only in the condition of the atmosphere as it then existed; so the greater part also of the present vegetation must be destroyed, when the constitution of the atmosphere undergoes the requisite change. Thus, every being which now has life depends for its existence on the presence of 21 per cent. of oxygen, and 79 per cent. of nitrogen in the atmosphere. Whenever this proportion is materially altered, every being now alive on the earth must die, and another series of plants and animals, perhaps a different race of rational beings also, will appear.

It is not known how many such successive changes of organized beings have already happened on the earth's surface; but that they have happened, is established as a certainty. Ehrenberg continues to make us acquainted with races of minute beings, which have powerfully contributed to the transformation of the earth's surface, and of which the influence on the condensation of the component parts of the former atmosphere must have been not less important than that of the gigantic arborescent ferns, pines, and other plants of the primitive world, of which the remains are now buried under the earth's surface, but of which the organic parts once belonged to the atmosphere.

CHAPTER IV.

WATER, CONSIDERED IN ITS CONNECTION WITH ORGANIC NATURE.

While on the one side a mixture of two gases, both in a state of constant change, are the chief constituents of the existing atmosphere—on the other, a chemical combination of two volumes of hydrogen and one of oxygen constitutes water, which performs a powerful part in organic nature, and greatly exceeds the atmospheric air in quantity. This difference between two substances, both equally indispensable to life, is of much importance. From the constituents of the atmosphere *not* being chemically combined, and from the elements of the water being so combined, many peculiarities of organic nature arise. The elements of the atmosphere, by their non-combination, afford plants the opportunity of restoring the quantity of oxygen which was changed into carbonic acid by respiration and combustion—no other phenomenon taking place than a simple separation of oxygen.

But from the chemical combination of hydrogen and oxygen in water, a series of special consequences follows in the organic kingdom. It is a known fact that when substances chemically combined are again decomposed, the action of other substances also which are contained in the circle of action, is reciprocally awakened. Wherever in the organic kingdom water is decomposed—and this frequently happens—the decomposition reacts on the substance from which the influence proceeded, and produces important chemical transformations of all the substances included in the circle of action. This chemical action proceeds, as regards water, from two elements which are both chief constituents of organic bodies.

1. The first, and a very important effect of the water upon organized substances, is, that they are moistened by it. All the organized bodies of plants and animals need water to keep them alive. That water frequently plays a chemical

part, forming hydrates with the organic compounds; but very often also it acts merely as a liquid, either to moisten, to dissolve, or to keep solid substances in suspension. We could not imagine vitality without water, or at least without some fluid which would be a perfect substitute for water. The elements of such a fluid, therefore, must necessarily be chemically combined with each other.

2. This moistening water is indispensable to keep the fleshy parts soft, to enable them to grow and be fed. The procreation of individuals is accompanied by the access of a large quantity of water; the germs of animals freely float in a liquid, that they may be able to move themselves easily, and by the ciliar motion at their surface, to produce from the water a continual renovation of substances at its surface. For the same reason, in young plants as well as in young animals whose development and growth are rapid, the amount of water in the solid parts is also much greater. Regarded from this point of view, the presence of water in the atmosphere is a most beautiful contrivance, which has an intimate connection with life. If the atmosphere were completely dry, the water of organic substances would quickly pass off by evaporation, many of them would be deprived of it, and the living being must necessarily die for want of water.

3. It is not less indispensable to life as a dissolving and a suspending fluid. For it is only by the circulation of a fluid through the existing parts of an organic whole, that the support and nourishment of the whole organism can be effected; and many of its actions rest entirely upon this process. Without water, it would be impossible for the four organic elements to form the thousands of combinations which we observe; for by its intervention the most heterogeneous substances are brought into mutual contact in the organism. Here the circulating fluid deposits some constituents, there it takes up others, making them produce a new effect at a third place;—in short, the existence of water is inseparable from that of life.

4. The service performed by the water in plants and in animals is partly the same and partly different. It is the same in so far as it forms hydrates of several compounds;—for instance, the hydrates of protein which appear in plants and animals under different forms, though always in the state

of hydrates, and those of mucilage, both of plants and animals. It is the same in so far as it keeps in suspension small particles, which are insoluble in water—such as the globules of chlorophyle in plants, and of the blood in animals; in so far as it carries dissolved substances through all parts of the organism—such as the soapy matter of Scheele in plants, the extractive substances in animals, and in both, a series of salts under various forms, and of diversified composition; and finally, in so far as it supplies to both animals and plants certain substances in a state of solution or minute division, which, being fitted to nourish, are indispensable to the existence of the organism.

5. The action of water differs, however, in plants and animals, chiefly as to the way in which it disappears again from the organic substances; by which difference, these two classes of beings are essentially distinguished from each other. In the greater part of animals, an aqueous fluid is circulated through the whole structure, and enters also into certain organs, by which a part of the substances either dissolved by that fluid or suspended in it, are separated and expelled from the body, so that the latter gets rid of these substances. In plants this process is different. They are deficient in the organs which are exclusively destined to this service, and thus retain all the non-volatile substances which have ever entered into their composition. Exposing a large surface to the air, they lose aqueous vapors through their leaves, if the atmosphere can take up aqueous vapor; that is to say, if it be dry enough for that purpose, and if the hygroscopic power of the parts of the leaves be less than the power of the air to contain aqueous vapor. Though this be by no means always the case, it is, however, a condition which often arises; so that plants, though not possessed of peculiar organs, fit for the expulsion of an aqueous fluid, yet lose, in many states of the atmosphere, almost pure water through their leaves. This function, therefore, is wholly different in plants and in animals. The latter, though they also lose water through their skin—both by exhalation through the pores, and by evaporation from the moist skin, covered with a thin epidermis—usually excrete, nevertheless, through peculiar organs (urine-excreting organs) a large portion of aqueous fluid. The leaves of plants, being possessed of stomata, and being

besides in a moist state, lose water both through their stomata and over their whole surface, and impart it to the atmosphere. As this water can differ but little from pure water, a large part of the solid substances contained in the sap of plants must remain where the evaporation takes place—the growth of young leaves, which evaporate much, being thereby materially promoted. There is thus a growth, an increase of mass, in direct connection with the evaporation of the aqueous fluid—that is, with the power of the atmosphere to absorb water. It is not to be denied, that by this evaporation of the water through the leaves and at the surface of plants, the renovation of the sap in the drying parts, and at the same time, the circulation of the sap in plants in general, is materially supported. The evaporated liquid must be restored, and besides the portion of the solid substances contained in the sap of plants, which this water leaves behind, the succeeding portion of liquid supplies a fresh quantity, which, in its turn, is left behind at the place of evaporation.

Another consequence of this evaporation and circulation is, that the ascension of new fluids through the whole plant is promoted, and so through its whole mass a new change of constituents must be produced.

6. Pure water is scarcely ever to be found at the earth's surface. Generally, it holds some saline substances in solution. These are found abundantly in nature, especially in sea-water. Without these very saline substances, animals and plants could not exist. They are as indispensable to life as the four organic elements themselves. This connection is undoubtedly not an accidental, but a necessary one. It places living nature in a peculiar relation to the so-called dead nature. If we imagine the organic parts of the serum of the blood separated from it, then there remains a saline solution, which, in many respects, approaches in composition to common water. Such coincidences are by no means accidental, neither is the necessity of common salt for animal life, and its abundance in the earth, accidental. Besides, not only in the serum of the blood, and in common water, but also in the aqueous fluid which circulates through plants, are contained the chlorides of calcium and magnesium, the carbonates of soda, lime and magnesia, and sulphate of soda, and in the se-

rum of the blood, potash salts, and phosphates also. The greater part of these salts, essential to the constitution of the serum of the blood, are found in common water, and also in the saps of those plants which are destined for the nourishment of man and animals—an arrangement which establishes an intimate connection between the subdivisions of nature, which scientific writers commonly separate too much.

By these salts, undoubtedly, an important part is played in the whole organic kingdom. It is known that the greater part of them retard chemical changes among the elements of organic bodies. By common salt, and many others of them, for example, meat is preserved from corruption. Thus, the first purpose for which salts exist in the organic kingdom, is undoubtedly to limit, in a greater or less degree, the change of materials, or to modify it here and there—which change would undoubtedly proceed much too rapidly in the animal body, consisting of parts very susceptible of change, if these salts were wanting. Some of them, for instance the alkaline carbonates, serve to dissolve the compounds of protein; others supply supports for the soft parts,—such as the phosphates of lime, and in grasses, silica,—and form chemical compounds with many organic substances; at the same time, from these and from the sulphates is derived the phosphorus and sulphur by which, in certain combinations, the organic substances are accompanied. Finally, the oxide of iron, present in the ash of plants, must be dissolved in water before it can be taken up by plants, which convey it to animals, solely in order that, through the influence of the same de-oxidizing circumstances in the organism of animals, it may enter as an organic element into the coloring matter of the blood, in the same way as phosphorus and sulphur do into many protein compounds.

All the salts, soluble in water, which are not fixed in the animal body, or whose constituents are not combined there, are necessarily carried away in the urine. We cannot imagine any reason why they should be retained in the kidneys, since they occur dissolved in the serum, and are also soluble in urine, which is an aqueous liquid. These salts must therefore, be continually, and to the same amount, supplied from without. Except common salt, they are sufficiently abundant either in animal or vegetable food, or in common water, to restore what has been lost. Man requires common salt, in addition to these, and knows, even in the most uncivilized state, how to appropriate it, and so to satisfy this want of his body.

7. The light in which water exhibits itself is peculiarly striking, when we consider, that this fluid is the medium in which a countless multitude of plants and animals live, find food, die, and putrefy; and that the substances they leave behind serve for the production, growth, and sustenance of new organized beings, in the same manner as the atmospheric air and the soil together do, for plants and animals which are said to live in the air.

More than two-thirds of the surface of our planet are covered with water. In that amazingly extended mass, multitudes of beings live. The solid part of the earth is besides intersected and diversified, in every direction, with rivers and other bodies of water, in which various plants and animals live. Being concealed from the eye by the surface of the water, and less accessible than substances on the dry land, they have less attracted the attention of the natural philosopher. This world, however, deserves to be accurately known. Who would venture to determine, whether the number of organized beings, living in the water, or in the atmosphere, is the greater?

8. By the mobility of organic substances dissolved in fluids, their displacement and their union are in the highest degree promoted. In infusions of vegetable and animal substances, small animalcules, which thence derive their generic name of *Infusoria*, are easily produced. Their existence, commonly, is of short duration, as they devour each other, and disappear, while their substance serves to produce new individuals and new forms, and is converted into infusorial plants, which, in their turn, disappear, and make room for others. In every kind of stagnant water, in marshes and ditches, wherever they are found on the earth's surface, similar metamorphoses of small organized beings occur. Their production is promoted by the stillness of the mass of water; hence they are not so frequently found either in rivers, or in more extended collections of water, or in inland seas. The innumerable multitudes of small organized beings in marshy waters, derive their birth and existence from organic sub-

stances, present in those waters. The organized beings there produced, vary with the nature of the water itself, the circumstances to which it is exposed, and the substances with which it is mixed. Previous to the existence of our present plants and animals, similar infusoria existed in innumerable multitudes: perhaps they have contributed to condense the component parts of the former atmosphere.

9. There subsists an intimate mutual connection between the atmosphere and a limited portion of water. Wherever and in whatever way a small quantity of water is prevented from escaping into the ground, if it be exposed to the atmosphere, such an accumulation of organic substances takes place, that the shallow body of water becomes at last wholly filled up. The distribution of seed causes plants to spring up within it, which—finding abundant food in the organic substances which have been produced from the constituents of the atmosphere, and deposited there, altered by infusorial animals and plants, putrefied, changed into humic acid, apocrenic acid, &c.—grow there luxuriantly, raise their leaves beyond the water, drink in carbonic acid from the atmosphere, retain the carbon, and restore the oxygen. Every shallow mass of water is thus gradually filled up with peaty soil. In ponds and ditches this happens every year, so that they require to be widened and deepened, otherwise they would soon disappear.*

We therefore observe an intimate relation between the atmosphere and the water. All the particles from the atmosphere which are washed down by the rains, are taken up by the water into which the rains fall. The great variety of substances diffused through the atmosphere, being mixed with the water, are gradually decomposed in it, and at last substances are produced similar to those which appear in the soil. (See Chapter V.)

Hence, in every confined mass of water the same substances are present as in the soil, and consequently, the plants living there are surrounded by a diluted solution of inorganic and organic salts, which are more or less the same with those of the soil. The water of ditches is colored by apocrenates, and from these is derived an abundant supply of organic food, to

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* Wiegmann, Entstehung des Torfs.

be taken up by the roots of plants, which in great numbers are floating in the water.

In the great ocean an immense number of plants grow. Besides the sea-weeds and other water-plants with which the shores are covered, the vast quantities of the Sargassum Columbi, which float on the sea like the weeds on the surface of our ditches, are for this reason remarkable. This plant feeds on the organic substances of the sea-water, of which substances the water contains so great a quantity, that it has always a yellowish color, and leaves behind a colored mass of salt after evaporation. In those large masses of water where gigantic animals live, where their excrements are diffused, and their dead bodies putrefy, an amazing quantity of organic substances is accumulated, and for the greater part dissolved, or diffused in a state of minute division.

It is certain, also, that by these water-plants, a relation between the water and the atmosphere is established. When growing, all the green plants give off oxygen, which is diffused through the water, and, by its intervention, partly through the atmosphere.

By the continual evaporation of almost pure water from the ocean, by the anti-putrescent power of the salts in sea-water, and by the continual supply of organic substances, carried by the rivers into the ocean,—the quantity of organic substances in the soil must necessarily be diminished, and consequently the quantity of food for the organized beings in the ocean, and at the same time their very number, must be increased. Thus we observe a tendency to enlarge that multitude of living beings in the ocean.

