XVII.—*Observations on the Principle of Vital Affinity, as illustrated by recent discoveries in Organic Chemistry.* By WILLIAM PULTENEY ALISON, M.D., F.R.S.E., Professor of the Practice of Medicine in the University of Edinburgh.

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PART I.

THE most important steps in a science are those which lead most directly to the establishment of principles or laws peculiar to that science itself, and which constitute its claim to be regarded as a distinct branch of human knowledge. It has been long acknowledged that such is the character of many of those phenomena of living bodies which depend on mechanical movements, or changes of position in their particles, and therefore that the laws of vital contractions are to be regarded as equally elementary and distinctive principles in physiology, as the laws of motion or of gravitation in natural philosophy. But a difficulty has been long felt, as to whether a similar claim to peculiarity of the principle on which they depend, can be urged for the chemical phenomena of living bodies.

In laying down the first principles of Physiology and of Pathology, I have, however, uniformly maintained the existence of a power peculiar to living bodies, and to which the term Vital Affinity, as recommended by several authors, may be properly applied;—a power by which “the elements of nutritious matter are thrown into the combinations necessary for forming the organic compounds, and restrained from entering into other combinations, to which they are prone as soon as life is extinct;—a power which supersedes and counteracts ordinary chemical affinities in living bodies, as completely as vital contractions counteract gravitation or the inertia of matter.”—(*Outlines of Human Physiology*, p. 22.) And in delivering lectures on physiology, I always expressed my belief that a time would come, when discoveries in the chemical department of the science,—connecting the ingesta of living bodies with the nourishment of their different textures, and with the nature of the different excretions,—would elucidate the chemical changes which are continually going on in them, and are essential to their living state, as completely as the discovery of the circulation of the blood illustrated many of the conditions of the existence of living animals. It appears to me that this anticipation has been more nearly realized by recent chemical observations, than professed physiologists have yet admitted;—that not only the existence of the principle of vital affinity has been established, but its limits and mode of

action, the cases in which it acts, and those in which it is unconcerned, are to a certain degree defined;—and that a short and general illustration of these points may be of some advantage, if not to the progress of the science, at least to the due appreciation, and proper generalization and expression of the knowledge which has been already acquired.

To shew the importance of this inquiry, I need do no more than quote a single sentence from CUVIER, with a statement which is nearly a commentary upon it by Professor WHEWELL. “It belongs to modern times to form a just classification of the vital phenomena; and upon the zeal and activity given to the task of analysing the *forces* which belong to each organic element, depends, according to my judgment, the advancement of physiology.”* “As the vital functions became better understood, it was seen more and more clearly at what precise points of the process it was necessary to assume a peculiar vital energy, and what sort of properties this energy must be conceived to possess. It was perceived when, and in what manner and degree, mechanical and chemical agencies were modified, overruled, or counteracted by agencies *which must be hyper-mechanical and hyper-chemical*.” “In attempts to obtain clear and scientific ideas of the vital forces, we have first to seek to understand the cause of change and motion in each function, so as to see at what points of the process *peculiar causes* come into play; and next, to endeavour to obtain some insight into the *peculiar character and attributes of these causes*.”†

When we say that the chemical changes which take place in living bodies are elucidated, we mean, of course, that they are referred to general laws, by which the phenomena observed in this department of Nature are found, by experience, to be regulated. And when we say that these are laws of vitality or of vital action, we mean merely, that they are laws deduced from the observation of phenomena peculiar to the state of life,—taking for granted that it is always possible to describe, and practically to distinguish, those substances which we call living, from inorganic or dead matter; and that the only correct definition of vital principles or vital powers, is, that they are the laws or the powers which regulate the phenomena that are peculiar to the state of life. They are the general expression of the results of the observation, and generalization of the facts, which are observed in this department of nature, and which are ascertained to belong to this department alone.

We are not, indeed, justified in asserting the existence of laws peculiar to the state of life, merely by the *negative* observation, that the phenomena referred to them are *inexplicable* by any known laws of inorganic or dead matter; we must have the *positive* observation that they are *inconsistent with*—that they take place

* Hist. des Sciences Naturelles depuis 1789, p. 218.

† Philosophy of the Inductive Sciences, vol. ii., pp. 39 and 47.

in despite of—the laws which regulate the changes of dead matter. It is thus that we are led to ascribe the visible movements of living bodies to vital powers; not because we do not perceive how gravitation, elasticity, or any other known causes of movement in dead matter should produce them, but because we do perceive, that, in the circumstances in which we see these motions, all those principles, deduced from the observation of dead matter, would determine either rest, or motion in a different direction from that which really takes place.

I formerly laid before this Society the grounds of an opinion, then much disputed, but now, I think, pretty generally admitted, that there are Attractions and Repulsions, as well as contractions, peculiar to the living state: chiefly, but not exclusively, observed at those parts where chemical changes are effected in living bodies, and connected with these changes; and, without reference to this general fact, I maintain that it is impossible to have a right understanding of many phenomena of essential importance in physiology and pathology.*

But the general principle is obviously equally applicable to chemical changes as to mechanical movements. It is not, indeed, so easy to ascertain, in regard to chemical changes in living bodies, that they are truly inconsistent with the chemistry of dead matter; the science must be allowed to make some progress before this can be confidently asserted in regard to any individual chemical change; but no one can doubt that, as science advances, it must become possible to say with certainty, whether the chemical changes in living bodies are consistent with those laws which regulate chemical changes elsewhere, or not; *i. e.*, whether the same chemical elements can be so brought together by the chemist, as to tend to the same combinations as are found in living bodies; or whether, in his hands, they will enter uniformly into other combinations, and form different compounds.

Farther, it appears to me that, even before any of the recent discoveries, it might be legitimately inferred from facts already known, that this last description is truly applicable, in some cases, to the chemistry of living bodies. It was known, for example, that when water, impregnated with carbonic acid and with a small proportion of ammonia, is brought into contact with vegetable substances, in a certain stage of their existence, the elements of these bodies rapidly combine so as to form starch, albumen, and oil, which are added to the substance of the vegetables,—that under no other circumstances can water, carbonic acid, and ammonia, or their elements, be made to form these compounds,—and farther, that after a time, when brought into contact, at the same temperature, with the same vegetable substance in an ulterior stage of its existence, they will form no such com-

* Professor WHEWELL, in his instructive abstract of the general principles ascertained in Physiology, regards it as established, chiefly on the authority of MÜLLER, in regard to the vital force concerned in assimilation and secretion, that “it has mechanical efficacy, producing motions, &c. But it exerts at the same point both an attraction and a repulsion, attracting matter on one side and repelling it on the other; and in this it differs entirely from mechanical forces.”—*Philosophy of Inductive Sciences*, vol. ii., p. 51. See also CARPENTER’S *Manual of Physiology*, § 597, *et seq.*

pounds, but will aid and participate in the successive changes to which vegetable matter is liable after the phenomena of its living state are over, and of which the ultimate result is, the resolution of that matter into its original constituents. And from these facts it seems quite reasonable to infer, that during the former, or what we call the living state of the vegetable, certain affinities peculiar to the living state—*i. e.*, certain vital affinities—actuate the elements of which it is composed.

