THEORY OF THE CELLS.

The whole of the foregoing investigation has been conducted with the object of exhibiting from observation alone the mode in which the elementary parts of organized bodies are formed. Theoretical views have been either entirely excluded, or where they were required (as in the foregoing retrospect of the cell-life), for the purpose of rendering facts more clear, or preventing subsequent repetitions, they have been so presented that it can be easily seen how much is observation and how much argument. But a question inevitably arises as to the basis of all these phenomena; and an attempt to solve it will be more readily permitted us, since by making a marked separation between theory and observation the hypothetical may be clearly distinguished from that which is positive. An hypothesis is never prejudicial so long as we are conscious of the degree of reliance which may be placed upon it, and of the grounds on which it rests. Indeed it is advantageous, if not necessary for science, that when a certain series of phenomena is proved by observation, some provisional explanation should be conceived that will suit them as nearly as possible, even though it be in danger of being overthrown by subsequent observations; for it is only in this manner that we are rationally led to new discoveries, which either establish or refute the explanation. It is from this point of view I would beg that the following theory of organization may be regarded; for the inquiry into the source of development of the elementary parts of organisms is, in fact, identical with the theory of organized bodies.

The various opinions entertained with respect to the fundamental powers of an organized body may be reduced to two, which are essentially different from one another. The first is, that every organism originates with an inherent power, which models it into conformity with a predominant idea, arranging the molecules in the relation necessary for accomplishing certain purposes held forth by this idea. Here, therefore, that which arranges and combines the molecules is a power acting with a definite purpose. A power of this kind would be essentially different from all the powers of inorganic nature, because action

goes on in the latter quite blindly. A certain impression is followed of necessity by a certain change of quality and quantity, without regard to any purpose. In this view, however, the fundamental power of the organism (or the soul, in the sense employed by Stahl) would, inasmuch as it works with a definite individual purpose, be much more nearly allied to the immaterial principle, endued with consciousness which we must admit operates in man.

The other view is, that the fundamental powers of organized bodies agree essentially with those of inorganic nature, that they work altogether blindly according to laws of necessity and irrespective of any purpose, that they are powers which are as much established with the existence of matter as the physical powers are. It might be assumed that the powers which form organized bodies do not appear at all in inorganic nature, because this or that particular combination of molecules, by which the powers are elicited, does not occur in inorganic nature, and yet they might not be essentially distinct from physical and chemical powers. It cannot, indeed, be denied that adaptation to a particular purpose, in some individuals even in a high degree, is characteristic of every organism; but, according to this view, the source of this adaptation does not depend upon each organism being developed by the operation of its own power in obedience to that purpose, but it originates as in inorganic nature, in the creation of the matter with its blind powers by a rational Being. We know, for instance, the powers which operate in our planetary system. They operate, like all physical powers, in accordance with blind laws of necessity, and yet is the planetary system remarkable for its adaptation to a purpose. The ground of this adaptation does not lie in the powers, but in Him, who has so constituted matter with its powers, that in blindly obeying its laws it produces a whole suited to fulfil an intended purpose. We may even assume that the planetary system has an individual adaptation to a purpose. Some external influence, such as a comet, may occasion disturbances of motion, without thereby bringing the whole into collision; derangements may occur on single planets, such as a high tide, &c., which are yet balanced entirely by physical laws. As respects their adaptation to a purpose, organized bodies differ from these in degree only;

and by this second view we are just as little compelled to conclude that the fundamental powers of organization operate according to laws of adaptation to a purpose, as we are in inorganic nature.

The first view of the fundamental powers of organized bodies may be called the *teleological*, the second the *physical* view. An example will show at once, how important for physiology is the solution of the question as to which is to be followed. If, for instance, we define inflammation and suppuration to be the effort of the organism to remove a foreign body that has been introduced into it; or fever to be the effort of the organism to eliminate diseased matter, and both as the result of the "autocracy of the organism," then these explanations accord with the teleological view. For, since by these processes the obnoxious matter is actually removed, the process which effects them is one adapted to an end; and as the fundamental power of the organism operates in accordance with definite purposes, it may either set these processes in action primarily, or may also summon further powers of matter to its aid, always, however, remaining itself the "primum movens." On the other hand, according to the physical view, this is just as little an explanation as it would be to say, that the motion of the earth around the sun is an effort of the fundamental power of the planetary system to produce a change of seasons on the planets, or to say, that ebb and flood are the reaction of the organism of the earth upon the moon.