We have seen, that oxygen is given off by plants in stagnant waters, as far as they possess green parts. From this fact, and from the property which the water possesses, of absorbing oxygen more easily than nitrogen, we are forced to conclude, that the proportion of oxygen in the air which is dissolved in water, is greater than in that of the atmosphere. This was first observed in the water of the Seine, by von Humboldt and Gay Lussac, and it has been ascertained by others, in reference to every kind of water, not containing an abundance of organic putrefying substances. Instead of 21 per cent., we find 28 to 32 per cent. of oxygen in this air, dissolved by water. Hence the fishes are supplied more readily with oxygen,—the water thus impregnated flowing along the ramifications of the blood-vessels in the gills, and the carbonic acid, which at the same time is given off, being dissolved by the water. This carbonic acid is a food for plants, and thus in the water almost the same succession of changes takes place as in the atmosphere, namely, that oxygen is supplied to animals by plants, and carbonic acid to plants by animals.

It is well known, that by the plants which live upon the earth's surface and in the atmosphere, those organic substances are prepared, of which the bodies of animals are composed—for though some animals are carnivorous, yet the animal food they eat obtained its first existence from vegetable food. Such a process, however, does not take place in all the animals which live in water. First, there is an infinite number of smaller animals,—most of the Infusoria, for instance, which owe their production, growth, and increase, to organic substances, either diffused through the water or dissolved in it, as is the case with plants of the lowest orders, such as moulds. It appears, besides, that some aquatic animals, of larger size, possess other sources of nourishment than those from which the food of the larger land animals is derived. For we see that many of them, for a considerable time, live, increase, and grow, in a small enclosed quantity of river-water, provided only it be gradually renewed by fresh river-water. It may be that they can be satisfied with little food, but whence do they derive that small quantity ? Whence, if not from substances similar to those on which plants subsist—from organic substances in a state either of minute division or of solution, of which a small portion is present in the river-water. A familiar example of this kind we have in the common leech.

On this point, therefore, considerable obscurity still involves the economy of those animals that live in the water, which science is as yet unable to clear up. And though, among these animals, there are some herbivorous and others carnivorous, it is more than probable that many, like plants, can change organic substances, when minutely divided, into food. Perhaps from these organic substances infusoria are formed in the first instance; then the larger-sized animals devour these, and so are nourished in the same manner as land animals are, upon vegetable and animal food.

CHAPTER V.

RELATION OF THE SOIL TO ORGANIC NATURE.

FROM what has been already stated, it is obvious that the black matter of the soil, with which the earth is covered—to the depth, in many places, of several feet, in others of a few inches, but which is often also entirely wanting—is the production of plants and animals. In fact, we perceive the formation of substances, similar to those of which its chief constituents are made up, from the products of the decomposition of organized beings, and we do not see it formed in any other way. We are, therefore, sufficiently entitled to assume, that these substances, wherever they are present in the earth's crust, have always been produced by the condensation of substances from the atmosphere through the intervention of animals and plants. There are other considerations, also, which lead to the same conclusion. Thus where neither plants nor animals exist, this black soil is not to be found; and on the other hand, where plants and animals exist in abundance, its quantity is materially increased. It is thus augmented by the plants which grow upon our dry heaths, and which, in reality, contribute, in a considerable degree, to the elevation of the ground. The water-pools, also, of the Old Netherlands, which in former times were at some periods of the year 40 or 60 feet deep, and of which a great part of the lower districts of the country consisted, have been filled up, and changed into habitable ground, by means of other races of plants and their decomposed remains.

The black layer of soil, so far as it contains organic substances, in whatever part of the earth we suppose it to exist without the interference of art, has therefore been produced by substances which were condensed from, and at one time formed part of, the atmosphere. It constitutes an intermediate link between the atmosphere on the one hand, and plants and animals on the other. Were we to adopt the practice now generally followed, of calling water, carbonic acid, ammonia, oxygen, and nitrogen, *inorganic* substances—a practice, however, which I consider inconsistent with accuracy and propriety—then surely we could not attribute the formation of the black matter of the soil to any thing but the so-called organic substances. Its elements are combined in the same way as cellular fibre, starch, gum, and sugar—as every other organic substance. From this point, undoubtedly, proceeded the first and sustaining causes of the movements to which the molecules in plants and in animals are subjected. The change of constitution, which takes place in its elements, is unquestionably transferred to the plants, which require a larger or smaller portion of it to be supplied to their roots for their luxuriant growth; and the same molecular motion passes afterwards from plants to animals. The soil, therefore, is, as I have said, an intermediate substance between the atmosphere on the one hand, and plants and animals on the other, through which that peculiar circle of chemical action, usually called organic action, is kept up. Some plants, it is true, may grow without soil; but it is also true, that almost all existing plants *require* to be fixed in the soil for their vigorous growth; and though their growth may not be in proportion to the amount of organic substances in the soil, still, a certain quantity of them appears to be required for the growth of many plants,—a fact well known to every one at all acquainted with horticulture. Hence, undoubtedly, carbonate of ammonia alone is not an adequate food for plants in general, though it may be the only food of some, if in certain circumstances it be supplied to them by the soil. The continual decomposition of the substances in the soil is thus a principal cause of the molecules in plants being put in motion—a motion which is transferred by them to animals. Without this continual decomposition of substances in the soil, many plants which now exist would disappear from the earth. This continual decomposition, therefore, is a service performed by the black soil, which is altogether different from what is called the *supplying of food* to plants.

The earth, which at first was surrounded by a mere atmosphere, and had nothing but rocks and water—and not even these at the very beginning—on its surface; which was a dead and arid mass, covered with fogs, and studded with volcanoes and lofty rocks, has been exposed to a great number of alterations on its surface. Soon after the water had been condensed, the influence of air, light, and moisture made its rocks crumble down and decay, the winds dispersing their *debris*, the water carrying them away, &c., by which processes the angular parts of the earth's surface would necessarily become rounded. In this manner, the exterior crust of the earth has been covered with many pulverized or granular substances. These must be a mixture of the fragments of those rocks which were most elevated above the earth's surface, and therefore, of silica, of salts of lime, magnesia, soda, and potash, and of alumina, oxide of iron, and oxide of manganese, combined with the acids of the same salts—with carbonic acid, sulphuric acid, phosphoric acid, and chlorine. In different parts of the earth, this external, decayed, powdery substance must be different,—no sufficient cause in most cases existing to move it far from the place where it was first formed. From the heights, from the mountains, or rocks themselves, they must have been carried down to the lower districts in the neighborhood; but there they must have remained, until carried forth elsewhere by powerful revolutions. Hence the difference of the inorganic substances on the earth's surface,—a difference dependent on the nature of the rocks, the decaying surface of which was crumbled down. This decay is still going on, and the surface of the globe, originally angular, has been gradually rounded; the crumbled rocks are still widely dispersed by winds and streams, and by them the depths and valleys of the earth's surface are filled up. The high mountains, covered with eternal snow and ice, will follow at the last. After their bases have been worn down and undermined by the action of water, they, in their turn, being overthrown and transported into the lower parts of the atmosphere, will be subjected to the ordinary influences which tend to round the earth, and will be finally broken to pieces and levelled.

Of these decaying rocks, some are very well known, namely, those from which clay originated—that very generally diffused substance, which is so valuable for the growth of plants. This clay is produced from feldspar, albite, and porcelain spar.

Feldspar, . $KO, SiO^3 + Al^2O^3, 3(SiO^3)$
Albite, . $NaO, SiO^3 + Al^2O^3, 3(SiO^3)$
Porcelain spar, $NaO, SiO^3 + Al^2O^3, SiO^3 + 3(CaO)2(SiO^3) + 2(Al^2O^3, SiO^3)$

From these silicates of potash, soda, lime, and alumina, while decaying—that is, while influenced by the action of water and carbonic acid—part of the silica, together with the potash or soda, is washed away by the rains, and silicate of alumina, free silica, as well as undecomposed feldspar, albite, or porcelain spar, mixed together as clay, in the state of a fine powder, are carried down to the rivers or valleys, by the rains or melted snows.

It is chiefly the feldspar, so generally diffused, which is of importance here. Together with silicate of alumina, quartz, mica, free silica, free alumina, a little chalk, and oxide of iron, &c., it may be considered as mainly constituting common clay —mixed, however, with a great many other substances, which are met with by the clay in its course, and while it is suspended in the water. The part of these rocks, which, on their crumbling down, becomes soluble in water, supplies the salts of the common river-water.

The inorganic constituents of the arable soil have an unlimited influence upon the organic kingdom. Animals obtain their inorganic constituents partly from the water they consume—by which they have been washed out and taken up from the decayed rocks,—and partly from plants, which again extract their inorganic constituents from the earth's crust. Hence, we perceive an intimate connection between the organic kingdom, and the composition of the upper layers of the earth's surface.

We cannot here present a complete view of the nature of those substances; a few remarks, therefore, must suffice.

Every thing on the earth's surface, which is exposed to the influence of air, water, light, and heat, loses its cohesion, and crumbles down more or less. This is what we call decay.

If the decaying rocks are destitute of what are more properly called metallic oxides, such as those of lead, copper, &c.; but, on the other hand, contain compounds of silica, alumina, and oxide of iron, mixed with salts of potash, lime, magnesia, &c., they then may favor vegetation. The growth of certain groups of plants may be promoted by such decayed minerals as contain what those groups require; the growth of other groups by the constituents of other rocks.

It is, therefore, of the highest importance to become acquainted with these decayed rocks, which exist almost every where on the earth's surface. Those pulverized substances are but seldom found on the spot where they originated. They are carried along with the water, floating down from elevated places. Hence, it is often very difficult to indicate their origin with accuracy; for this reason, also, they are generally mixtures of various decayed rocks.

It is clear that the products of decay must vary with the nature of the minerals from which they are derived. But when silicates, however composed, are acted upon by moist air and carbonic acid, the silica is separated, and carbonates are produced.

This is the case, not only with the generally diffused feldspar above mentioned, but also with clay-slate, basalt, porphyry, and many other minerals of frequent occurrence. Along with the silicates of alumina, potash, soda, and lime, found in feldspar, the silicates of iron and manganese are also present. When these silicates decompose, the bases are converted into carbonates, and silica and alumina are separated. This applies to all the silicates which are soluble in water. But even upon those which are insoluble in water, the same decomposing action is exerted by moist carbonic acid, and so they fall to a powder, which becomes the basis of the vegetable world. From this basis water takes what is soluble, and in that state supplies it to plants.

The silica which has been separated is in part taken up by certain salts, which are soluble in water; namely, by the alkaline carbonates. Through their means it is held in solution by all water, both upon and within the earth's surface, and is thus conveyed into the roots of plants.

All these mixed silicates of alumina, lime, potash, soda, and oxide of iron, produce fertile soils. Not only have they the property of absorbing and holding water, but they commonly retain also a large quantity of alkali,—especially if the original mineral is not entirely decayed,—which alkali they supply to plants.

I will select, as examples, three specimens of clay from one country (the Netherlands), taken from the Zuiderzee, analyzed by E. H. von Baumhauer:—

	First.	Second.	Third.
Insoluble quartzose sand, with alumina and silica,	57·646	51·706	55·372
Soluble silica,	2·340	2·496	2·286
Alumina,	1·830	2·900	2·888
Peroxide of iron,	9·039	10·305	11·864
Protoxide of iron,	0·350	0·563	0·200
Protoxide of manganese,	0·288	0·354	0·284
Lime,	4·092	5·096	2·480
Magnesia,	0·130	0·140	0·128
Potash,	1·026	1·430	1·521
Soda,	1·972	2·069	1·937
Ammonia,	0·060	0·078	0·075
Phosphoric acid,	0·466	0·324	0·478
Sulphuric acid,	0·896	1·104	0·576
Carbonic acid,	6·085	6·940	4·775
Chlorine,	1·240	1·302	1·418
Humic acid,	2·798	3·991	3·428
Crenic acid,	0·771	0·731	0·037
Apocrenic acid,	0·107	0·160	0·152
Humin, vegetable remains, and water chemically combined,	8·324	7·700	9·348
Wax and resin,	trace	trace	trace
Loss,	0·542	0·611	0·753
	100·000	100·000	100·000

On considering the constituents of these clays, it will be clearly seen, how valuable they are for the growth of plants, and how many substances—which are really constituents of plants—are contained in them. This clay, like all the other species in Holland, derives its origin from the Rhine countries, and is thus a product of decayed rocks.

The sulphuric acid which it contains is derived from decomposed sulphurets; the phosphoric acid from apatite (phosphate of lime), a mineral which very frequently occurs. These two constituents must be present in every fertile soil.

Of an entirely opposite kind to these are our sandy soils, in which the chief part is quartzose sand. From this substance, water dissolves nothing—acids hardly any thing. Unless, therefore, they are artificially mixed with the substances which are indispensable to the growth of plants, they are wholly unfit for this purpose.*

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* This is so far true; and yet these quartz sands, from which water, and even boiling acids extract nothing, do still contain small quantities of those bases, lime, magnesia, potash, &c., which plants require. Seeds sown in them sprout, and their roots extract from the sand a por-

Some of the lands, reclaimed by dykes, in the province of Gröningen, have not as yet been in want of any additional alkaline salts ;—while on the contrary, the barren sandy soils in the neighboring provinces require to be repeatedly supplied with ash from plants, to give to new plants that of which the old had exhausted the soil.[*]

We think it fit to conclude this exposition by a brief enumeration of some principal rocks, whose decay has given rise to the formation of soil.