In asserting the existence of vital affinities, we do not, in the first instance, give any opinion whether it is by the addition of certain chemical attractions, or by the suspension of others, during the living state, that the chemical changes peculiar to that state are effected; we assert nothing more than what is, as I think, correctly stated in the following sentence of LIEBIG:—"The chemical forces in living bodies are subject to the invisible cause by which the forms of organs are produced." "The chemical forces are subordinate to this cause of life, just as they are to electricity, heat, mechanical motion, and friction. By the influence of the latter forces, they suffer changes in their direction, an increase or diminution of their intensity, or *a complete cessation or reversal of their action.*

"Such an influence, and no other, is exercised by the vital principle over the chemical forces."

"The equilibrium in the chemical attractions of the constituents of the food is disturbed by the vital principle, as we know it may be by many other causes. The union of its elements, so as to produce new combinations and forms, indicates the presence of *a peculiar mode of attraction*, and the existence of a power distinct from all other powers of nature, viz., the vital principle."—(*Organic Chemistry, &c.*, pp. 355, 357).

In these passages I think that LIEBIG has expressed himself with perfect accuracy; but in other parts of his writings he uses language in regard to the nature and results of chemical changes in living bodies, which seems to me vague and speculative, and even inconsistent with what he had stated in the passages just quoted, *e. g.*, when he says that "the ultimate *causes* of the different conditions of the vital force in nutrition, reproduction, muscular motion, &c., are *chemical forces.*"—(*Organic Chemistry*, p. 10).

The following sentence by MÜLDER expresses the very same idea, although it might be thought, from the manner in which this author expresses himself against any introduction of the vital principle in this department of physiology, that he considers all the chemical changes in living structures to be referable to the same laws as in inorganic matter.

"By a small organ of a plant *a force is exercised*, exciting forces which slumbered in the carbon, oxygen, and hydrogen, or rather *modifying the forces which existed in these*, so that 12 equivalents of carbon unite with 10 of hydrogen and 10 of oxygen; and from 12 equivalents of carbonic acid (12 C O_2) and 10 of water

(10 H O) starch is produced, 12 C 10 H 10 O, 24 of oxygen passing off.”—(*Chemistry of Vegetable and Animal Physiology*, p. 67).*

But it is important to fix our attention, for a short time, on the instances adduced by MÜLDER, of the formation of starch, or some of its allied compounds, out of carbonic acid and water, by the combination of the carbon of the acid with the elements of water, and the expulsion of the oxygen of the acid ; because this is the grand and fundamental power, which must have been called into operation when organized structures were first created on earth, and on the continued exercise of which the existence of all such structures, vegetable and animal, is still essentially dependent ; and because the simplicity of the process makes it a fit case for considering the question, whether the power here named is strictly entitled to the epithet vital ; or whether, as some eminent physiologists in this country maintain, the idea expressed by that term is incorrect and unscientific.

The opinion of those who oppose the doctrine of vital affinity, is thus distinctly stated in the *Anatomy* of Drs QUAIN and SHARPEY :

“ Although the products of chemical changes in living bodies for the most part differ from those appearing in the inorganic world, the difference is nevertheless to be ascribed, not to a peculiar or exclusively vital affinity different from ordinary chemical affinity, but to common chemical affinity, operating in circumstances or conditions which present themselves in living bodies only ; and undoubtedly the progress of chemistry is daily adding to the probability of this view.”

I consider this to be a hasty and ill advised statement ; and to shew this, I request attention, *first*, to the perfect simplicity of the apparatus by which this change is effected. “ In all plants,” says MÜLDER, “ there exists a small organ, of the most simple form, although employed by nature for the most varied purposes. It is a small filmy sac, a thin membrane, which encloses a small space, which it enables to communicate with the exterior space through invisible pores. These little sacs or cells are the chief organs of plants. A countless multitude of them, grouped together, forms the whole bulk of the plant, so that if every thing except the cells be destroyed, the shape and size of the plant are not in the least changed or diminished.”

Into this simple apparatus in certain parts of plants, water, impregnated with carbonic acid, is introduced, while the plants exhibit the phenomena of life ; and

* In the foregoing and other translations from recent German writers, the word *force* is used in a sense which I think would be much better expressed by the term *power* or *property*, merely on this account, that the English word *force*, in physical discussions, has usually a precise and limited meaning assigned to it, as a cause capable of producing visible motion, and of which we have a measure, either in the velocity or in the quantity of motion which it can excite ; whereas the term *power* or *property*, applied to any material substance, has a more general meaning, as simply the cause of change of any kind, and is therefore applicable where the result of the property ascribed to any substance may be very different from visible motion.

let us next observe the intensity of the action by which the carbonic acid is there decomposed, the carbon attached to the elements of the water, and the oxygen set free. "This is done by a power," says LIEBIG, "to which the strongest chemical action cannot be compared. The best idea of it may be formed by considering, that it surpasses in power the strongest galvanic battery, by which we are not able to separate the oxygen from carbonic acid. The affinity of chlorine for hydrogen, and its power to decompose water, under the influence of light, and set its oxygen at liberty, cannot be considered as nearly equalling the power and energy with which a leaf, separated from a plant, decomposes the carbonic acid which it absorbs."—*Organic Chemistry*, p. 134.

Next let us observe the extent to which this energetic power is exercised by living plants. Perhaps the most accurate idea of it may be formed from attending to the statement of THEODORE DE SAUSSURE, that on a mean of 54 observations made in a country district, the proportion of carbonic acid in the atmosphere during the night was to its proportion in the day-time as 432 to 398, *i. e.*, the carbonic acid existing in the atmosphere was found to be diminished very nearly 10 per cent. in a few hours of every day; and for this diminution we know no cause, except that this power of the green parts of vegetables, of decomposing the carbonic acid of the atmosphere, is exercised only under the influence of light.*

Now if a power of this extraordinary energy and extensive operation, and acting in so very simple a manner, were really to be regarded as depending only on ordinary chemical affinities, exerted under peculiar conditions, it might surely be expected, that the chemist might so regulate the conditions under which he might bring together carbonic acid, air, and water, as to exhibit some traces of this power, and effect some decomposition of the carbonic acid and evolution of oxygen. But we know, not only that this cannot be done, but that when air, water, and carbonic acid, are introduced into the very same vegetable cells, within half an hour after they have exhibited this phenomenon, at the same spot, under the same light, and at the same temperature, they will not only fail to exhibit the same change, but will uniformly exhibit the very reverse, *i. e.*, the absorption of oxygen and the formation and evolution of carbonic acid.

Nay, we know that it is only in certain cells of the living vegetable, that this peculiar chemical change, under the action of light, is effected; the same fluid, introduced into cells composed of the same material in the parts of fructification, undergoes no such change; but, on the contrary, gives occasion only to the reverse process, the absorption of oxygen and evolution of carbonic acid.†

Then it is to be remembered, that this complete inversion of ordinary chemical affinities, in the case of the living plant, is only one of several cases to

* See MACAIRE'S Memoir of THEODORE DE SAUSSURE, in *Edinburgh Philosophical Journal*, vol. xl. p. 31. (Jan. 1846.)