In physics, all those explanations which were suggested by a teleological view of nature, as "horror vacui," and the like, have long been discarded. But in animated nature, adaptation —individual adaptation—to a purpose is so prominently marked, that it is difficult to reject all teleological explanations. Meanwhile it must be remembered that those explanations, which explain at once all and nothing, can be but the last resources, when no other view can possibly be adopted; and there is no such necessity for admitting the teleological view in the case of organized bodies. The adaptation to a purpose which is characteristic of organized bodies differs only in degree from what is apparent also in the inorganic part of nature; and the explanation that organized bodies are developed, like all the phenomena of inorganic nature, by the operation of blind laws

framed with the matter, cannot be rejected as impossible. Reason certainly requires some ground for such adaptation, but for her it is sufficient to assume that matter with the powers inherent in it owes its existence to a rational Being. Once established and preserved in their integrity, these powers may, in accordance with their immutable laws of blind necessity, very well produce combinations, which manifest, even in a high degree, individual adaptation to a purpose. If, however, rational power interpose after creation merely to sustain, and not as an immediately active agent, it may, so far as natural science is concerned, be entirely excluded from the consideration of the creation.

But the teleological view leads to further difficulties in the explanation, and especially with respect to generation. If we assume each organism to be formed by a power which acts according to a certain predominant idea, a portion of this power may certainly reside in the ovum during generation; but then we must ascribe to this subdivision of the original power, at the separation of the ovum from the body of the mother, the capability of producing an organism similar to that which the power, of which it is but a portion, produced: that is, we must assume that this power is infinitely divisible, and yet that each part may perform the same actions as the whole power. If, on the other hand, the power of organized bodies reside, like the physical powers, in matter as such, and be set free only by a certain combination of the molecules, as, for instance, electricity is set free by the combination of a zinc and copper plate, then also by the conjunction of molecules to form an ovum the power may be set free, by which the ovum is capable of appropriating to itself fresh molecules, and these newly-conjoined molecules again by this very mode of combination acquire the same power to assimilate fresh molecules. The first development of the many forms of organized bodies—the progressive formation of organic nature indicated by geology—is also much more difficult to understand according to the teleological than the physical view.

Another objection to the teleological view may be drawn from the foregoing investigation. The molecules, as we have seen, are not immediately combined in various ways, as the purpose of the organism requires, but the formation of the elementary parts of organic bodies is regulated by laws which

are essentially the same for all elementary parts. One can see no reason why this should be the case, if each organism be endued with a special power to frame the parts according to the purpose which they have to fulfil: it might much rather be expected that the formative principle, although identical for organs physiologically the same, would yet in different tissues be correspondingly varied. This resemblance of the elementary parts has, in the instance of plants, already led to the conjecture that the cells are really the organisms, and that the whole plant is an aggregate of these organisms arranged according to certain laws. But since the elementary parts of animals bear exactly similar relations, the individuality of an entire animal would thus be lost; and yet precisely upon the individuality of the whole animal does the assumption rest, that it possesses a single fundamental power operating in accordance with a definite idea.

Meanwhile we cannot altogether lay aside teleological views if all phenomena are not clearly explicable by the physical view. It is, however, unnecessary to do so, because an explanation, according to the teleological view, is only admissible when the physical can be shown to be impossible. In any case it conduces much more to the object of science to strive, at least, to adopt the physical explanation. And I would repeat that, when speaking of a physical explanation of organic phenomena, it is not necessary to understand an explanation by known physical powers, such, for instance, as that universal refuge electricity, and the like; but an explanation by means of powers which operate like the physical powers, in accordance with strict laws of blind necessity, whether they be also to be found in inorganic nature or not.

We set out, therefore, with the supposition that an organized body is not produced by a fundamental power which is guided in its operation by a definite idea, but is developed, according to blind laws of necessity, by powers which, like those of inorganic nature, are established by the very existence of matter. As the elementary materials of organic nature are not different from those of the inorganic kingdom, the source of the organic phenomena can only reside in another combination of these materials, whether it be in a peculiar mode of union of the elementary atoms to form atoms of the second

order, or in the arrangement of these conglomerate molecules when forming either the separate morphological elementary parts of organisms, or an entire organism. We have here to do with the latter question solely, whether the cause of organic phenomena lies in the whole organism, or in its separate elementary parts. If this question can be answered, a further inquiry still remains as to whether the organism or its elementary parts possess this power through the peculiar mode of combination of the conglomerate molecules, or through the mode in which the elementary atoms are united into conglomerate molecules.