Quartz-rocks.—To these belong rock-crystal, common quartz, flinty slate (quartz, with alumina, lime, and oxide of iron), flint[†] (quartz, with alumina, lime, and oxide of iron), sandstone, and sand.

Feldspar-rocks.—To these belong granite, which contains quartz, mica, and feldspar ;[‡] gneiss, in which feldspar, quartz, and mica are contained, so as to make its composition allied to that of granite ; compact feldspar, which constitutes the chief part of clinkstone,[§] and feldspar-porphyry or keratite (silica

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tion of these bases, though not enough in general to enable them to grow in a healthy manner, and to ripen their seeds. But these first races die ; those which succeed find a portion of the work of extraction already performed,—they, therefore, grow better, and their successors better still ; and thus a thick herbage at last covers the loose, and apparently barren ground. This fact is encouraging to the husbandman. It shows the existence of a power, so to speak, in the roots of plants, which we should not have expected, and a latent capability in soils which we are apt to pronounce hopelessly barren. See Wiegmann and Polstorff, *Ueber die Anorganischen Bestandtheile der Pflanzen*, p. 32.—J.

[*] See further : Sprengel's Bodenkunde.

[†] *Flint.*

	Klaproth.
Silica,	98·00
Alumina,	0·25
Lime,	0 50
Oxide of iron,	0·25
Water and volatile matter,	1

Berzelius has more recently found, that flints contain a small per centage of potash.—J.

[‡] *Common Feldspar.*

	Vauquelin.	Berthier.
Silica,	64	64·20
Alumina,	20	18·40
Potash,	14	16 95
Lime,	2	0·00

[§] In *Clinkstone* has been found as much as 8 per cent. of potash, 9 per cent. of soda, and 3½ per cent. of lime.

and alumina, combined with potash, soda, lime, magnesia, oxide of iron, and oxide of manganese.) They contain, as occasional mixtures, sulphuret of iron, hornblende, and mica; trachyte* (silica, alumina, potash, and oxide of iron;) pearlstone† (alumina, silica, oxide of iron, potash, and lime;) and pumice‡ (silica, alumina, soda, potash, oxide of iron, and oxide of manganese.)

Mica-rocks.—To these belong mica-slate, consisting of quartz and mica,§ (mica is either potash, magnesia, or lithia

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* According to Berthier.

	From Puy de Dome.	From Pertuis.
Silica,	65·5	61·0
Alumina,	20·0	19·2
Potash,	9·1	11·8
Lime,	2·2	0·0
Magnesia,	0·0	1·6
Oxide of iron,	3·0	4·2
Water,	0·0	2·0

† *Pearlstone*, from Tokay.

	Klaproth.
Silica,	72·25
Alumina,	12·00
Potash,	4·50
Soda,	
Lime,	0·50
Oxide of iron,	1·60
Water,	4·50

‡ *Pumice.*

	Berthier.
Silica,	70·0
Alumina,	16·0
Oxide of iron,	0·6
Soda,	6·5
Potash,	
Lime,	2·5
Water,	3·0

§ *Mica.*

	Potash-mica.	Magnesia-mica.	Lithia-mica.
	Rose.	Klaproth.	Gmelin.
Silica,	47·50	42·50	49·060
Alumina,	37·20	11·50	33·611
Oxide of iron,	3·20	22·00	—
Oxide of manganese,	0·90	2·00	1·420
Potash,	9·60	10·00	4·186
Magnesia,	—	9·00	0·408
Oxide of lithium,	—	—	3·594
Hydrofluoric acid,	0·56	—	3·445
Phosphoric acid,	—	—	0·112
Water,	2·63	1·00	4·184

mica, and contains, in combination with one of these bases, silica, alumina, oxide of iron, oxide of manganese, hydrofluoric and phosphoric acids;) chlorite-slate (alumina, oxide of iron, silica, lime, magnesia;) and lime-slate.

Hornblende-rocks.—To this class belong hornblende* (magnesia, lime, silica, alumina, protoxide of iron, and manganese;) and greenstone† (a mixture of hornblende and labradorite.) The formula of labradorite is, according to the analysis of Klaproth, calculated by Berzelius:—

$$(NaOSiO^3+Al^2O^3SiO^3)+3(CaO, SiO^3+Al^2O^3SiO^2).$$

Serpentine-rocks, to which belong serpentine‡ (magnesia, silica, lime, oxide of cerium, oxide of iron.)

Augite-rocks, to which belong basalt, being an intimate mixture of augite, labradorite, or feldspar, and protoxide of iron. The whole basalt§ consists of silica, alumina, oxide of iron,

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* *Hornblende*, free from alumina, consists of—

$CaO, SiO^3+3MgO, 2SiO^3$ (Tremolite).
$FeO, SiO^3+3MgO, 2SiO^3$ (Anthophyllite).
Or— $NaO, SiO^3+3FeO, 2SiO^3$ (Arfvedsonite).

Hornblende, with alumina, consists of—

$CaFl+5(CaO, SiO^3+3MgO, 2SiO^3)$.

† *Greenstone.*

	Beudant.
Silica,	63·3
Alumina,	14·2
Oxide of iron,	5·8
Lime,	2·5
Magnesia,	2·0
Potash,	1·2
Soda,	1·2
Water,	0·3

‡ *Serpentine*, after Mosander and Lychnell.

$3MgO, 2HO+2(3MgO, 2SiO^3)$.

§ *Basalt*, from Stettin in Hoegan. Gmelin.

	Part soluble in acids.	Part insoluble in acids.
Silica,	35·741	48·500
Alumina,	11·121	6·792
Oxide of manganese,	1·487	—
Oxide of iron,	—	9·383
Protoxide of iron,	16·015	—
Lime,	11·914	17·395
Strontian,	0·112	—
Magnesia,	10·434	13·131
Soda,	3·264	—
Potash,	1·204	—
Water,	6·530	—

oxide of manganese, lime, and magnesia, with soda, or potash. The composition of dolerite nearly approximates to that of basalt.

Alumina-rocks, to which belong alumina-slate (silica, alumina, lime, magnesia, oxide of iron;) often also potash, soda, gypsum, and common salt.

Lime-rocks, of which the chief constituent is carbonate of lime.

Gypsum, or sulphate of lime.

Iron, oxidulated iron, magnetic oxide of iron, iron-slate.

We perceive that the substances above enumerated, and which after their decay cover so large a portion of the earth's surface, contain for the most part, the same constituents. Their real difference consists either in their less important ingredients, or in the various proportions they contain of the several constituents, whose mutual combinations form the several minerals. Hence it is clear, that in different parts of the earth's surface, they must be very different.

These rocks, which covered the earth in the beginning, and which, during the long period of their existence, have been gradually crumbling down, have thus produced the inorganic constituents of the soil, and are every day still doing so.

By the condensation of the four elements from the earth's atmosphere, carbon, hydrogen, nitrogen, and oxygen, during the first growth of plants—by the continual increase of this condensation in living plants—and by the production therefrom of the black organic substance, which we now find in the ground,—this black substance, must have been immediately mixed with the fragments of the decayed rocks. The final result of this process must necessarily have been the production of a mixture, in which inorganic compounds, both alone and in combination with organic compounds, would be found. On considering the chief inorganic constituents of the soil briefly enumerated above, we see that such of them as are soluble in water, are the same with those which we formerly noticed as being also found in common water, owing to the facility with which they are dissolved out of the decayed rocks, either by the falling rain water, or by the melted snows. And as these salts are also indispensable constituents of plants and animals, the whole inorganic earth appears to be in intimate relation with organic nature, and *vice versa.* Finally, the substances soluble in water are mixed both with the organic constituents of the soil, and with the insoluble remains of decayed rocks; and so they are supplied to plants in a finely divided state.

Supposing the products of the decomposition of plants and of animals to be the very same, in certain circumstances, it is still impossible that the several kinds of soil should be the same in different places. The inorganic substances present in the soil influence this decomposition, and frequently modify it. The presence of bases, acids, or salts,—all acting so powerfully in inducing changes among the elements of organic substances,—must necessarily influence the decomposition of plants and animals, and modify the products which result from it, influencing at the same time also the motion imparted by the decomposing molecules of the black crust of the earth to the plants which grow there. Hence the difference of soils which arises from a difference in their inorganic parts; hence the difference in the new products, which spring from the soil, according as the inorganic constituents of the earth's crust differ; hence, in other words, the relation between the rocks of any district, and the vegetation which grows upon their decaying fragments.

It is a known fact, that the flora of our country (the Netherlands), agrees with that of the whole district on the Rhine.* This is justly ascribed to the diffusion of seed by means of the waters of the Rhine; but another cause may be superadded, namely, the uniformity of the inorganic parts of the soils, carried down by the stream.

In different plants, different constituents of the salts, bases, and acids are found. It may be true, that substances, to which they are nearly allied, may be substituted for them, as potash for soda, &c.; but every species of plant preserves a high degree of peculiarity in this respect, and often dies from want of its peculiar inorganic constituents.

Hence the reason why certain plants prefer certain soils—why they refuse to live in some tracts of land, though in other respects they are placed in the same circumstances: hence the necessity that fields, from which plants are continually reaped, should have the ash of plants occasionally added; hence, finally, the increased fertility of pastures irrigated by

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* Miquel, Distributio Geographica Plantarum.

the winter floods, which restore the inorganic substances of which the soil has been exhausted by its vegetable produce.

A fertile arable soil, therefore, is an intimate mixture of inorganic substances, insoluble in water,—especially fitted to make the soil penetrable, by the roots of plants, and by water ; or, by their hygroscopic force, to retain the water, a property of which clay is possessed in a very high degree—or of substances soluble in water, which can be taken up by plants, and to which the salts already enumerated belong. It is a mixture, also, of organic with inorganic substances, with the latter of which the former may or may not be combined.

These organic substances existing in the soil, would be of an incalculable variety, if they were not, by a general cause, reduced to a small number. If this general cause did not exist, the first plants produced on the decayed rocks would, when dying, have deposited on the earth's crust all their materials ; to these, the succeeding plants would have added their share—and thus there would have been formed every where a mixture of all sorts of vegetable substances, differing with the nature of the materials, from which different tribes of plants are built up. In nature, however, this operation proceeds in a very different way.

Not only is the individual destroyed at its death, but all its organic substances are decomposed, transformed, changed, and modified in such a manner, that, finally, a few only are produced, whatever may have been the plant or the animal whose individuality was destroyed. There are, however, some vegetable as well as animal substances, in which this common change is not yet known ; nor is it likely to take place. As to these, the inquiry still remains, what becomes of them in the earth's crust ? The resins, fats, vegetable bases, and acids are of this class. As to the chief component parts of the organic kingdom, however, it is known into what they are transformed during their decay in the soil, that is, during the formation of humus. This decay is a peculiar decomposition of organic bodies, not to be confounded with putrefaction, from which it greatly differs ; owing, especially, to the influence of the decayed rocks, and the division of the organic substances, effected by this cause. This change is remarkably uniform, since, from the innumerable organic combinations, which exist in plants and animals, the same few constituents of the black layer of soil are derived.

If we exclude the substances accidentally mixed with the black soil, as well as those substances which have not yet undergone sufficient decomposition, its constituents are limited to a small number of organic substances—substances existing in it every where, and on the decomposition of which the growth of plants depends.

These substances have the following properties:—Some of them are soluble in water, others in alkalies, others again are insoluble in both, while some dissolve more or less readily in alcohol and ether. The latter are resinous substances, and they appear to have no share in vegetation at all. The resins obtained from turf are of an exceedingly singular composition, which indicates that they contain combinations of carbon and hydrogen, in different proportions—namely, CH, and C^5H^4—either combined or not combined with oxygen.

In the hard Frisian turf, 4 resins exist:[*]—

$$\begin{array}{l} \alpha.\ C^{50}H^{40}O^{9}=10(C^{5}H^{4})+O^{9}. \\ \beta.\ C^{77}H^{67}O^{9} \\ \gamma.\ C^{104}H^{94}O^{9} \\ \delta.\ C^{131}H^{121}O^{9} \end{array}$$

In the three latter, the α resin is no doubt chemically combined with carburetted hydrogen, CH, for if, from each of them, we subtract the α resin, we have:—

$$\begin{array}{ll} 1. & \beta.\ C^{77}H^{67}O^{9} \\ & \alpha.\ C^{50}H^{40}O^{9} \\ \hline & C^{27}H^{27}=9\times C^{3}H^{3} \end{array}$$

$$\begin{array}{ll} 2. & \gamma.\ C^{104}H^{94}O^{9} \\ & \alpha.\ C^{50}H^{40}O^{9} \\ \hline & C^{54}H^{54}=18\times C^{3}H^{3} \end{array}$$

$$\begin{array}{ll} 3. & \delta.\ C^{131}H^{121}O^{9} \\ & \alpha.\ C^{50}H^{40}O^{9} \\ \hline & C^{81}H^{81}=27\times C^{3}H^{3} \end{array}$$

In long Frisian turf, the composition of these resins is somewhat different:—

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[*] Bulletin, 1839, p. 147.

$$C^{35}H^{28}O^{5}=7(C^{5}H^{4})+O^{5}$$
$$C^{90}H^{168}O^{6}=6(C^{5}H^{4}+O)\,60(CH).^{*}$$

These are all the substances of this kind which, so far as they exist in the soil, have been as yet investigated. But similar substances, produced from the decomposition of organic bodies, exist undoubtedly in all sorts of soils, and in other strata. The light carburetted hydrogen, CH^2, is a product resulting from the decomposition of plants, which have been buried under the ground to a great depth, and transformed into coal. There are two other carburetted hydrogen compounds, CH and C^5H^4, which have a solid form, and by a similar change are produced at the surface. It is very likely that further investigation will make us acquainted with more of them.[†]

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[*] α Resinate of lead, hard Frisian turf.