† THEODORE DE SAUSSURE, in *Edinburgh Philosophical Journal*, vol. xl. pp. 22, 23.

be afterwards noticed, where we see chemical compounds uniformly formed in living bodies, quite distinct from any that can be formed by the chemist from the same elements, and quite distinct from those to which the same elements uniformly revert, after the phenomena of life are over.

Lastly, we must remember, when we see this apparent inversion or alteration of the ordinary chemical relations of matter, taking place in the interior of living bodies, that in that scene, by the admission of all, matter comes under the dominion of *mechanical* laws, which operate in no other department of nature; so that it is quite conformable to analogy to suppose that its chemical relations will undergo a similar modification.

When all these considerations are duly weighed, I cannot perceive what further evidence can be required in order to justify the expression which I have quoted from LIEBIG, viz., that the "*new combinations*," as well as the forms, assumed by that matter which goes to the composition of organized beings, "indicate the existence of a power distinct from all other powers of nature, viz., the vital principle;" *i. e.*, that the vital principle regulates the changes of chemical composition, as well as the changes of position which the particles of that matter undergo; which is more simply expressed by saying, that there are vital affinities as well as vital contractions and attractions.

But even if we are to regard it as doubtful whether or not ordinary chemical affinities can determine, under any conditions, this decomposition of carbonic acid and evolution of oxygen by its contact with carbon and the elements of water, I maintain that it is sound philosophy, when we see this and other rapid and extensive and important chemical changes, essentially different from those which the same elements present under other circumstances, uniformly attending the phenomena of life in vegetables,—to investigate and generalize the laws by which these changes are regulated, as laws of living action, leaving it open to future inquirers, if they can, to resolve them into other laws of more general application. For although I acknowledge the force of the aphorism, "*Frustra fit per plura quod potest fieri per pauciora*," still I apprehend, that in every case to which this aphorism is applied, the *potest fieri* must be established, not by conjecture, but by experiment; otherwise we fall into the error, so strongly condemned by BACON and others, of prematurely generalizing, and supposing the laws of nature to be fewer and more comprehensive than they really are.

Having thus, in reference to this first and simplest example, vindicated the soundness of the principle which I propose to illustrate, I think we may next shew, that the main object of inquiry in the chemical department of physiology is more simple and precise, and the extent of that inquiry, necessary to elucidate most questions in physiology, much less than might be supposed from the multiplicity of details, of which what is called the science of organic chemistry is made

up. After what LIEBIG calls the "peculiar mode of attraction" which operates in living bodies, has led to the formation of certain organic compounds, these compounds lose their connection with living bodies, become liable to an infinite number of changes and decompositions, and thus give origin to an infinite variety of substances—generally of temporary duration only, because retained in their form by attractions of no great intensity—applicable to many useful purposes, *but foreign to the inquiries of the physiologist*. He is concerned only with the chemical changes which take place *in living bodies themselves, and during the state of life*; and the results of recent inquiries seem to me sufficient to shew, that the fundamental and peculiar arrangements of chemical elements there observed are less numerous, and the laws regulating them more simple, than they have usually been thought.

In considering this subject, we are enabled, by the results of the inquiries of geologists and physiologists, to revert to the period of the introduction of living bodies into the world, and reflect on the conditions then assigned for their existence. We are justified, by reason, in allowing the imagination to fall back on the time when this Earth rolled through space an inanimate mass; and if any minds, besides that of the Great Ruler of the universe, were connected with it, they did not hold their connection through the medium of any organized structure. For I believe we are justified in laying down these propositions as established, *first*, That the simply physical arrangements of this globe were completed before any organised beings were created; *secondly*, That vegetables were created and lived chiefly on the atmosphere, fixing large quantities of carbon from it on the earth's surface, before animals were called into existence; and, *thirdly*, That at whatever time their existence began, either the first living being of every species, vegetable and animal, or the first ovum from which that being was developed, must have been formed in a manner wholly different from that in which any living bodies, at least of the higher orders, are now reproduced; *i. e.*, that they must have been formed in a manner strictly miraculous, and, of course, beyond the limits of physical science.

But although we cannot ascend higher, in prosecuting this subject, than to inquire in what manner the first plants, or the germs of the first plants, were enabled so to act on the inorganic matter around them as to extract from it the materials, first of their own growth and sustentation, and afterwards of all other organized beings,—yet in the inquiry, thus limited, important progress has been made. From the time when these nascent organized bodies sprung into existence, we must regard it as an ultimate fact, that they were endowed with the power, which all the vegetables that have succeeded them have exercised, of so modifying the attractions existing among the particles of matter, as to cause many of these particles from the air and the water immediately surrounding them, to enter into their substance, by their roots and leaves, or by the organs which soon

became their roots and leaves, and then to arrange themselves there, in those peculiar forms by which the numberless species of the vegetable world are characterized. I apprehend we must also regard it as an ultimate fact, that they were endowed with the power of so modifying the chemical relations of the elements composing those absorbed matters, as to select and retain certain of these elements, and allow others to pass away from them, to decompose the carbonic acid, fix the carbon, and invest it with those peculiar affinities for the water, the hydrogen of the water, and a few other elements, contained in the surrounding media, by which all the proximate principles, first of vegetables and then of animals, and therefore the whole substance of organized beings, are formed.

But it is important to have a precise exposition, although not an explanation, of the power thus exercised by the first plants; and it is still more important and satisfactory to be able to shew how, by the exercise of these and analogous vital powers, the atmosphere must have been gradually changed, the proportion of carbonic acid in it diminished, and the proportion of oxygen increased; how it became fitted, and is kept fitted, for the residence, first of cold-blooded and then of warm-blooded animals; how most of the other conditions of existence of these animals have been, and still are, continually prepared for them by these living actions of vegetables; how all the variety of the textures of all organized bodies, from the origin of vegetables to the death and decomposition of animals, are continually formed and maintained; and how, in both divisions of organized beings, Nature has provided, not for the permanent existence, but for the development and decay of successive generations of individuals, and thus for the perpetuation of the species. These are the subjects of investigation in the chemical department of physiology; and if it can be shewn, that, by a few simple laws, regulating what we call vital attractions and affinities, *i. e.*, modifying, in organized bodies, the attractions and affinities to which matter is everywhere liable, provision is made for all this succession and continual renewal of the phenomena of life; then, although we cannot explain the introduction of living beings into the world, any more than we can explain the dissemination of the stars throughout space,—although we must always regard the appearance of organized bodies on the earth's surface as the clearest indication which human knowledge presents of the subjection of the universe, not only to general laws, but to an arbitrary Will, superior to these laws and changing them at pleasure,—yet I think it may be said that we have nearly as clear an insight into the designs and arrangements of Providence for the maintenance of living beings upon earth, and for the eternal reproduction of them there, so long as these laws shall be in force, as we have into those by which the movements of the heavenly bodies are directed and controlled.

I. Our first business is to study the facts that have been ascertained in regard to the simplest form of chemical change to which the term vital may be applied,

which is merely the *selection*, by a portion of a living structure, of some one substance existing in a fluid, and the consequent attraction of this to a particular part of the structure, while other materials, equally presented to that living part, are excluded.