	Found.	Atoms.	Calculated.
C	57·33	50	57·77
H	7·81	40	7·55
O	13·44	9	13·61
PbO	21·42	1	21·07

β Resin.	Found.	Atoms.	Calculated.
C	77.37	77	77·21
H	10.98	67	10·97
O	11.65	5	11·82

γ Resin.	Found.	Atoms.	Calculated.
C	79·12	104	79·32
H	11·94	94	11·79
O	8·94	9	8·98

δ Resin.	Found.	Atoms.	Calculated.
C	80·77	131	80·60
H	12·15	121	12·15
O	7·08	9	7·25

α Resin, long Frisian turf.

	Found.	Atoms.	Calculated.
C	76·20	35	75·89
H	10·21	28	9·92
O	13·59	5	14·19

γ Resin.	Found.	Atoms.	Calculated.
C	80·38	90	80·68
H	12·52	84	12·29
O	7·10	6	7·03

[†] Johnston.

2. The organic substances which are soluble in water and alkalies, are present in certain kinds of soil in considerable quantity, in others to a very small extent. Their characters are analogous to those of the substances which are insoluble in water and alkalies, with the exception of the resins above mentioned. These soluble substances present themselves with different characters in the soil, owing to their being combined with different inorganic bodies; the same organic substance, which forms a soluble compound with potash, forming an insoluble one with oxide of iron or lime. There are, however, two organic constituents of the soil which do not combine with bases, and are insoluble both in water and in alkalies.

At present seven different organic substances are known to exist in the soil. They are crenic acid, apocrenic acid, geïc acid, humic acid and humin, ulmic acid and ulmin. Humin and ulmin are insoluble in alkalies and in water; the others are readily soluble in alkalies, and more or less in water also. In different kinds of soils the relative proportions in which these substances are present, are very different, as are many of their physical and chemical properties; but numerous experiments seem to show, that a greater number cannot at present be admitted.*

It is of importance to be acquainted with these substances. I shall divide them into two groups, the crenic and the humic. In the latter, I include geïc acid, humic acid and humin, ulmic acid and ulmin; in the former, crenic acid and apocrenic acid.

In a good arable soil—that is, one of which the organic constituents are as far as possible decomposed—none of these substances contains nitrogen as a constituent element. All their nitrogen exists in the state of ammonia. And as five of the constituents of the soil already enumerated are acids, five different salts of ammonia, and also double salts of potash, soda, lime, magnesia, and oxide of iron, may be formed from these five acids; which salts, being soluble in water, can be supplied to plants in a state of solution.

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* In a subsequent page, I shall state the result of some researches of my own, which show that to this number others may already be added.—J.

If the soil is exhausted by means of water, a great many salts are extracted from it. Three different kinds of soil gave of salts in 100 parts:*—

0·424
2·771
1·540

These salts are the chlorides of sodium, potassium, calcium, magnesium, and ammonium, with formic, acetic, sulphuric, carbonic, crenic, apocrenic, and humic acids, in combination with the oxides of the same metals. They form altogether what is called *humus extract*.

From the soils treated with water in the manner described, alkaline solutions extract substances, which may be precipitated by acids. In different kinds of soils the substances thus extracted are sometimes different. They all consist, however, of one or more of the following three, namely:—

Geïc acid,	$C^{40}H^{12}O^{14}$
Humic acid,	$C^{40}H^{12}O^{12}$
Ulmic acid,	$C^{40}H^{14}O^{12}$

The latter is that which, in neutral vegetable substances undergoing decay, is formed first. From it, by absorption of oxygen from the air, humic acid is produced, and finally, by a further absorption, geïc acid.

Of these three substances—soluble in alkalies, and precipitable by acids from their solutions—the above mentioned three kinds of soils gave in 100 parts:†—

4·249
5·289
8·667

The substances which are insoluble in alkalies, (ulmin and humin,) can be rendered soluble, and so converted into ulmic and humic acids respectively, by the decomposition which is always going on in the constituents of the soil.

The organic substances now enumerated, which in the mass we call *humic*, may thus in part be supplied to plants, provided there be an alkali at hand to bring them into a soluble state. This may either be one of the fixed alkalies, or ammonia—especially the latter, which, in a way I shall

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[*] Scheikundige Onderzoekingen, Vol. II, p. 92.

[†] Scheikundige Onderzoekingen, II, p. 92.

presently describe, may be so easily formed from the atmospheric air included in the soil. In this way the humic substances, in a state fit for supplying food for plants, are added to the soluble salts above enumerated—provided ammonia have access to render them soluble in water—and, therefore, they *must* be taken up by the roots of plants, along with the salts, unless plants be able to select—a supposition which is by no means probable.[*]

In the fluid, from which the humic substances have been precipitated by an acid, apocrenic and crenic acids are still contained, which substances may also be collected, and their proportion calculated by adding first acetate of copper, and afterwards carbonate of ammonia. By the former, apocrenate of copper is thrown down, in which about 50 per cent. of apocrenic acid is contained; by the latter, crenate of copper, which contains a variable proportion—from 40 to 70 per cent. —of crenic acid. When treated in this way, the three soils referred to gave respectively—

Apocrenate of Copper.
1·865
1·228
0·701

Crenate of Copper.
0·774
1·901
1·260

These two acids, also, as they exist in the soil, can be separated from their insoluble combinations with lime and oxide of iron, by means of ammonia, potash, or soda, with which they form soluble salts. If ammonia, therefore, be present, the soil will be found to contain five different compounds of this base, sometimes in considerable quantity,—substances which can be supplied to plants in a soluble state, and which are thus of great importance to their growth.

In giving a slight outline of the production of all these substances, and of their influence on the life of plants, we shall

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[*] Some of the reasons in support of the opposite view, which I am inclined at present to regard as the more probable, will be found in my published "Lectures on Agricultural Chemistry and Geology," p. 112.—J.

begin with the humic, and treat afterwards of the crenic group.

First, however, we must advert to the ammonia, which so powerfully supports the growth of plants, and deserves to be particularly noticed, not only as a base, rendering the five acids above mentioned soluble, (in which respect, like the ashes of plants, so valuable as a manure, it plays an important part,) but also as a substance containing nitrogen, the only one, indeed, of this kind, which exists in a soil sufficiently decomposed.

We are, I believe, entitled to conclude, from the experiments of Liebig himself, (page 99,) that this ammonia cannot be carried down to the soil from the atmosphere, by means of the rain-water. It exists in the atmosphere in too small a proportion—a proportion which has never been determined. Nay, it is so minute, that it appears not to be capable of being determined,—its mere presence even is difficult to be detected.

Nitrogen, in the state of pure gas, and also atmospheric air, are, however, possessed of one common property, namely, that when in contact within an enclosed space with putrefying substances,—from which hydrogen is in consequence given off, —the nitrogen combines with the hydrogen and forms ammonia. This property of nitrogen is known. It is the principle on which saltpetre is formed ; the production of that substance, as has been correctly remarked by Liebig, being always preceded by that of ammonia. Now, air is contained in the soil, and is in continual contact with moist and decomposing substances. This air could produce saltpetre, if there were only a sufficient abundance of bases, and even without the presence of putrefying organic substances. There are in Ceylon twenty two natural saltpetre grottoes, where there are no organic substances, from which nitrogen might be supplied. Nitrogen is derived from the air contained in these caverns, and, in favorable circumstances, even the water is decomposed, and ammonia at the same time produced, which afterwards is oxidized into nitric acid by the oxygen of the air, in places where it has more easy access ; this acid then combines again with the bases from the walls of the grottoes, and forms nitrates.

All this would happen in the soil if organic substances were not present to absorb the oxygen, and thus to prevent the oxidation of the nitrogen in the ammonia, and the formation of saltpetre.

In a porous soil, in which moist air is contained, nitrogen combines with the hydrogen of the organic bodies only into ammonia, the oxygen from the water and the air being consumed in the higher oxidation of the organic substances themselves. In this way, the first product of the decomposition of organic substances, namely, ulmic acid, $C^{40}H^{14}O^{12}$, is converted into humic acid, $C^{40}H^{12}O^{12}$, and this again into geïc acid, $C^{40}H^{12}O^{14}$; the latter, again, being then further oxidized into apocrenic and crenic acids, which we intend to treat of hereafter.

It may be enough to repeat here, that in the soil, as in the natural caverns of Ceylon, the ammonia is produced from the nitrogen of the atmosphere, and that the oxygen of the air converts the organic substances successively into ulmic, humic, geïc, apocrenic, and crenic acids, instead of forming nitric acid.

What is said here of the formation of ammonia from the nitrogen of the atmosphere, contained in the moist soil, has been treated of elsewhere at great length.*

By all porous substances, therefore, ammonia is produced—provided they are moist, are filled with atmospheric air, and are exposed to a certain temperature.† It is by this process, that the porous lime in the walls of moist rooms comes to contain first ammonia, and afterwards nitrate of lime,—that moist charcoal becomes impregnated with ammonia, and forms, afterwards, by oxidation, the substances resembling humus extract, which Büchner found in charcoal to the amount of 2 per cent., and in which Lucas cultivated plants—substances consisting chiefly of apocrenate of ammonia, produced from the charcoal by oxidation.

This formation of ammonia from the nitrogen of the atmosphere has been denied by several writers, especially on the ground, that at an elevated temperature nitrogen does not form any combination with hydrogen. But the combination

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* Scheik. Onderz. Vol. II.

† See Kuhlman upon the formation of saltpetre, in Annalen der Pharmacie, Bd. 29, s. 272, who ascertained, in 1839, that the formation of ammonia precedes that of saltpetre.

of nitrogen with hydrogen at ordinary temperatures, in various circumstances, is equally true with the result of the experiments made upon the former point. It has been demonstrated by many experiments, that, at an elevated temperature, nitrogen has an indifferent character, being unable to form direct combinations at a red heat, either with hydrogen or with oxygen. This is, however, not the case with regard to carbon. Coke, when heated to redness with potash in the open air, produces cyanuret of potassium. There are some circumstances also in which nitrogen does combine with oxygen at a high temperature:—for instance, Cavendish obtained nitric acid by passing electric sparks through moist atmospheric air, and the same acid is also produced, when a mixture of hydrogen and nitrogen is burned in the air.

It is a fact, especially important to our present purpose, that hydrogen, *in the nascent state*, combines directly with nitrogen into ammonia. When reddened litmus paper is hung up in a bottle, filled with pure atmospheric air, and when pure iron-filings, moistened with pure water, are laid at the bottom, then the red litmus is quickly turned blue by the action of ammonia, formed from the nitrogen in the air, and the hydrogen of the decomposed water, the oxygen of which had combined with the iron.

Such a formation of ammonia continually takes place in the soil. There, atmospheric air is present, and consequently nitrogen; hydrogen is continually liberated (see below,) and thus the conditions, necessary to the formation of ammonia, are fulfilled as often as cellulose, ligneous matter, starch, &c., are changed either into humic acid, or into other constituents of the soil.

To this formation of ammonia from the constituents of atmospheric air and water, we must look for the cause of one of the most important peculiarities in the growth of plants. It is owing to this slow formation of ammonia, that the organic substances of the soil, insoluble in water, are rendered soluble, and so can be offered to plants as organic food, even without a supply of ammoniacal manure to the soil. In other words, it is owing to this cause that the five acids already mentioned can all be converted into soluble ammoniacal salts.

The *humic substances*,—that is, the substances which can be extracted from the soil by alkalies, and precipitated from the alkaline solution by acids—from whatever kind of soil they may have been prepared, have a very great uniformity, and are remarkably similar to those substances which, by the action of several chemical agents, may be obtained from the materials which are generally diffused through the vegetable and animal kingdoms. Hence, we perceive *a remarkable conformity* between putrefaction and chemical action, and also a change of very dissimilar bodies into the same substances, by which we are led to recognize a certain conformity in the natural arrangement of the elements of these bodies. While, therefore, we see woody fibre, starch, gum, sugar, and also protein, severally yield the same chemical substances by means both of putrefaction and of an acid, and woody fibre by means of putrefaction, an acid, or heat (in soot,)—we have undeniable proof, that putrefaction, acids, and heat, must exert on these substances the same effect, and consequently their chemical influence must be uniform. Putrefaction being thus a chemical action, and at the same time a phenomenon which immediately succeeds the individual vital force, we are, in spite of ourselves, led to draw the conclusion, that this individual vital force is very much regulated by chemical action, though it may be determined by other series of chemical actions, than those by which putrefaction is effected.

But we are not less entitled to draw the conclusion, that, as the same substances are produced in circumstances so very different (putrefaction and the action of acids), and from so many different materials (woody fibre and protein, starch and phloridzine),*—there must exist in all these dissimilar complex substances (viz. protein, woody fibre, starch, gum, sugar, phloridzine, and a great many others,) a uniform arrangement of the molecules, or some unknown combination of the elements, which occurs as a prototype in humic acid and humin, and which is constantly liberated from these different substances under very different circumstances. This presents another generality in the arrangement of the organic world, and exhibits in a beautiful light the simplicity of the whole scheme.

3. The soil contains a humic substance, which is insoluble

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* Nitro-humic, and nitro-phloretic acid are identical; they are both apocrenate of ammonia. (Scheik. Onderzoek. Vol. II, p. 105.)

in alkalies. A similar one is found also in the products obtained by the action of acids upon sugar, &c. The composition of the latter is known. That of the former is very difficult to ascertain, because the different insoluble products of putrefaction remain in a state of mixture, and can scarcely be completely separated—such, for instance, as rotten wood, which cannot be separated from that which is but partly rotted. We may, however, suppose, with a certain degree of probability, that the substance of the soil, which is insoluble in alkalies, will also be similar to that which can be produced from sugar, &c., by means of acids.