We need not here enter into the question, on which chemists and agriculturists are not yet agreed, whether the nourishment of plants, in the present condition of the earth's surface, does or does not require the pre-existence, in the soil, of organic compounds, resulting from previous living beings, which are absorbed from it. But we may justly give the name of vital attraction or affinity to that power by which certain saline matters, dissolved in the compound fluid which is absorbed, are retained in the substance of the plant, while others are returned to the soil. "The experiments of MACAIRE PRINCEP," says LEIBIG, "have shewn that plants, made to vegetate with their roots, first in a solution of acetate of lead, and then in rain-water, give back to the latter all the salt of lead which they had previously absorbed. Again, when a plant, freely exposed to the air, rain, and light, is sprinkled with a solution of nitrate of strontian, the salt is absorbed, but is again separated by the roots, and removed farther from them by every shower of rain, so that at last not a trace of it is to be found in the plant. A fir-tree, the ashes of which were analysed by a most accurate chemist, grew in Norway, on a soil to which common salt was conveyed in great quantity by rain-water. How did it happen that its ashes contained no appreciable quantity of salt, although we are certain that its roots must have absorbed it after every shower? We can explain this only by the observations above referred to, which have shewn that plants return to the soil all substances unnecessary to their own existence; and we are thus led to the conclusion that the alkaline bases, existing in the ashes of plants, must be necessary to their growth, since, if this were not the case, they would not be retained." (Ib. p. 103, 4.) Another inference is at least equally obvious, that plants have the power of fixing and retaining within them, those matters which are suited or essential to their composition; and this power we regard as the simplest form of vital affinity. It may be said, that the alkaline bases are thus fixed in plants, because they enter into combination with organic acids, and that, therefore, it is the formation of these acids, not the retention of the bases which combine with them, that is truly the vital change. But this does not apply to other saline matters contained in vegetables, which must have been taken up from the soil in the same state in which they are found in the plants, *e. g.*, the phosphate of magnesia, which is "an invariable ingredient in the seeds of grasses;" or the silica which is found in certain parts of various plants.

Were it not for this selecting and appropriating power, indicating a simple attraction of some parts of the vegetable for certain earthy or saline matters only, we should find some salts of alumina, as well as of lime or magnesia, in the ashes

of almost all vegetables,—that earth existing in large quantity in all fertile soils, whereas it is “very rarely found in the ashes of plants.”

In the animal kingdom the same power of simple selection and extraction is more fully exemplified, perhaps most strikingly in the development of many of the lower classes, of which the organization is simple, and the matters deposited from the nourishing fluid remarkably diversified, as in many of the radiata and mollusca, which have horny and earthy integuments. And in all animals, so far as any chemical change is effected in the vital actions of absorption, secretion, and even nutrition, it would appear to be chiefly of this simple kind, consisting in the selection and appropriation of compounds already existing in the fluids on which these functions are performed, not in the formation of new compounds. The chyme which is found in the intestines of an animal during digestion contains all the compounds (albuminous, fatty, and extractive matters) which are found in the chyle absorbed from it, although these are in a different state of aggregation, and associated also with other matters which are not absorbed. Since it has been ascertained that the compounds which used to be thought peculiar to the greatest secretions in the body, the bile and the urine, pre-exist in the blood, and are only evolved at the liver and kidneys,—accumulating, therefore, in the blood, when the secretive action of these organs is suspended,—it has become obvious that the main office of these organs is not *formative*, but only *attractive*, to extract from the blood compounds already existing there. And, although there is one material extensively employed in the formation of animal textures, viz., gelatin, which cannot be detected in the blood; yet, as this is the only material so employed which cannot be found there, and as a substance very closely resembling it is found there under certain circumstances, we may assert that in animals by far the greater part of the act of nutrition, numerous and diversified as the compounds forming the solid materials of animal bodies may be, is likewise of this simple kind.

We may consider, then, the selection and extraction, from a previously existing compound fluid, by the agency of a previously existing compound solid, of certain portions of that fluid already elaborated, as a chemical action, essential to all living beings, and so peculiar to them that it may be, at least with high probability, termed an exercise of a vital affinity. And, in regard to this simplest kind of such action, the following points may be considered as ascertained :—

1. It seems to be always performed, in the perfect vegetable or animal, by an agency, not of vessels, as was formerly supposed, capable of a vital contraction, and of changing the nature of their contents by the degrees of that contraction, but of *cells*, either pre-existing in the solid structure, or carried about in the nourishing fluid, and having the name of the globules or corpuscles of that fluid. Most of the textures seem to be formed by the gradual transformation, elongation, or flattening of cells, which have sprung from nuclei at-

tached to previously existing cells; and it seems to be only by the successive formation, distension, rupture, and disappearance of cells, that secretions make their way into the excreting ducts of glands, or on the surface of membranes.

The dependence of all living structures, and of all secretions, not simply on vascular action, by which nourishing fluids are circulated through them, but on *cellular action*, by which this nourishing fluid is changed, appropriated, and retained, or restored to the circulation, is the great step which has been recently gained in physiology by the use of the microscope; and seems to me to be one of the clearest proofs of the dependence of all vital phenomena, on peculiar attractions and repulsions, actuating both solids and fluids, and causing motions in the latter,—not on any vital powers residing exclusively in solids. When it is stated, *e. g.* by Mr PAGET, that “the purpose to which the capillaries are habitually subservient, is only the passive one of conveying blood close to those parts of the body which either grow or secrete, and that it is proved that if a part be only able to imbibe the fluid portion of the blood from an adjacent vessel, it nourishes itself as completely, and after the same method, as one whose substance is traversed by numerous capillaries,”*—it becomes obvious that the movements of the fluid portion of the blood, whereby they are applied to growth and secretion, must be determined by causes quite distinct from the contractions of vessels.

2. Living and growing cells, therefore, whether acting on the nourishing fluid just taken into the system (as in the case of the intestinal villi, or the tufts of the placenta), or on the blood brought to them by the capillaries (as in the nutrition of the different textures), appear always to have two functions to perform,—to extract from the nourishing fluid the matter of which they are themselves composed, and to extract from it, likewise, the matter which is contained within them,—*i. e.*, in the organs of secretion, the secreted fluids, and in the different solid textures, that additional matter which is always found, whether lignin, oil or fat, fibrinous, cartilaginous, or bony substance, in a granular or less definite form, incrusting the walls of the cells. It does not appear possible to explain what is distinctly seen in all these cases, without supposing that the pre-existing cells exert a peculiar attraction or affinity, both for the matter by which they are themselves to be nourished, and their successors to be reproduced,—and likewise for another matter, different in the different parts of the structure, by which they are to be filled or distended. And in the case of vegetables, there seems to be this general distinction between the two,—that the former is a matter destitute of azote, and the latter one containing that element.