The humic substances, soluble in alkalies, are divisible into three classes according to their composition—into those, namely, which can be supposed to consist of carbon and the elements of water,—those which contain more hydrogen than the oxygen requires to form water,—and those which contain an excess of oxygen. Such are the humic, ulmic, and geïc acids. Their composition is as follows:*—

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[*] Bulletin, 1840, p. 1.

Ulmic acid from sugar, at 195° Cels. (383° Fahr.)

	Found.	Atoms.	Calculated.
C	68·95	40	68·98
H	4·23	14	3·94
O	26·82	12	26·08

Ulmin at 140° Cels. (284° Fahr.)

	Found.	Atoms.	Calculated.
C	65·27	40	65·65
H	4·52	16	4·28
O	30·21	14	30·07

Ulmic acid from long Frisian turf, at 140° Cels. (284° Fahr.)

	Found.	Atoms.	Calculated.
C	61·85	40	62·62
H	4·79	18	4·62
O	33·36	16	32·76

Humin from sugar, at 140° Cels. (284° Fahr.)

	Found.	Atoms.	Calculated.
C	64·67	40	64·44
H	4·32	15	3·94
O	31·01	15	31·62

Humic acid from sugar, combined with oxide of silver, at 100° C. (212° Fahr.)

	Found.	Atoms.	Calculated.
C	49·05	40	49·36
H	3·23	15	3·02
O	24·58	15	24·21
AqO	23·14	1	23·41

	C	H	O	HO	O
Ulmic acid from sugar by means of acids, ...	40	14	12		
Ulmin from the same, .	40	14	12	+ 2	
Ulmic acid from long Frisian turf,	40	14	12	+ 4	
Humic acid from sugar by means of acids, ...	40	12	12		
Humin from the same, .	40	12	12	+ 3	
Humic acid from hard turf,	40	12	12	+ 3	
Humic acid from a rotten tree,	40	12	12	+ 4	
Humic acid from an arable soil,	40	12	12	+ 4	
Humic acid from soot, .	40	12	12	+ 4	
Geïc acid from two kinds of soil,	40	12	12	+ 3	+ 2
Humic acid from a pasture field,	40	12	12	+ 2	
Humic acid from an arable soil,	40	12	12	+ 5	
Humic acid from protein, by means of muriatic acid, . .	40	12	12		

Humate of ammonia from hard Frisian turf, at 140° C. (284° Fahr.)

	Found.	Atoms.	Calculated.
C	0·13	40	60·28
H	4·74	19	4·68
N	3·61	1	3·49
O	31.55	16	31·55

$=C_{40}H_{12}O_{12}+NH_3+4HO$

Humate of ammonia from an old willow, at 140° C. (284° Fahr.)

	Found.	Atoms.	Calculated.
C	59·06	40	58·98
H	4·96	20	4·82
N	2·80	1	3·41
O	33·18	17	32·79

$=C_{40}H_{12}O_{12}+NH_3+5HO$

Geate of ammonia from an arable soil, at 140° C. (284° Fahr.)

	Found.	Atoms.	Calculated.
C	57·37	40	58·00
H	4·43	19	4·48
N	3·25	1	3·37
O	34·95	18	34·15

$=C_{40}H_{12}O_{14}+NH+4HO_3$

Humate of ammonia from an arable pasture soil (284° Fahr.)

	Found.	Atoms.	Calculated.
C	57·16	40	56·63
H	5·38	23	5·32
N	6·11	2	6·56
O	31·35	17	31·49

$=C_{40}H_{12}O_{12}+2NH_3+5HO$

Almost all these substances are combined with ammonia in the soil, and contain different proportions of water, with which they remain in combination, if dried at the same temperature of 140° Cels. (=284° Fahr.) They ought, therefore, not to be considered as the same, though analogous substances; they differ from each other in accidental, and not in essential, properties. The varieties of the three acids—ulmic, humic, and geïc acids—must be viewed in the same light as the different kinds of sugar, in which it is clear, that $C^{12} H^9 O^9$ is contained, but from many of which the whole of the water cannot be driven off by bases.*

Let us now briefly consider the manner in which the above three acids are produced.

Ulmin and ulmic acid are formed from cellulose, starch, gum, and sugar, by the influence of acids, and at the same time, formic acid is produced. The following may serve as an example :—

	C	H	O
½ of 7 equiv. of sugar, = .	42	35	35
1 equiv. of ulmin, = .	40	16	14
1 equiv. of formic acid, = .	2	1	3
18 equiv. of water, = .		18	18
	42	35	35

Humate of ammonia from a garden mould, at 284° Fahr.

	Found.	Atoms.	Calculated.
C	57 87	40	57·72
H	4 98	21	4.97
N	3·52	1	3 34
O	33·53	18	33 79

$=C^{40}H^{12}O^{12}+NH^3+6HO$

Humate of ammonia from protein by means of muriatic acid, at 284° Fahr.

	Found.	Atoms.	Calculated.
C	64·86	40	64·58
H	4 61	16	4·22
N	3 70	1	3·74
O	26·83	13	27·46

$=C^{40}H^{12}O^{12}+NH^3+HO$

* See Scheikund. Onderz. Vol. II, p. 88.

It is certain that a change similar to the above takes place during the formation either of ulmin or ulmic acid from cellulose or other neutral substances during decay. In this case, however, the formic acid either cannot be produced at all, or cannot be so exclusively; but, in its stead, two equivalents of carbonic acid and one of water must be produced, two of oxygen being absorbed from the air.* In the same manner the above organic substances are changed into humin nnd humic acid, which are formed in the soil more frequently than ulmin and ulmic acid, and consist of $C^{40}H^{12}O^{12}$. They are produced from sugar, by the action of acids, with access of air, as follows:—

	C	H	O
½ of 7 equiv. of sugar, .	42	35	35
1 equiv. of humin, .	40	12	12
1 equiv. of formic acid, .	2	1	3
22 equiv. of water, .		22	22
	42	35	37

Thus, *two* equivalents of oxygen are taken from the atmosphere, when humin is formed in this way. In the soil, again, during the decomposition of sugar, *four* of oxygen are absorbed, and two of carbonic acid and one of water are formed, instead of one of formic acid. (See preceding note.)

The change of sugar, therefore, either into humin or ulmin, or into their acids, during decay, is a simple transposition of its elements. Thus ulmin is formed from it, with absorption of two of oxygen, humin of four of oxygen, and geïc acid of six of oxygen, as follows:—

	C	H	O
½ of 7 equiv. of sugar, $+O^2$,	42	35	37
2 equiv. of carbonic acid,	2		4
19 equiv. of water, . .		19	19
1 equiv. of ulmin, . .	40	16	14
	42	35	37

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* These two of oxygen are required to convert the formic acid into carbonic acid and water. Thus:—

Formic acid+2 of oxygen=2 of carbonic acid+water.

$$C^2H^1O^3 + \quad 2O \quad = \quad 2CO^2 \quad +HO$$

½ of 7 equiv. of sugar, $+O^4$,	42	35	39
2 equiv. of carbonic acid,	2		4
23 equiv. of water,		23	23
1 equiv. of humin,	40	12	12
	42	35	39

½ of 7 equiv. of sugar, $+O^6$,	42	35	41
2 equiv. of carbonic acid,	2		4
23 equiv. of water,		23	23
1 equiv. of geïc acid,	40	12	14
	42	35	41

As to cellulose, starch, gum, inuline, and lichen starch, what has been said with regard to sugar, holds true of them also. Pectin, and other analogous substances, which are so very much diffused through plants, do not require any oxygen from the air, to be converted into humin. They consist of $C^{12}H^{8}O^{10}$; and thus, taking the same tabular view as for sugar, they would give:—

	C	H	O
½ of 7 equiv. of pectin,	42	28	35
2 equiv. of carbonic acid,	2		4
16 equiv. of water,		16	16
1 equiv. of humin,	40	12	12
	42	28	32

There is here, then, a remainder of three equivalents of oxygen, so that cellulose, starch, sugar, &c., if mixed with a certain quantity of pectin, might produce humus, and give off a certain quantity of carbonic acid to the atmosphere, without taking from it any oxygen.

Of these neutral materials plants chiefly consist, and it is highly probable that their decomposition is effected in the manner above described. There are some organic substances, of which the mode of conversion into humus cannot, with any probability, be demonstrated: with many, however, it might be; but the illustrations already presented in regard to such of the neutral vegetable substances as are most generally diffused, may suffice for the present.

There is one of the chief component parts, belonging both to the bodies of animals and of vegetables, the change of which into humus is equally simple. This substance is protein. By the influence of hydrochloric acid, and the oxygen of the air, it is converted into humic acid, in the following manner :[*]—

	C	H	N	O	Cl
1 equiv. of protein,	40	31	5	12	
4 equiv. of hydrochloric acid,		4			4
4 equiv. of oxygen,				4	
	40	35	5	16	4

From these are produced :—

	C	H	N	O	Cl
1 equiv. of humin,	40	15		15	
1 equiv. of ammonia,		3	1		
1 equiv. of water,		1		1	
4. equiv. of chloride of ammonium,		16	4		4
	40	35	5	16	4

In the formation of humus from protein, again, humin and ammonia are produced; four equivalents of oxygen being absorbed from the air :—

	C	H	N	O
1 equiv. of protein, $+O^4$,	40	31	5	16
1 equiv. of humin,	40	15		15
1 equiv. of water,		1		1
5 equiv. of ammonia,		15	5	
	40	31	5	16

The other chief constituents of the animal body have not been investigated with reference to these transformations; so that it is not known what kind of changes they undergo in the soil, when they are converted into humus.

Though it be true, that the products of the decomposition of organic substances differ with circumstances, and consequently

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[*] Bulletin, 1840, p. 74.

that, in the above outline, the decomposition is stated for one particular case only; yet it results from what has been said, that the same substances, of which the black layer of soil chiefly consists, are formed from the most different products of the vegetable and animal kingdom, especially from their constituents—*both* by the influence of chemical agents, and by that of the formation of humus.

The ulmic, humic, and geïc acids, however prepared, have the property of condensing ammonia and water, to the extent of several parts per cent. This water cannot be separated from them, unless they are exposed to a very high temperature. We have observed that from 8 to 16 per cent. of water are given off at 284° Fahr. from different kinds of humin and ulmin.[*] They can be entirely deprived of water, only by a temperature of 383° Fahr. By this great hygroscopic power, the growth of plants is very materially promoted. In the soil, humic and geïc acids are always combined with ammonia. All the ammonia produced by the decay of substances containing nitrogen, (protein from plants and animals, &c.;) and all that is formed in the porous soil from the component parts of the atmosphere and of water, combines with the humic and geïc acids, into humate and gëate of ammonia, which are severally present in different kinds of soils. We have found, in different specimens of soils and turfs, humates and gëates of ammonia, which, at a temperature of 284° Fahr., had the following composition:—

Turf, .	$C^{40}H^{12}O^{12}$	$+ NH^3 + 4HO$
Decayed tree,	idem	$+ NH^3 + 5HO$
Soil from an orchard,	idem	$+ 2NH^3 + 4HO + O^2$
Garden mould,	idem	$+ 2NH^3 + 4HO + O^2$
Soil from pasture land,	idem	$+ 2NH^3 + 5HO$
Garden mould, planted with young oaks,	idem	$+ NH^3 + 5HO$
Garden mould, planted with currant bushes,	idem	$+ NH^3 + 6HO$

This power of condensing ammonia, possessed by the ulmic, humic, and geïc acids, is so powerful, that the acid, prepared from sugar by means of muriatic acid, contains almost

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[*] Bulletin, pp. 10, 47, 50.

always ammonia, unless the air be carefully excluded. The ammonia, which always either exists in the atmosphere, or is produced from it in the manner above mentioned, (p. 143,) (for instance, the ammonia, from which the incrustations round the necks of bottles containing phosphoric acid, &c., and the collections of liquid on the necks of bottles containing nitric acid, &c., are formed,) combines with the geïc, humic and ulmic acids, and thus gëate, humate, and ulmate of ammonia are produced. By this property, Hermann was, no doubt, misled, when he thought that the humic acid from sugar contained nitrogen.* We may ascribe to it a very important function of the soil. It enables these acids to retain ammonia, either condensed from the atmosphere, or formed from its constituents, and thus to supply nitrogen to plants—to absorb the ammonia formed during the decay of substances which contain nitrogen—and greatly to promote the growth of plants by means of nitrogenous manures.

It is by this ammonia also, that the gëic, humic, and ulmic acids of the soil are made soluble in water, and so fitted to be taken up by the roots of plants, in the same manner as so many inorganic salts, such as the alkaline sulphates and chlorides, are taken up by them. Thus, the ammonia is an additional base in the soil, and joins the potash, magnesia, soda, lime, and the oxides of iron and manganese, to form a long series of ulmates, humates, and gëates, some of which are soluble, and others insoluble in water.

As the proportion of ammonia increases, more of the other bases,—for instance, oxide of iron and manganese—are displaced by it, and in this way gëates, humates, or ulmates, which are either insoluble, or soluble with difficulty, are converted into the very soluble gëate, humate, or ulmate of ammonia. Thus, as substances, giving off ammonia, decay in the soil, they must produce soluble gëate, humate, or ulmate of ammonia.