3. The cell, growing always by attracting to itself a compound matter, existing in the fluid state, and giving it a simple increase of aggregation, the nature of the change which takes place as this matter becomes solid, is simply

* Report in FORBES'S Medical Review, July 1843.

consolidation, not *precipitation*, just as the fibrin of the blood, differing from the albumen only in its stronger (vital) tendency to aggregation, is consolidated in its compound form from the liquor sanguinis in the act of coagulation. And thus it happens that these organic solids possess (as was particularly noticed by Dr PROUT) that peculiarity which, in the inorganic world, is observed only in fluids, that even the minutest portion of them contains the very same ingredients (whether earthy or saline, animal or vegetable matters) as is found in the whole mass.

The absence of all crystalline arrangement, and the complex nature even of the smallest particle of an organized body, are the characteristics of matter which has assumed the solid from the fluid form,—not by a chemical precipitation, or separation from matter formerly united to it, but by a vital attraction, subjecting it to “the invisible cause by which the forms of organs are produced.”

4. In the next place, we may inquire what difference exists among the cells in different parts of the same structure, to explain the great difference of the compounds which are deposited in them from the same nourishing fluid; and I apprehend, that, on this point, we must come to the same conclusion which CUVIER drew from examining, throughout the animal kingdom, the structure of the different glands, the vessels entering them, and the ducts passing out of them, viz., that *there is no difference* of structure or of composition, corresponding, in the slightest degree, to the great difference of the products which appear. All cells, in the vegetable kingdom, appear to consist of the same matter, cellulose, and in the animal kingdom of the same matter, protein; and in the first instance they are quite similar to one another. When we attend to the early stages of the existence of a living body, when the difference of textures is only beginning to appear, we find only that a fluid passing through similar capillary vessels, and effused into similar cells, in different *parts of the structure*, acquires different properties. And when we carry our inquiries farther back, and observe the first development of cells themselves out of the granular matter inclosed within the sac of the yolk, it appears obvious that the particles of this matter are attracted, not into cells already existing, but to *points where cells are about to be formed*. The facts known as to the evolution of the chick in ovo from the matter that lies in contact with the germinal membrane, sufficiently indicate that the powers which effect the separation of the different component parts of that matter, so as to form the beginning of the different textures and organs, reside, not in pre-existing cells of different composition or structure, but simply in different points of a pre-existing membrane, which, in the first instance, is homogeneous. The expression of LIEBIG, that “the chemical forces in living bodies are subject to the invisible cause by which the forms of organs are produced,” when the action of that cause is duly considered, implies, that they are subject to a cause which undoubtedly acts differently at different points of the same matter; but the differ-

ence of the action of which, at these points, is determined by no other condition, that we can see, than their *position*.

This mode of limitation of the vital affinities by which the selection and appropriation of living matter is effected, is only a statement of fact, and the most general fact that has been ascertained; and it seems highly probable, that it will be found an ultimate fact, in this department of science. It may serve to familiarize our minds with this principle to observe, *first*, that it is precisely analogous to the principle which is now well established as a first truth in the physiology of the nervous system, that portions of nervous matter, precisely similar in structure and composition, have perfectly different endowments according to the anatomical position which they occupy; and, *secondly*, that the same principle seems distinctly exemplified in various cases of diseased action. The phenomena of inflammation, and especially the easy recurrence of inflammation once excited at any one spot in a living animal, indicate that certain vital attractions and affinities existing among the particles of the blood, and between them and the surrounding textures, are peculiarly modified, not merely in a particular manner, but exclusively at a particular spot. From the spot where it commences (*e. g.*, on a serous membrane), this alteration of vital actions extends, as from a centre, to parts that are contiguous to, although having no vascular connection with, that where it commenced, as we see in tracing it from one fold of the peritoneum to another. And when we examine the results of the inflammation in the dead body, we see what clearly shews the operation of a force, producing chemical changes of the kind we are now considering, but acting only at one part, and in one direction. "The capillaries which have taken on the appearance of inflammation, are all on one side of the fine membrane, and the serum and lymph, effusions from these vessels," by which the diseased state is essentially characterized, "are all on the other."—(GOODSIR, *Anatomical and Pathological Observations*, p. 43.)

In saying that the fundamental property of chemical selection, essential to the growth of all living bodies, is strictly a vital property, we do not overlook the fact that various substances, composed of inanimate or inorganic matter, have likewise different powers of attraction for different elements or compounds brought into contact with them. It appears to be only by reference to this property, that we can explain the well-known phenomena of *endosmose* and *exosmose*, in which different fluids, brought in contact with a solid body, are attracted into its pores with very different degrees of force. It is not the nature of the process by which the selection, in the case of the living body, is effected; but the peculiarities of the selections themselves, their great force, and yet uniformly temporary existence, that entitle us to regard them as indicating a vital property.

II. But when we attend to the peculiar changes effected by living solids on the fluid matters which are brought in contact with them, we find that these are by no means confined to the *selection* and appropriation, at particular points, of

compounds pre-existing in that fluid; but that, under the influence of the living solid, *transformations* or new arrangements of the chemical elements take place, and new compounds are formed.

In regard to the precise nature, or seat, of some of these transformations, there is considerable difficulty, but we are at present concerned only with the principle; and may state in illustration of it, two cases of transformation, of which there is no doubt, the change from carbonic acid and water to starch in the cells of plants (oxygen escaping), and the change from starch to fat in the cells of animals (carbonic acid and water escaping). And that I am correct in asserting that the organ which exercises this and other chemical powers in living plants is not only of the simplest construction, but of uniform construction, while the products of its action are very various, will appear from the following statement by MÜLDER.

“ Pure cellulose is easily obtained from the pith of the elder-tree, from very young roots, and from other young parts of plants. From these parts it is prepared by digesting them, after being minutely divided, with alcohol, ether, diluted potash, hydrochloric acid, and water. In this manner, the starch, gum, fats, resins, vegetable alkalis, salts, sugar,—and at the same time the peculiar woody matter are separated.”

“ After the action of these solvents, and especially of the alkali, the cellulose, which was formerly solid and dense, appears in a spongy form. We may state as a fact, that the proper tissue of *all plants* which have been previously exposed to the influence of these solvents, leaves a *substance which is identical in all of them*, a substance which contains carbon and the elements of water.”—(*Chemistry of Vegetable and Animal Physiology*, pp. 188–195.)

MÜLDER annexes to this statement a speculation in regard to the influence of *forms* in organized bodies, as affecting their chemical powers or properties, which, so far as I can understand it, I think fitted to convey an erroneous impression.

“ One of the first and chief laws visible in organic nature is, that the form has as much influence on the character of the phenomena as the substance of which that form consists. The effects of the primary forces existing in the molecules, have become, by the combination of elements into hollow globules, altogether peculiar.”

“ In organic nature, besides all the peculiarities existing in the carbon, hydrogen, and oxygen, we must suppose, as a chief consequence of this, a tendency to form membranaceous, concave, spherical little bodies, in which, *because of this form*, new peculiar properties manifest themselves, which cannot be brought out by other forms. Thus, by matter and form, all that we observe in nature is, to a great extent determined.”—(*Ibid.*, p. 189.) If by this it is meant that the acquisition of the form is the physical cause of the existence of the properties which cells, or any other organized structures present in the living state, two questions

immediately present themselves, *first*, How are the cells themselves formed (*e. g.* on the germinal membrane of the ovum) out of a matter which is originally without form, otherwise than by those very properties which are here ascribed to their existence? and, *secondly*, If the properties are dependent only on forms, why do they not exist in the dead state, when the forms are, in many instances, still perfect? The enunciation of these questions seems to me sufficient to shew, that the correct expression of the state of our knowledge on this point is that already quoted from LEIBIG, that the chemical forces in living bodies are subject, not simply to an influence of forms, but to "*the invisible cause by which the forms of organs are produced,*" *i. e.*, that we must include under the head of vital properties, both the mechanical, or simply attractive power, by which cells or other organs are formed out of amorphous matter, and likewise the chemical powers with which these cells are endowed.