4. These remarks may suffice in regard to the humic substances in the soil, that is, such as can be extracted from it by

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* Journal für Practische Chemie, 1841, Erster Band, p. 68. The whole treatise of Hermann, in this and the following parts, 1841, Part II, p. 375, and 1842, Part I, p. 189, proves of itself the inaccuracy of his results.

alkalies, and precipitated by acids from the alkaline solution. There are two other constituents of the soil, however, which deserve particular attention, viz. the *crenic* and *apocrenic acids.* Both of these, like the humic acids, exist in the soil as double salts, that is, in the state of salts of ammonia, potash, and soda, combined with lime, magnesia, and oxide of iron; being also partly soluble, and partly insoluble in water, and changeable into soluble salts by means of ammonia.

The composition of these acids is the following :—

Apocrenic acid,	$C^{48}H^{12}O^{24}$
Crenic acid,	$C^{24}H^{12}O^{16}$

These acids, of course, never exist uncombined in the soil. They unite intimately with ammonia, so as to exhibit the characters of quaternary substances. Treated with potash, however, at an elevated temperature, this ammonia is completely separated. But these acids are also combined in the soil with other bases, in such a manner, that the ammonia forms almost always a component part of a double apocrenate or crenate of potash, soda, lime, magnesia, or oxide of iron.

From the three soils above mentioned, (p. 140,) as well as from others, the following crenates and apocrenates were obtained, either in the state of double apocrenates, or of simple crenates of ammonia and of copper, according to the mode of preparation. These acids, like the ulmic, humic, and geïc acids, are extremely difficult to dry, and, when dried at the same temperature, they retain different proportions of water, which increases as the quantity of base, in combination with the acid, decreases. From these soils were obtained apocrenates of oxide of copper and of ammonia, the organic constituents of which gave the following formulæ :—

$$C^{48}H^{12}O^{24}+1\tfrac{1}{2}NH^{3}+5Aq.$$
$$C^{48}H^{12}O^{24}+\tfrac{1}{2}NH^{3}+10Aq.^{*}$$

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[*] Scheik. Onderzoek. Vol. II, p. 99.

Apocrenate of ammonia fiom two kinds of soils, at 284° Fahr.

	Found.		Atoms.	Calculated.
	I.	II.		
C	51·89	50·83	48	51·66
H	3·75	4·16	21½	3·78
N	3·37	4·09	1½	3·74
O	40·99	40·92	29	40·82

$$=C^{48}H^{12}O^{24}+1\tfrac{1}{2}NH^{3}+5HO$$

The apocrenic acid is an acid which saturates five equivalents, either of base or of water. It is thus a five-basic acid,—at least the artificial acid is so. That which exists in the soil may, perhaps, be able to combine with a greater number of equivalents of water, or of bases, as the humic class of acids does.

There are several modes of preparing an artificial apocrenic acid, two of which are of especial importance, in connection with the subject we are now considering.

Apocrenate of ammonia, from two other kinds of soils, at 284° Fahr.

	Found.		Atoms.	Calculated.
	I.	II.		
C	48·37	48·18	48	49·24
H	3·90	4·04	23½	3·94
N	1·11	1·48	½	1·19
O	46·62	46·30	34	45·63

$=C_{48}H_{12}O_{24}+\frac{1}{2}NH_3+10HO$

Apocrenate of ammonia, from humic acid prepared from sugar by nitric acid, at 230° Fahr.

	Found.	Atoms.	Calculated.
C	55·43	48	55·10
H	3·49	17	3·19
N	2·98	1	2·66
O	38·10	26	39·05

$=C_{48}H_{12}O_{24}+NH_3+2HO$

Neutral apocrenate of ammonia and lead, at 230° Fahr.

	Found.	Atoms.	Calculated.
C	28·97	48	29·98
H	1·88	17	1·73
N	1·80	1	1·45
O	22·67	26	21·20
PbO	44·68	4	45·64

$=C_{48}H_{12}O_{24}+NH_3+4PbO+2HO$

Anhydrous apocrenic acid.

	Found.	Atoms.	Calculated.
C	59·06	48	59·00
H	2·87	12	2·41
O	38·07	24	38·59

Crenate of ammonia from an arable soil, at 284° Fahr.

	Found.	Atoms.	Calculated.
C	45·98	24	45·59
H	5·50	17	5·27
N	3·88	1	4·41
O	45·64	18	44·73

$=C_{24}H_{12}O_{16}+NH_3+2HO$

When humic acid, in whatever way prepared, or wood charcoal, is exposed to the action of nitric acid, apocrenate of ammonia is produced. Thus in every case, where humic acid can be formed from bodies by nitric acid, apocrenate of ammonia is the final product. For instance, phloridzine is converted into phloretine and grape sugar by diluted nitric acid; this grape sugar again into humic acid, and the humic acid into apocrenic acid,—all by the same nitric acid. Thus phloridzine, when acted upon by nitric acid, gives apocrenic acid, though always in combination with ammonia, as represented by the formula:—

$$C^{48}H^{12}O^{24}+NH^{3}+2HO$$

This is the composition of a compound produced by the action of nitric acid upon humic acid from sugar, from soil, and from turf, and dried at 284° Fahr., and which is thus an apocrenate of ammonia. The same substance, if saturated with ammonia, and dried at 248° Fahr., gave

$$C^{48}H^{12}O^{24}+3NH^{3}, 3Aq.$$

And again, a lead-salt, from neutral acetate of lead and a solution of neutral apocrenate of ammonia, dried at 230° F., gave

$$C^{48}H^{12}O^{24}+NH^{4}O+4PbO, Aq.$$

It is probable, that the last atom of water might be separated at a higher temperature, but, as the salt is readily decomposed and difficult to be dried, this has not been attempted.

We are, therefore, entitled to call the artificial acid a five-basic one. Like the ulmic, humic, and geïc acids, it belongs to the gelatinizing substances, which, like alumina, exhibit

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Crenate of ammonia, from another cultivated soil, at 284° Fahr.

	Found.	Atoms.	Calculated.
C	45·77	24	45·53
H	5·35	15½	5·11
N	1·94	½	2·20
O	46·94	18	47·16

$$=2(C^{24}H^{12}O^{16}+HO)+NH^{3}+HO$$

Crenic acid, from a third kind of arable soil, at 284° Fahr.

	Found.	Atoms.	Calculated.
C	46·87	24	46·78
H	4·97	15	4·77
O	48·16	19	48·45

$$=C^{24}H^{12}O^{16}+3HO$$

The crenates and apocrenates, separated from the cultivated soils as well as the crenic acid, the analyses of which are above given, were all in combination with oxide of copper.

different characters in relation to water, bases and acids, according to the difference of circumstances;—by which property it is enabled both to absorb a large proportion of water, and to combine with several bases at once. Nay, it is by this five-basic character that insoluble apocrenates—for instance, that of oxide of iron—are rendered soluble in water, by being combined into double salts with soluble apocrenates. In virtue of this property, plants may, along with the four organic elements, either be supplied with several bases at once, or these bases may be alternately exchanged, according as the proportion of a more powerful base in the soil is less, and that of a more feeble one, temporarily greater. There may exist, for example, apocrenates represented by the following formulæ, which, being all soluble in water, and existing in the soil, can be supplied as food to plants:—

$C^{48}H^{12}O^{24}+5NH^{4}O$
$C^{48}H^{12}O^{24}+4NH^{4}O+KO$
$C^{48}H^{12}O^{24}+3NH^{4}O+KO+CaO$
$C^{48}H^{12}O^{24}+2NH^{4}O+KO+CaO+MgO$
$C^{48}H^{12}O^{24}+ NH^{4}O+KO+CaO+MgO+FeO$

For this reason, the apocrenic acid is of inestimable value to plants, and in the series of substances which are useful to them, it deserves, no doubt, a much higher rank than the humic class of acids.

It is from the latter that the apocrenic acid is produced in the soil. We have seen, that when nitric acid acts upon humic acid, apocrenate of ammonia is produced. This action takes place in such a way, that, when nitric acid is poured upon humic, ulmic, or geïc acid, in whatever way these acids may be prepared, formic and oxalic acids are simultaneously produced. From two equiv. of humic acid, for example, and NO^{45} (one of nitrogen, and 45 of oxygen) derived from nitric acid, are formed,—

	C^{80}	H^{30}	N	O^{75}
1 equiv. of apocrenic acid,	C^{48}	H^{12}		O^{24}
1 equiv. of ammonia, .		H^{3}	N	
12 equiv. of formic acid, .	C^{24}	H^{12}		O^{36}
4 equiv. of oxalic acid, .	C^{8}			O^{12}
3 equiv. of water, . .		H^{3}		O^{3}
	C^{80}	H^{30}	N	O^{75}

During this action of nitric acid on humic acid, which takes place with much vehemence, deutoxide of nitrogen is abundantly given off.

It is thus that apocrenic acid is formed in the soil, but of course accompanied by the production of carbonic acid, instead of either oxalic or formic acid. The ammonia of the soil,—produced in it from the atmospheric air it has absorbed,—may, by the influence of decaying organic substances and water, be converted into nitric acid, and no doubt is so, when the bases required for nitrification are present. Saltpetre was long extracted from the soil exclusively, as in many places of Egypt, India, &c. By the oxygen of the atmospheric air contained in the soil, the hydrogen and nitrogen of the ammonia—produced from the constituents of the air—are oxidized, water and nitric acid being the products. But this nitric acid, as soon as it is formed, meets with a substance in the soil—humic acid or humin—which, by its influence, is converted into apocrenate of ammonia, and, at the same time, produces carbonic acid, instead of formic or oxalic acids. This change of humic acid into apocrenic acid takes place in minute quantities, as is the case with the formation of ammonia which precedes it. Thus, to form 1 equivalent of apocrenic acid, there are required 2 equiv. of humic acid, 1 equiv. of ammonia, and 76 equiv. of oxygen, thus :—

	C^{80}	H^{33}	N	O^{106}
1 equiv. of apocrenic acid,	C^{48}	H^{12}		O^{24}
1 equiv. of ammonia,		H^{3}	N	
32 equiv. of carbonic acid,	C^{32}			O^{64}
18 equiv. of water,		H^{18}		O^{18}
	C^{80}	H^{33}	N	O^{106}

In this production of apocrenic acid, the ammonia from the humate of ammonia is only transferred to the apocrenic acid, but it performs an intermediate part, namely, the fixing of oxygen. Through the tendency of ammonia to form nitric acid, the oxygen of the atmospheric air contained in the soil is combined with the constituents of the humic acid, the ammonia itself remaining unchanged, neither leaving the soil, nor being oxidized into nitric acid. If there be not an abundance of organic matter, and if the air be moist, and lime, magnesia, or potash, be present, ammonia is first produced, and afterwards nitric acid. If, on the contrary, instead of these bases, organic substances are in excess, humic acid is formed by their decay; at the same time, ammonia is produced from the nitrogen of the atmosphere; and finally, apocrenate of ammonia, carbonic acid, and water.

This formation of apocrenate of ammonia by the oxidation of humate of ammonia, is continually going on in the soil during the warmth of summer, (except on the very surface, which is directly exposed to the air.) Each minute portion produced can be taken up by the roots of plants, in the form of double apocrenates of ammonia and various fixed bases, provided there be a sufficient supply of water at hand; and whilst in this way the soil loses its apocrenates, a new portion of apocrenate of ammonia is formed from the humic acid or humin, which is present in large excess.

Thus we may call the production of apocrenic acid, in one respect, an organic nitrification.*

We have hitherto represented the apocrenic acid as formed directly from the humic acid. But the existence, in the soil, of a substance which is composed of $C^{40}H^{12}O^{14}$, instead of $C^{40}H^{12}O^{12}$—namely, the geïc acid—renders it probable that the apocrenic acid derives its origin, not from humic, but from geïc acid, the several acid substances succeeding each other in this order,—ulmic, humic, geïc, apocrenic acid. This series is concluded by a fifth important substance, a final product of the oxidation of organic substances before they are entirely changed into carbonic acid and water, namely, *crenic acid.*

The composition of this acid, as already mentioned, is $C^{24}H^{12}O^{16}$. It also is combined with ammonia in the soil, and forms double salts which are soluble in water.† These exist, along with the apocrenates, in all kinds of water, which have been in contact with organic substances in the soil. They were first found by Berzelius, in spring water; they exist also in the water of ditches, marshes, and bogs. The crenate of ammonia, when combined with oxide of copper, contains also a variable per centage of water and ammonia,

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* For the facts upon which these propositions are founded, see Scheik. Onderz., Vol. II.

† See the note at p. 155.

like the apocrenates of ammonia obtained in the above mentioned analyses of different soils (p. 131). The specimens analyzed gave, after subtraction of the oxide of copper:—

$$C^{24}H^{12}O^{16}+NH^4O+Aq.$$
$$2(C^{24}H^{12}O^{16})+NH^4O+2Aq.$$

According to the atomic weight of crenate of ammonia, as determined by Berzelius, the crenic acid is four-basic. Of this acid, therefore, the following series of combinations may exist in the soil:—

$$C^{24}H^{12}O^{16}+4NH^4O$$
$$C^{24}H^{12}O^{16}+3NH^4O+KO$$
$$C^{24}H^{12}O^{16}+2NH^4O+KO+CaO$$
$$C^{24}H^{12}O^{16}+NH^4O+KO+CaO+MgO$$

Just as in the apocrenates, there will be in these salts a larger portion of crenate of ammonia, according as the quantity of ammonia in the soil is increased. Now, during the warmth of summer, the moist air, contained in the soil, has a continual tendency to form ammonia. Among the bases of the crenates, therefore, the ammonia will be the most prevalent, just as in the case of the apocrenates.