It is no objection to what has been stated, of the strictly vital nature of these chemical powers, to admit that their action is very often *analogous* to the principle to which the name *catalysis* is given by chemists, and which is exemplified likewise in the chemistry of inorganic compounds, where the combination of two substances is determined by the presence of a third, which nevertheless takes no part in the combination itself; or that it is analogous to that disturbance of the equilibrium of chemical compounds, by which the fermentation of an organic compound is transferred to another in contact with it, although the changes in the two go on separately, and the compounds formed are different. It is quite true, that these modes of chemical action resemble and illustrate the manner in which living solids, themselves undergoing continual changes of composition, determine new arrangements of the elements of the compound fluids which are brought in contact with them. But this analogy is far from being an explanation or resolution of the one phenomenon into the other. In the first place, the analogy is essentially defective; because although it is true that in any living being, already existing, different chemical compounds already exist in different parts of the structure, which may act in these modes on the nourishing fluid, and determine distinct transformations of these at different parts; yet this does not apply, as already observed, to the first formation of each of the textures, at its appropriate point, from a homogeneous semi-fluid matter. But farther, although we were to admit the *analogy* of all the chemical processes going on in living beings, to these forms of simply chemical action, we should not thereby be authorised to conclude that the vital processes have not that peculiarity which makes it incumbent on us to regard them as a separate class. We say that the decomposition of carbonic acid, the combination of the carbon with the elements of water to form starch, and the evolution of the oxygen, is a vital action,—not because it is a change different in kind from the decomposition of water and evolution of the hydrogen by iron and acid,—but simply because it indicates an affinity peculiar to the state of life;—because in no other circumstances, when the elements of

water are brought into contact with carbonic acid, is any such decomposition effected. So also, although it is true that the presence of spongy platinum enables oxygen and hydrogen to unite and form water, or the presence of fermenting yeast enables sugar to undergo transformation into carbonic acid and alcohol, still these facts do not interfere with those essential peculiarities on which the doctrine of vital affinity depends, viz., that the presence of living cells composed of carbon and the elements of water, determines both the addition of new matter, from a compound fluid, to those cells, and likewise the formation of other compounds within the cells, varying in different parts of the same structure,—all these compounds being different from any which the chemist can form out of the same elements, and different from those to which the same elements inevitably return, after the phenomena of life are over. The physical principle of catalysis may be said to *illustrate* the transformations in living bodies, as that of endosmose illustrates the selection and appropriation of chemical elements or compounds in living structures; but these principles, as exemplified in dead matter, include none of the peculiarities of the vital chemical actions, and therefore furnish no *explanation* of them.

The materials of which animal bodies are composed, have been now so generally found to have been prepared for them by vegetables, that it has been reasonably doubted, whether any such power of decomposing the fluids presented to them, and forming new compounds, exists in animals. There are some cases, however, in which it appears certain that an action of this kind goes on in living animals, and that it is effected, as in vegetables, by an agency of cells. Thus, there is good evidence that, in the natural state, much of the bile which is discharged into the intestines from the liver is re-absorbed in its passage along the *Primæ Viæ*; yet it never appears in the chyle, nor, in the natural state, in the blood; which seems to imply that it is decomposed, and its elements thrown into other combinations, in the course of the *cellular action* which attends the absorption of chyle.

In like manner, the formation of fatty compounds out of starch, or its kindred principles, as illustrated by the recent precise observations on the formation of wax by bees, and the formation of gelatine in the living animal, are undoubted instances of chemical transformations thus effected. The precise scene of these transformations is not yet ascertained, but we have strong reason from analogy to suppose that they are effected in the course of the circulation. And as we are certain that the greatest of all the chemical changes which are peculiar to living beings are effected within the cells of vegetables, it seems in the highest degree probable, that the corpuscles or cells (both red and white) which form so large a part of the blood of animals, are concerned in the chemical transformations which take place in blood; and therefore, that we are to regard organized and living cells as the agents or instruments employed by nature in effecting all those chemical changes which are peculiar to the state of life. And if we consider this

principle as established, it goes far to explain several facts, long regarded as obscure, in regard to the structure and position of the lymphatic and lacteal vessels. We know that the mode of origin of these vessels gives *time* and opportunity for cellular action, (*i. e.*, the development, growth, and rupture of cells,) and consequent chemical changes, at their extremities; we know that such cellular action does in fact go on there, particularly in the lacteals; and we know that the substances absorbed there, and probably elsewhere, by these vessels, are in fact altered, and so far assimilated, in the act of absorption; as in the case, already mentioned, of bile absorbed from the intestines. Thus we are led to see the importance of these vessels being placed at all points where substances are to be absorbed, which are foreign to the animal economy, or require chemical change, in order that they may be introduced with safety or good effect. Hence, also, we see the use of the lymphatic glands, at which another opportunity for cellular action, for chemical changes and assimilation, according to the observations of Mr GOODSIR, is provided.* And this also enables us to understand a general fact, which, although disputed, I believe to be both true and important in pathology,—that a substance destined for excretion, but retained in the blood by reason of disease of its excreting gland (particularly the bile or urine), is more injurious than the same matter when secreted by the gland, but re-absorbed from a mucous surface, and consequently subjected to cellular action, and thereby to chemical change.

III. Another general fact appears to be sufficiently illustrated by observations on the chemical changes in living bodies,—*viz.*, That the vital properties by which these are effected are *transferred* from the portions of matter already possessing them, to those other portions of matter which are either taken into their substance, or deposited in their immediate neighbourhood. It is, indeed, obvious, that if we are right in saying that living matter possesses these peculiar vital properties, the act of assimilation which we know to be continually going on in living bodies, is not merely the attraction and addition of new matter, but must include this transference of vital properties to the matter which is continually added to the existing solids.

“The force with which life is kept up,” says Professor WHEWELL, “not only produces motion and chemical change, but also *vitalizes* the matter on which it acts, giving it the power of producing the same changes in other matter, and so on indefinitely. It not only circulates the particles of matter, but puts them in a stream, of which the flow is development as well as movement.”—(*Philosophy of Inductive Sciences*, vol. ii., p. 52.)

Several facts which are known in physiology and pathology, may be noticed as more special exemplifications of this principle. Thus, we know that vessels in

* See CARPENTER'S Manual of Physiology, § 493.

any part of the body communicate certain properties to the whole mass of blood which lies in contact with them, so as to modify or suspend for a long time the coagulation of such blood;—that the blood which enters the vessels of any part where inflammation has been excited, has peculiar properties impressed on it, and even changes on its composition effected, merely by coming in contact with the portions of vessels where that process is going on, and with the portions of blood previously subjected to it;—that the exudation from inflamed vessels acquires peculiar properties from the contact with the living surface on which it lies, first arranging itself as an organized structure, and then selecting and appropriating, from the neighbouring bloodvessels, those materials by which it is assimilated to the texture with which it is connected;—again, that, in the sound state, every portion of matter which is deposited from the bloodvessels, to form part of a muscle or of a nerve, immediately acquires the peculiar vital properties of the part which it nourishes; and, in the case of muscles, even that the change produced in a portion of a fibre by the application of a stimulus, is instantly communicated to the whole length of that fibre, and to many adjoining fibres. It appears to be nearly in the same manner that every portion of carbon and water which enters into the composition of any living vegetable cell, acquires the power of exerting the same vital affinities as actuated the matter which it replaces, or to which it is added.

IV. Another principle, at least equally important and characteristic, may be stated in regard to this communication of vital properties to the materials which are added to living bodies, viz., That such powers are imparted only for a brief period of time, and that long before the time of the death of the structure to which they belong, all those materials lose the vital properties which have been given to them; perhaps, as has been lately stated, as a consequence of the exercise of their peculiar vital powers, perhaps merely as a general law of vitality; but equally, whether the peculiar properties which they acquire in living bodies are of the nature of nervous actions, vital contractions or attractions, or vital affinities. But as this principle is best illustrated by reference to the phenomena of excretions, we delay doing more than merely enunciating it at present.

Having so far considered the general nature of the chemical changes which are peculiar to living bodies, and the kind of apparatus provided by nature for carrying on these changes, we may next take a more special view of the different chemical changes themselves, beginning with the greatest and most fundamental of all, the formation of the amylaceous matters by vegetables, acting on the water and carbonic acid with which they are supplied, both in the liquid form by their roots, and in the gaseous form by their leaves,—and the consequent evolution of oxygen. In regard to this grand function of living plants, the following facts seem the most important that have been ascertained.

1. We see this change effected, in the present order of things, only by the agency of one of the amylaceous principles themselves, although the quantity of that pre-existent matter, in the case of the seeds of many vegetables, is exceedingly minute. We need not enter on the question how far, besides the pre-existence of matter capable of forming cells, in the textures of the plant itself, previously existing organized matter, in the dead state, is essential as part of the nutriment of vegetables,—farther than to observe, that, as the seed of every plant contains a store of organic compounds already formed, there is certainly a strong presumption that a certain quantity of such compounds, formed by previous living processes, is highly useful, if not necessary, to the nourishment of vegetables as well as animals. This, however, appears most important in the early period of the existence of plants, when their power of decomposing the carbonic acid has not yet attained its full intensity. The evidence of the greater part of the nourishment of vegetables being from carbonic acid, water, and ammonia, applied to their leaves, or absorbed by their roots, is quite conclusive; and when we consider that vegetables preceded the appearance of animals on earth, that the first vegetables (as is well observed by LIEBIG) were of the kind which depend least on their roots and most on their leaves for subsistence, and that the kinds of animals which first inhabited the earth, were those which consume the smallest quantity of oxygen, and can live, therefore, in air highly charged with carbonic acid,—it appears in the highest degree probable, that a gradual purification of the atmosphere by the agency of vegetables abstracting carbon, was a necessary prelude to the introduction of animals, especially of warm-blooded animals, into the world: and that the greater part of the carbon now existing in the soil on the earth's surface, originally existed in the form of carbonic acid in the atmosphere, and has been gradually fixed, and enabled to become the chief support of all living beings, by this vital affinity of vegetables, and of those tribes of the lowest marine animals, which have been found to possess the same property, whereby carbon is separated from oxygen, and combined with the elements of water, to form the amylaceous matters.

2. The dependence of the exercise of this property on the presence of light, and its connection (according to the statements of Dr DRAPER), not with the heating portion of the rays, nor with those which effect other chemical changes, but simply with the luminous portion of the rays, shews distinctly that all living action on this globe is equally dependent on light as on heat, although it is, and may long be doubtful, in what manner the influence of light is exerted in producing this change; whether the theory long ago proposed by Sir H. DAVY is admissible, that light enters into the composition of oxygen gas when disengaged from any solid or liquid compound containing it; or whether the agency of light may be better expressed by saying, that it is the necessary stimulus to that kind of vital action which leads to this primary transformation of the elements of which organized beings are composed.

3. It is unnecessary to enter here on the varieties of this amylaceous matter which are formed in different vegetables or parts of the same, the *cellulose* of which the cells are formed, the *starch*, the *dextrin*, the *gum*, the *inuline*, which are deposited in different species and in different parts. All these appear to have the same simple fundamental composition, consisting almost entirely of carbon with the elements of water, and all are formed out of the same compounds and by a vital affinity essentially the same; it may be partly owing to some imperceptible difference in the relative position of the ultimate atoms, partly to differences in the minute quantities of inorganic matter, and of other organic compounds not yet mentioned, which enter into their composition, that so many varieties are found, not only in these compounds themselves, but in the qualities which they present as found in different species of plants, and even in different individuals of the same species. In the case of a graft inserted on the stem of an individual, or even of a species, different from that which furnishes the shoot, we see that the vital affinities of the particles composing the shoot are capable, not only of extracting from the nourishing fluid of the stock all the compounds required for its development, but of imparting to the living textures formed of those compounds which they extract, all those peculiar properties of form, of colour, of smell, of roughness, smoothness, &c., by which species, and even individuals of the same species, are characterized. And when we consider these facts, I apprehend we must admit that, under the influence of the vital affinities which operate in the cells of living vegetables, much more minute differences of compounds are produced, than can be detected and explained by any chemical analysis.

4. An important question here is, whether the carbonic acid of the air is decomposed in the leaves where it is chiefly taken in, the amylaceous compounds immediately formed with the help of water, and the oxygen set at liberty, or whether that acid is taken into the juices of the plant, as we now know that oxygen is into the blood at the lungs, and gradually decomposed there, letting its oxygen escape gradually, and aiding in the formation of different compounds, besides the varieties of starch. That the latter is the more probable supposition may be inferred, partly from the analogy of the action at the lungs of animals, but chiefly from the fact, that a separation of oxygen is equally required for the elaboration, which certainly takes place in vegetables, of other compounds, of the varieties of oil, and of protein, which are chiefly deposited in other parts of their structures.