Berzelius has stated, that apocrenic acid is easily formed from crenic acid, by the action of atmospheric air. Oxygen is absorbed, and nothing but water produced:—

	C	H	O
2 equiv. of crenic acid, .	48	24	32
1 equiv. of apocrenic acid,	48	12	24
Difference, . . .		12	8
Add 4 of oxygen from the air,			4
12 of water produced, .		12	12

But Berzelius has remarked that, on the other hand, apocrenic acid can be converted into crenic acid by nitric acid:—

	C	H	O
1 equiv. of apocrenic acid,	48	12	24
1 equiv. of crenic acid, .	24	12	16
Difference, . . .	24		8
Oxygen from the nitric acid,			40
24 equiv. of carbonic acid,	24		48

By the continual tendency to nitrification in the soil, therefore, apocrenic acid must always be converted into crenic acid, the series of ulmic, humic, geïc, and apocrenic acids, thus terminating with crenic acid. In the upper layer of the soil, however, where the air is not inclosed, and consequently no tendency to nitrification exists, crenic acid must conversely be changed into apocrenic acid.

All that we have said here, regarding the formation of the apocrenic and crenic acids from the ulmic, humic, and geïc acids, through the influence of warmth and moist inclosed air, applies also to charcoal, and generally to all coaly substances. For we know that from charcoal apocrenic acid is formed by the action of nitric acid. We need not repeat that charcoal must, of necessity, promote the growth of plants, because, through the organic nitrification already described, which takes place in moist charcoal containing atmospheric air, first, ammonia is formed, and then, as this becomes oxidized, nitric acid and water. By this acid, again, the charcoal is changed into apocrenic acid and ammonia, and this apocrenic acid, by the progressive organic nitrification, is converted into crenic acid. Thus it is not at all singular, that by means of moist charcoal mixed with wood ashes, the growth of plants should be promoted.

This brief exposition of the peculiar changes which take place in the soil, may now be brought to a close. They are sufficiently plain of themselves. One point, however, remains to be noticed. The ulmic acid is produced from organic substances—for instance, from those which are neutral, such as cellulose (woody fibre), starch, &c.—carbonic acid being produced at the same time. Thus if

	C	H	O
From 2 equiv. of cellulose,	48	42	42
We take 1 equiv. of ulmic acid,	40	14	12
8 equiv. of carbonic acid,	8		16
14 equiv. of water, . .		14	14
Or the sum, ...	48	28	42

—then, of the 42 equivalents of hydrogen, 14 are still wanting, which, during the rotting or the slow decay of wood, must be otherwise worked up. In fact, this hydrogen, in the nascent state, promotes the production of ammonia from the nitrogen of the air. Such is the case, also, in the formation of apocrenic and crenic acids. For instance, if

	C	H	O
From 2 equiv. of humic acid, .	80	24	24
We take 1 equiv. of apocrenic acid,	48	12	24
There remain, ...	32	12	

So that, by the absorption of 64 equivalents of oxygen from the atmosphere, all the carbon would be converted into carbonic acid, and again 12 equivalents of hydrogen would be left behind.

It deserves particular notice, that hydrogen is always liberated whenever those substances which are the most generally diffused in the vegetable kingdom, are changed into constituents of the soil—that is, when cellulose, starch, gum, sugar, &c. are in a state of decay. First, these substances are converted into ulmic acid, and that again becomes humic acid; from this, geïc acid is formed, which again produces apocrenic acid, and from that, finally, crenic acid is derived. This whole series of transformations must be passed through, before the organic substance is converted into carbonic acid and water. The whole process consists in an oxidation, and so may be called a slow combustion. It is evident, from the composition of the five substances mentioned, that during the formation of humus a new quantity of oxygen is continually fixed. Thus—

Ulmin and ulmic acid, . .	$C^{40}H^{14}O^{12}$
Oxygen from the air, . .	O^{2}
Form, ...	$C^{40}H^{14}O^{14}$
Which is equal to—	
Humin and humic acid, . .	$C^{40}H^{12}O^{12}$
2 equiv. of water, . . .	$H^{2}\ O^{2}$
	$C^{40}H^{14}O^{14}$

Again,—

Humin and humic acid, . .	$C^{40}H^{12}O^{12}$
With oxygen from the air, .	O^{2}
Form geïc acid, ...	$C^{40}H^{12}O^{14}$

Or, let us suppose that cellulose is at once converted into a portion of each of the three acids—the ulmic, the apocrenic, and the crenic acids. Then we have—

Ulmic acid,	$C^{40}H^{14}O^{12}$
Apocrenic acid,	$C^{48}H^{12}O^{24}$
Crenic acid,	$C^{24}H^{12}O^{16}$
Making together,	$C^{112}H^{38}O^{52}$

When these three acids are thus produced from cellulose, (carbonic acid and water being formed at the same time,) thirty of hydrogen (H^{30}) remain behind. Thus—

5 equiv. of cellulose,	$C^{120}H^{105}O^{105}$
Ulmic, apocrenic and crenic acids as above,	$C^{112}H^{38}O^{52}$
37 equiv. of water,	$H^{37}O^{37}$
8 equiv. of carbonic acid,	$C^{8}O^{16}$
30 equiv. of hydrogen,	H^{30}
	$C^{120}H^{105}O^{105}$

Thus, in whatever way we suppose the decomposition of cellulose, starch, gum, sugar, &c., to take place, there is always an excess of hydrogen. This may be shown by two additional examples:—

First, suppose ulmic acid to be changed into crenic acid. Then—

Ulmic acid,	$C^{40}H^{14}O^{12}$
With 36 equiv. of oxygen from the air,	O^{36}
Make together,	$C^{40}H^{14}O^{48}$

Which are equal to—

Crenic acid,	$C^{24}H^{12}O^{16}$
16 equiv. of carbonic acid,	$C^{16}O^{32}$
2 equiv. of hydrogen,	H^{2}
	$C^{40}H^{14}O^{48}$

Second, suppose all the carbon from ulmic, apocrenic, and crenic acids to be oxidized by the oxygen of the air, then we have—

Ulmic acid, . . .	$C^{40}H^{14}O^{12}$
Apocrenic acid, . .	$C^{48}H^{12}O^{24}$
Crenic acid, . . .	$C^{24}H^{12}O^{16}$
	$C^{112}H^{38}O^{52}$
Add to this 172 equiv. of oxygen from the air, .	O^{172}
	$C^{112}H^{38}O^{224}$
And deduct 112 equiv. of carbonic acid, which are formed,	$C^{112}\quad O^{224}$
And there remain 38 equiv. of hydrogen, . .	H^{38}

This hydrogen, when liberated, is, no doubt, to a great extent, oxidized into water; but while becoming free, it promotes the formation of ammonia from the nitrogen of the air, and this again of saltpetre. In the same way, as we have already seen, the repeated formation of apocrenic and crenic acid in the soil is effected.

From what has been stated, the observation of De Saussure, that the soil yields just as much carbonic acid, as it absorbs of oxygen—cannot possibly be accurate; for the existence of ulmic, apocrenic, and crenic acids in the soil, contradicts his theory.

We now approach, in its natural order, the important question, whether plants take organic substances from the soil—as crenates and apocrenates, gëates, humates, and ulmates, for example—or whether they live only on carbonic acid, ammonia, and water; or whether they do both. It were useless to enter here into a prolix exposition of what is known on this subject, since it more properly belongs to the chapter *on the nourishment of plants*. We shall here, therefore, advert only to what is supplied to plants from the atmosphere and from the soil, in addition to the substances we have hitherto spoken of, and which are never wanting in an arable soil. We intend to show what, besides the substances already mentioned, they may absorb; and inquire afterwards what they do really absorb, and in what way the component parts of plants are thence built up.

The black layer of soil, as regards its organic portion, is composed of insoluble ulmin and humin, of soluble ulmates, humates, gëates, apocrenates and crenates of ammonia, potash, soda, lime, magnesia, and oxide of iron. Till recently the opinion prevailed, that the humic acid was the especial feeding substance of plants;—that, in certain circumstances, it could become soluble in water; and that this solution of humic acid was absorbed by the roots of plants, new substances being formed from it in the plant itself: for this humic acid is composed of carbon, hydrogen and oxygen, three of the four elements of which all the parts of vegetables and animals are built up. The fourth element, namely, the nitrogen, caused some difficulty. It was not found in the humic acid, prepared from sugar, and it was overlooked in the acid, which exists in the soil.* Thus, an essential part of what is required to form organic substances, was still wanting. Boussingault thought that this fourth element, the nitrogen, was condensed from the atmosphere in the soil; he did not, however, indicate how this takes place.

The ancient idea was, that plants take all their food from the soil. But this was contradicted by a great many observations. First, many plants live in the atmosphere only; of others, the roots are fixed in the soil, but in such a soil as contains only a small quantity of soluble, and even of organic substances—at all events, much too little to supply nourishment to the plants. It is a known fact, that from good clay soils, which contain only a small proportion of organic substances, thousands of pounds of vegetable produce are reaped every year, although few or no organic substances—in the state of manures—be added to these soils. Are the organic constituents of such a soil inexhaustible? The absurdity of this supposition is palpable. The example of our heath-lands, however, is still more striking. A barren sandy soil, covered with a thin layer of organic substances, is ploughed and planted with pines. Nothing more is needed to make such a soil produce, in the course of time, a thick layer of organic substances, though nothing be laid on it from without. Here, therefore, the plants supply organic substances to the soil, that is, they do just the reverse of what the old theory supposes.

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* Sprengel.

If we consider, besides, that the luxuriant vine grows in a handful of soil, which is sometimes artificially laid down in the corners of the rocks; that many Cacti adhere to rocks, living where no soil is found at all; that many Orchidea are really air-plants, and do not require soil at all, but only an atmosphere which is suited to their nature; that in the natural forests, whence thousands of pounds are every year carried off for use, without any thing being returned, the quantity of organiç substances, with which the soil is covered, is continually increasing; that not a few farms can wholly supply their own wants, without laying any thing on the soil, except the products of the farm itself, though immense quantities of beef, grain, fruit, &c., are yearly carried off, and that such a farm continues to be among the most productive; that our pastures are yearly deprived of immense quantities of organic substances through our herbivorous stock, which carry off from the land immense quantities of beef and mutton, exceeding greatly the quantity of organic substances which they receive; that from meadows which are never supplied with an organic substance, immense quantities of hay are yearly carried off; finally, that the naked rock, where no soil is to be found at all, is, without any artificial aid, covered first with mosses, and afterwards with larger plants, till at last it is adorned with the most luxuriant woods, and covered with a continually increasing layer of black soil;* if we add further the numerous other examples, which will occur to every one;—then the conclusion is incontrovertible, that it is by no means indispensable that the soil should contain *all* the substances which nourish plants.

But since plants require to be fixed in the soil, and have roots for that purpose, are we entitled to suppose that the soil is not indispensable to their nourishment? This can by no means be asserted; all that we maintain is, that all the materials upon which, in certain circumstances, plants may thrive, are not continually present in the soil, and do not require to be so; that these substances need not constitute an essential part of the soil.

In order, then to conceive by what means plants may live, which have either no organic substances, or no sufficient sup-

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* Linnæus, de Telluris Habitabilis Incremento.

ply of these to live upon, it must be borne in mind that they receive nourishing substances, if not *from*, yet certainly *through*, the soil.

By the rain-water, carbonic acid is carried down into the soil, which is already thoroughly penetrated by the atmospheric air, and contains condensed ammonia besides. Thus the four organic substances are at hand in the soil. The water, atmospheric air, ammonia and carbonic acid, supply to the small roots of plants four primary materials, from which the plant may prepare all its organic parts. Here, therefore, we see food supplied to the roots of plants *through* the soil, but *from* the atmosphere ; and we can conceive how a soil may be *poor* in organic substances, and yet *rich* in plants.

When the soil really contains organic substances, the plants will thrive more luxuriantly the more these substances are enabled, by the presence of water and atmospheric air, to supply carbonic acid and ammonia, which are the main requisites. Here we see the vegetable kingdom appearing in a form peculiarly its own. The leaves which fall every year are thrown upon the ground, and after a time are withdrawn from sight. If in contact with a moist atmosphere, they gradually turn brown, decay, and form a powdery, dark-colored substance ; they putrefy, and as this process goes on, they give off a large portion of carbonic acid, which is diffused through the atmosphere, to be taken up by other plants. The brown, powdery residue of the putrefied leaves is ulmin and ulmic acid, and of itself is not fit to be taken up by plants in such a quantity as is requisite for their nourishment.

Finally, the putrefying animal portions produce ammonia, and, at the same time, carbonic acid ; and during their putrefaction, yield a continually increasing quantity of these. Hence the reason, why the arable soil is beneficial, nay indispensable to the greater part of plants ; hence also the utility of animal and vegetable manures, which enter the roots of plants, not in the form in which they are added to the soil, but in a state of either partial or of entire decomposition, and so in the form of carbonic acid and ammonia. Hence the reason, also, why soils, which contain either few or no organic substances, can yet enable plants to live and thrive, because the atmospheric air carried in by the rain-water can introduce into the soil, though to a smaller extent, the same substances which in arable land can be produced from humic acid and manures.

Though from all these incontrovertible facts, so beautifully connected together by Liebig, we have ascertained, that carbonic acid, water and ammonia, carried down from the atmosphere into the earth's crust and to the roots of plants, are a very healthy nourishment for many of them—we are not thereby precluded from asserting, that the ulmates, humates, and gëates in the soil, which are soluble in water, as well as the crenates and apocrenates, can also be taken up by the roots of plants ; nay, that to a great many they are absolutely indispensable. We shall return to this subject when treating of the nourishment of plants. Here we would only mention that some plants, for instance the mosses, which grow upon naked rocks, are really fed *exclusively* by means of the constituents of the atmosphere, carried down into the soil ;—which is, *more or less*, the case with all other plants ;—this fact being as incontrovertible, as that very few plants only can live on carbonic acid, water, and ammonia alone, and that by far the greater number must find organic matters in the soil to live and thrive upon. A simple glance at the practice of the horticulturist establishes this truth in the clearest manner.*

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* Among the facts mentioned by Liebig, to demonstrate that carbonic acid, water, and ammonia, do in truth exclusively supply nourishment to plants, are those relating to their culture in powdered charcoal. Having already (page 161,) investigated the value of this fact, I shall here add only this further illustration :—

Professor Numan informs me of peculiarities with regard to this point, which well deserve to be stated.