5. The relations of compounds of this class to sugar demand more special notice. It seems doubtful whether this is ever the first compound formed; it appears in the sap of various plants when the fluids from the soil are ascending and dissolving the starch which had been formed and stored up by the living actions of the preceding year; it appears in almost exactly the same circumstances dur-

ing the germination of seeds, and in both these cases is useful as giving a greater degree of solubility to the starch whence it is formed. In both cases it disappears, and probably is converted into some of the varieties of starch, as the vital actions of the plant become more vigorous. Its composition, in its different varieties, as given by most analysts, $C_{12} H_{11} O_{11}$, or $C_{10} H_{10} O_{10}$, or even $C_{12} H_{14} O_{14}$, denotes that if it be formed from the starch, $C_{12} H_{10} O_{10}$, it must be either by the addition of the elements of water, or by the abstraction of carbon; and as its formation, during the germination of seeds, is attended with evolution of carbonic acid, it seems most probable that, in that case at least, it is formed in this last way, under the influence of the oxygen of the air. It appears again in the nectaries of flowers, and in the ripening of fruits, as one of the latest results of the vital action of plants, in those parts of them which are fully exposed to air and light, but at a time when we may reasonably suppose that the vital affinities are becoming comparatively ineffective, and when carbonic acid is again evolved. It may be formed by the chemist from some of the varieties of starch by a kind of fermentation, excited by diastase, as in malting; or by a catalytic action of sulphuric acid; and it is formed from starch merely by the agency of cold, as in frozen potatoes, and from inuline merely by continued boiling in water; so that its formation from starch in vegetables seems to be most probably a simple chemical change, not the effect of a vital affinity. Farther, it is a compound which takes the crystalline form, essentially different from any form assumed by those parts of organized structures which exhibit truly vital phenomena, and retains its properties when exposed to air and water better than any of the matters of which organized forms are composed. From all these facts it may be inferred, with great probability, that sugar, as it appears in the living vegetable, is generally to be regarded as a first product of decomposition of starch, by the agency of water and of the oxygen of the air, which appears to be the great agent in the resolution of those compounds, which the vital affinities have built up.

6. On the other hand, the relation of starch and cellulose to the lignin, which forms the greater part of the solid matters of dicotyledonous plants seems to be nearly the reverse of their relation to sugar. This matter is always found incrusting, or incorporated with, the cells of vegetable textures; it gives them their solidity and strength, which all decompositions by chemical agents impair; it cannot be formed from the compounds of starch by artificial means, but is formed from them in greatest quantity when the vital actions of plants are strongest; and its composition is always stated as differing from the amylaceous compounds by containing more carbon; and less oxygen, in proportion to the hydrogen, than exists in the composition of water; its formula being stated as $C_{40} H_{23} O_{18}$. This, therefore, would appear to be clearly the result of truly vital affinities, continuing to actuate the elements of starch, after the formation of the

starch from carbonic acid and water has been completed, and effecting a decomposition of part of the water, as well as of the carbonic acid, presented to the living vegetable.

In studying this first and most striking of all the changes which are to be ascribed to vital affinities, it is especially necessary to understand the parts assigned to Carbon and Oxygen; and, in taking this general view, we must regard vegetables and animals as inseparably linked together, and look to the whole series of chemical changes which intervene between the origin of vegetables and the death and decomposition of animals. We must regard the carbon, originally existing in combination with oxygen in the atmosphere, in the proportion of one equivalent to two, as the great agent employed by Nature in the formation of the whole organized creation, insomuch that all organic chemistry may be said to be the chemistry of compounds of carbon.—(*Gregory's Chemistry*, p. 241.) That it may fulfil this office it is invested with peculiar but temporary powers; it is separated at particular points and under certain conditions from the oxygen, and attaches itself to the elements of water, always present where vegetables grow, and so forms various compounds, beginning with the varieties of starch; in all which it is the principal ingredient. The compounds thus formed next attack and partially decompose the water and appropriate the hydrogen, thus causing a farther evolution of oxygen, and forming oil; and afterwards nitrogen, in small quantity, is introduced, and fresh transformations take place, by which the protein compounds are formed. All the solid structures of vegetables, and indeed of organized beings generally, are made up of these compounds of carbon, in which oxygen exists either in the proportion to hydrogen which forms water, or in a less proportion than that; and the formation of these may be confidently ascribed to vital affinities. But it is easy to conceive that other compounds of carbon with hydrogen and oxygen will exist in plants in which the oxygen will be in larger proportion than this, without supposing oxygen from the air to be added; because the vital affinities may not have been in sufficient force to separate the oxygen completely from its original union with carbon, and these, therefore, may be regarded as compounds of carbon, water, and undecomposed carbonic acid. Such are the different organic acids (the citric $12\text{C } 8\text{H } 14\text{O} = 9\text{C} + 8\text{HO} + 3\text{CO}_2$, the malic $8\text{C } 6\text{H } 10\text{O} = 6\text{C} + 6\text{HO} + 2\text{CO}_2$, the tartaric $8\text{C } 4\text{H } 10\text{O} = 5\text{C} + 4\text{HO} + 3\text{CO}_2$, the oxalic $4\text{C } 2\text{H } 8\text{O} = \text{C} + 2\text{HO} + 3\text{CO}_2$) which are found in the juices of many vegetables, particularly in the immature state.

Again, it is always to be observed, not only that all organized bodies are destined ultimately to revert to the water, carbonic acid, and ammonia, from which they were originally formed, but that, in the case of animals at least, there is a process always going on during the state of life, by which these same inorganic matters are continually evolved from the living frames. Therefore, we cannot be surprised to find that the fluids of all living animal bodies contain other

compounds, in which the characteristic predominance of carbon is not perceived ; because they are those which are formed in circumstances where the vital affinities are losing their power, and where a step has been made towards that final dissolution of organic compounds, when the oxygen is to resume its power over the carbon, and this is to revert, directly or indirectly, to the condition of carbonic acid. This general principle as to the respective offices of carbon and oxygen in living bodies,—the one the main agent in nourishing and supporting living structures, the other in maintaining the excretions by which these structures are continually restored to the inorganic world,—we shall find to be applicable, not only to the excretion of carbonic acid and water by the skin and lungs, as compared with the amylaceous compounds taken into animal bodies, but likewise to the excretions by the liver and kidneys, as compared with the two other great constituents of the food of animals, viz., the oily and the albuminous substances.

Oxygen, in its elementary state, although indispensable to all living action,—although a condition of vitality equally universal as heat,—yet hardly enters, if it enters at all, into any of the combinations which are due to the vital affinities. Although taken into the interior of every living being, it appears to comport itself there almost, if not entirely, as it does in acting on dead matter. The expression of LIEBIG, that the action of the oxygen of the air in living bodies is *destructive*, is perhaps fitted to convey an erroneous idea, but we are certain that its chief, if not its sole, action in the animal economy, is on those portions of matter which have no vital properties; either because they are redundant,—not required for the nourishment of the tissues,—or because they have been re-absorbed from them, having lost their vital affinities ; and with these it unites, only to carry them off in the excretions, particularly in the great excretion by the lungs. We now know that the speculation as to the connection of the oxygen of the air with vital action, long and ably maintained by the late Mr ELLIS, viz., that its sole use is to dissolve and carry off excreted carbon, and therefore that in the bodies of animals it goes no farther than the lungs, was erroneous ; but we may assert with much confidence, that it goes no farther than the circulating blood ; and that, although its action there is essential to all the metamorphoses which are there accomplished, yet all the combinations into which it actually enters, are destined to immediate separation from the living body,—being, in fact, the media by which all living bodies, at all periods of their existence, are continually resolving themselves into the inanimate elements from which they sprung. This principle will be better illustrated, however, by a review of the leading facts lately ascertained as to the formation of the other compounds peculiar to organized bodies, and the excretions of animals.