Rye, oats, buck-wheat, and turnips, were sown in dry sand, contained in pots—the first three on the 21st of June, the turnips on the 29th of July. The uppermost layer was mixed with some coarse charcoal powder and peat-ash.

The buck-wheat was full grown in the beginning of September, blossomed very well, and in the latter part of that month ran to seed, which ripened.

The rye came up at the usual time, namely, 10 or 12 days after sowing. It had a fresh dark-green color, and reached in September the height of about one span and a half.

The oats also regularly advanced in growth, and had an uncommonly beautiful greenish blue color. The plants reached the height of 24 inches, and had broad and thick leaves. In the end of September these began to wither. A few stocks ran to seed, which, however, did not attain ripeness.

We have, therefore, now become acquainted with the atmosphere as an important, though not the exclusive, source of nourishment to the existing races of plants.

The service performed by the inorganic substances of the earth's surface must differ, according as they supply nourishment to plants from the constituents of the atmosphere, or from organic substances in the soil. Their relation to the carbonic acid is not known; neither is it known how they supply ammonia to plants, or how carbonic acid and ammonia are influenced by decaying rocks, wherever these two, together with water, must exclusively constitute the organic nourishment of plants. Carbonate of ammonia, if in contact with the roots of plants, though in a very diluted solution, has always a poisonous effect. It is still unexplained how those plants which live only on the atmosphere are fed, and what may be the influence exercised upon plants by the powdery substances in the soil, while supplying this atmospheric food.

As to the organic feeding substances, their relations are not unknown. The bases combine with the acids, and enter into the plants in the state of ulmates, humates, gëates, apocrenates, and crenates. There is, however, among the inorganic substances in the soil, one base entitled to particular notice, namely, alumina. In good arable land, it ought not to be absent. Its use is of importance. It combines with the apocrenic and crenic acids into compounds insoluble in water; and it is, therefore, by this substance that the whole quantity of these acids, present in the soil, is prevented from being washed out by the rains. Sandy soils are especially liable to this disadvantage. The spring waters of our moors are colored brown by apocrenates; while, in our clay soils, these

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The turnips also grew very luxuriantly, and are still perfectly green, (I saw them in January.) They have here and there very good tubers, which, however, would be much larger had the seed been more thinly sown.

It must be remarked, that from the 15th of August to the 15th of September, but little rain fell, so that the sand in the pots was completely dry, and they all continued to grow luxuriantly, though no water had been supplied to them.

The above seeds, sown in sand of which the upper layer was mixed with charred turf powder, gave almost the same results.

In sand alone, without the addition of charcoal, the seeds germinated well, but the plants remained exceedingly small, and died without producing seed.

waters are colorless, and almost free from organic substances, although they are equally penetrated by a layer of humus. These two organic acids are both thrown down from their solutions by recently precipitated alumina.* The crenic acid can be again set free from its combination with alumina, by ammonia. In small quantities, therefore, it is supplied as food to plants, ammonia being continually produced in the soil. By the alumina (clay), as well as by the other bases in the soil, another important service is performed, namely, that of preventing these two acids from being decomposed into carbonic acid and water, and thus preserving them unchanged, when once formed in the soil, for a very long period of time, till plants begin to grow, to take them up, and to convert them into food.

In this manner the decayed rocks again show their close and intimate connexion with organic nature; and we may thus understand how indispensable the dead earth is to every living being which now exists upon it.

NOTE.—*Upon the Organic Acids in the Soil.*

I have been unwilling to interrupt the narrative of the author in this very interesting chapter, or farther to load the pages with notes. I have reserved, therefore, for this place, a few remarks upon the organic acids in the soil. It is now several years since I made, and partly published, the results of an examination of some of these acids, and as these results add something to the facts stated above by Mülder, I shall here briefly explain them.

1. At the bottom or towards the lower part of most of the old and deep peat bogs in Scotland and Ireland, a black compact substance is here and there met with, in which no trace of vegetable fibre is to be observed, and which, when dry, breaks with the fracture and lustre of coal. I have analyzed this substance from both Scottish and Irish bogs, and have found it so far to agree with the humic acid of Mülder, as to consist, in its organic part, of carbon and water only. The acid, however, is never in an uncombined state. It always contains a trace of ammonia, with from 2 to 6 or 8 per cent.

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* Berzelius, Lehrbuch, Bd. 8, S. 401, and 410.

of alumina or lime alone, or of a mixture of these with oxide of iron.

2. Having received from Lord Willoughby de Eresby a quantity of his compressed peat, prepared from the black, soapy-looking peat of his estates in Perthshire, I digested a portion of it in fine powder in weak ammonia. It swelled up very much, became bulky, spongy, and difficult to wash, and gave a dark-brown solution, from which muriatic acid threw down a dark-brown acid. When dried and analyzed, the black, coaly acid was found to be a *humic* acid, containing carbon and water only. The salt of copper, however, gave me for the formula of the acid $C^{24} H^{12} O^{12}$. It differs, therefore, in the weight of its equivalent, from any of the humic acids of Mülder.

3. When treated with solutions of caustic potash, or of carbonate of potash, or carbonate of soda, the peat did not swell up as in ammonia, and gave a dark-brown solution, from which muriatic acid threw down a brown, flocky precipitate, very different in composition from that yielded by the ammoniacal solutions. When dried, this brown precipitate had the same black, coaly aspect as the humic acid already described, but its properties and composition differed considerably.

When heated in the air, it gave off white vapors, and a strong smell of burning peat. By the application of a taper, the vapors took fire and burned with a bright flame. The humic acid obtained by ammonia gave off scarcely a trace of these vapors, and only a faint odor of burning peat. The smell appeared to indicate that the acid extracted by alkaline carbonates, pre-exists in the natural peat—and the white combustible vapors, that it contains more hydrogen than the substance extracted by ammonia.

This was confirmed by the analysis of portions of the acid prepared at various times, and precipitated by different acids. The formula for this acid is $C^{24} H^{14} O^{9}$, agreeing therefore with the ulmic acids of Mülder, in containing an excess of hydrogen, but not being reducible to his ulmic group—the excess of hydrogen being very much greater than in his ulmic acid, and the equivalent containing only 24 of carbon, while that of Mülder contains 40 equivalents of carbon. The difference in the proportions of hydrogen in the two acids, will be most readily seen by comparing the formulæ for the two acids, supposing the equivalent of both to contain 40 of carbon (C^{40}) :

	C	H	O
Ulmic acid from Frisian peat (p. 147),	40	17	15
Ulmic acid from Scottish peat, - -	40	23	15
Difference, - - - - - -		6	

The acids here described agree with those of Mülder in their tendency to unite with several bases at once, and thus to form compounds soluble in water containing bases, with which, when alone, they form compounds nearly insoluble in water. They also, even when dry, absorb oxygen and nitrogen from the air, producing ammonia and acids, containing more oxygen than the humic and ulmic acids. The dry acids kept in well-corked bottles, after the lapse of twelve months had absorbed a considerable proportion of the air, and gave to alcohol a soluble salt, containing an organic acid in combination with much ammonia. It is almost impossible, as I have found, to prepare a portion of the acid from peat by means even of caustic potash, which will not give evidence of the presence of ammonia, when burned with oxide of copper: but it is only after a prolonged exposure to the air that it contains enough to give a decidedly dark-colored solution when boiled in alcohol.

4. It may naturally be asked, how, from the same peat, ammonia and carbonated alkalies extract substances so different in composition? Both acids are soluble alike in both fixed alkaline and in ammoniacal solutions; both therefore, do not exist ready formed in the peat. From the resemblance of the acid $C^{24}H^{14}O^{9}$ to the peat itself in giving off a strong odor of peat when burned, and, at a temperature of 500° or 600° Fahr., white vapors, which condense among other products into a white solid carbo-hydrogen, I believe it to exist ready formed in peat, and that the humic acid $C^{24}H^{12}O^{12}$, is produced from it.

a. If, for the sake of comparison, we represent the two acids by formulæ, in which the number of equivalents of oxygen is the same—we should have

	C	H	O
For the one acid (ulmic),	40	23	15
For the other (humic),	30	15	15
Difference,	10	8	

This difference is equal to two equivalents of a carbohydrogen C^5H^4, which may be supposed to be present in the acid with excess of hydrogen. If, by a cautiously regulated heat, such a compound could be driven off from it, then the humic acid would be produced. When the acid is dried at too high a temperature, this sometimes takes place to a certain extent, and the proportion of hydrogen is in consequence diminished.

b. Or the acid $C^{24} H^{14} O^9$ may be oxidized by the action of ammonia in the presence of the air. If this takes place directly, then each equivalent must absorb five equivalents of oxygen from the air. Thus,

	C	H	O
To the acid, . .	24	14	9
Add from the air, .			5
And we have, . .	24	14	14

which is equal to $C^{24} H^{11} O^{11} + 3HO$.

This is what I believe takes place either immediately or ultimately. This opinion is founded on the fact, that, when the acid obtained by means of carbonate of soda and sulphuric acid was dissolved in diluted ammonia, and boiled for a length of time, the solution gradually acquired an *acid* reaction, and threw down from a solution of sulphate of copper an insoluble dark brown compound, the organic part of which was represented by $C^{24} H^{11} O^{11}$—that is, the one acid was changed into the other.

5. On certain parts of the rocky coast of Cornwall, where caves occur, the surface water is observed to trickle through the granite rock, and gradually to cover the sides of the caves with a deposit of greater or less thickness. This deposit, which was first collected by a Mr. Pigot, has been called Pigotite by mineralogists. It consists of an organic acid, in combination with alumina in proportions which vary considerably in different specimens, showing that, like other acids, it

forms with alumina combinations in which different proportions of acid and base are present. Some portions of the Pigotite have the aspect and semi-transparency of resin—being in fact the appearance which gelatinous alumina and numerous gelatinous compounds assume when they are allowed to dry slowly in the air. The quantity of water present in this native product is therefore in some degree variable, but always large. When dried at 212° Fahr., it loses about 26, at 300° about 32 per cent.

When heated in the air over the lamp, the compound blackens, but the carbon burns away with extreme slowness. When reduced to powder, it dissolves readily in a solution of caustic potash, with the aid of heat, and is thrown down again by muriatic or sulphuric acid, apparently unchanged. The proportion of alumina in the precipitate may be changed by this treatment, but the organic acid itself is not altered in composition. The acid itself is separated from the alumina with extreme difficulty and slowness by caustic ammonia, and by carbonated alkalies. In the silver salt it is represented by the formula $C^{12} H^5 O^8$, and is tribasic,—this quantity of acid uniting with 3 equivalents of oxide of silver. In the native compound of alumina, the acid is represented by—

	C	H	O	Aq
Native compound,	12	5	8	27
Dried at 212°, .	12	5	8	10
Dried at 300°, .	12	5	8	8

The quantity of alumina present being 4 double equivalents. But, as I have already stated, the water varies. The alumina also varies from 44 to 48 per cent. of the dry salt, and is present, no doubt, in different states of saline combination—perhaps even in the state of *hydrate*. Traces of nitrogen are always observed in the analysis of this salt, showing that, like the other acids formed in the soil, it has a strong tendency to unite with ammonia. That this nitrogen, however, does not form a constituent part of the acid, is shown by the fact, that when dissolved in caustic potash, and precipitated by an acid, the composition of the organic part remains unchanged.

This acid is obviously formed from the decaying vegetable matter of the soil above, with the alumina of which it combines, and from which it is washed by the rains or springs, and descends through the crevices of the rocks into the caves below. The organic matter may not descend in the form of this acid, but may as it trickles down the sides of the cavern, undergo a further oxidation, and be converted into this acid. It approaches very closely in composition to the crenic acid, as analyzed by Mülder, and may even eventually be shown to be identical. Before Mülder's crenic acid was analyzed, I had proposed for this acid the name of Mudesous acid.

6. When the native Mudesite of alumina is treated with nitric acid, red fumes are given off, the Mudesous acid undergoes oxidation, and a new acid—the Mudesic—is formed, which is represented by the same formula as the Mudesous, with the addition of two equivalents of oxygen. Thus—

The Mudesous, . . . $C^{12} H^5 O^8$
The Mudesic, . . . $C^{12} H^5 O^{10}$

There can be little doubt, I think, that this oxidation takes place in nature also, in favorable circumstances; and, therefore, that the Mudesic acid is sometimes formed in the soil.

7. From what is above stated, it appears that, to the acids mentioned by Mülder, several others may be added as occurring in certain circumstances in the soil,—forming successive steps in the series of changes through which vegetable matter passes, on its way from the substance of the living plant to the state of carbonic acid and water, into which it is finally resolved. There are three groups of acid and other compounds, into which the organic substances of the soil may be arranged:—

a. The *humic* class, which may be represented by carbon and water only.

b. The *ulmic* class, in which the hydrogen is in excess; and

c. The *gëic* class, in which the oxygen is in excess.

The acid extracted by ammonia from Scottish peat belongs to the first; that extracted by carbonate of soda, to the second; and the Mudesous and Mudesic acids, to the third. An unwillingness to lengthen this note, prevents me from further expounding this view, which, to the scientific chemist, is perhaps less necessary, as I shall hereafter treat of it more fully in another work.—J.