We may, then, form the two following ideas of the cause of organic phenomena, such as growth, &c. First, that the cause resides in the totality of the organism. By the combination of the molecules into a systematic whole, such as the organism is in every stage of its development, a power is engendered, which enables such an organism to take up fresh material from without, and appropriate it either to the formation of new elementary parts, or to the growth of those already present. Here, therefore, the cause of the growth of the elementary parts resides in the totality of the organism. The other mode of explanation is, that growth does not ensue from a power resident in the entire organism, but that each separate elementary part is possessed of an independent power, an independent life, so to speak; in other words, the molecules in each separate elementary part are so combined as to set free a power by which it is capable of attracting new molecules, and so increasing, and the whole organism subsists only by means of the reciprocal[1] action of the single elementary parts. So that here the single elementary parts only exert an active influence on nutrition, and totality of the organism may indeed be a condition, but is not in this view a cause.

In order to determine which of these two views is the correct one, we must summon to our aid the results of the previous investigation. We have seen that all organized bodies are composed of essentially similar parts, namely, of cells; that these cells are formed and grow in accordance with essen-

[1] The word "reciprocal action" must here be taken in its widest sense, as implying the preparation of material by one elementary part, which another requires for its own nutrition.

tially similar laws; and, therefore, that these processes must, in every instance, be produced by the same powers. Now, if we find that some of these elementary parts, not differing from the others, are capable of separating themselves from the organism, and pursuing an independent growth, we may thence conclude that each of the other elementary parts, each cell, is already possessed of power to take up fresh molecules and grow; and that, therefore, every elementary part possesses a power of its own, an independent life, by means of which it would be enabled to develop itself independently, if the relations which it bore to external parts were but similar to those in which it stands in the organism. The ova of animals afford us examples of such independent cells, growing apart from the organism. It may, indeed, be said of the ova of higher animals, that after impregnation the ovum is essentially different from the other cells of the organism; that by impregnation there is a something conveyed to the ovum, which is more to it than an external condition for vitality, more than nutrient matter; and that it might thereby have first received its peculiar vitality, and therefore that nothing can be inferred from it with respect to the other cells. But this fails in application to those classes which consist only of female individuals, as well as with the spores of the lower plants; and, besides, in the inferior plants any given cell may be separated from the plant, and then grow alone. So that here are whole plants consisting of cells, which can be positively proved to have independent vitality. Now, as all cells grow according to the same laws, and consequently the cause of growth cannot in one case lie in the cell, and in another in the whole organism; and since it may be further proved that some cells, which do not differ from the rest in their mode of growth, are developed independently, we must ascribe to all cells an independent vitality, that is, such combinations of molecules as occur in any single cell, are capable of setting free the power by which it is enabled to take up fresh molecules. The cause of nutrition and growth resides not in the organism as a whole, but in the separate elementary parts—the cells. The failure of growth in the case of any particular cell, when separated from an organized body, is as slight an objection to this theory, as it is an objection against the independent vitality of a bee, that

it cannot continue long in existence after being separated from its swarm. The manifestation of the power which resides in the cell depends upon conditions to which it is subject only when in connexion with the whole (organism).

The question, then, as to the fundamental power of organized bodies resolves itself into that of the fundamental powers of the individual cells. We must now consider the general phenomena attending the formation of cells, in order to discover what powers may be presumed to exist in the cells to explain them. These phenomena may be arranged in two natural groups: first, those which relate to the combination of the molecules to form a cell, and which may be denominated the *plastic* phenomena of the cells; secondly, those which result from chemical changes either in the component particles of the cell itself, or in the surrounding cytoblastema, and which may be called *metabolic* phenomena (τὸ μεταβολικὸν, implying that which is liable to occasion or to suffer change).

The general plastic appearances in the cells are, as we have seen, the following: at first a minute corpuscle is formed, (the nucleolus); a layer of substance (the nucleus) is then precipitated around it, which becomes more thickened and expanded by the continual deposition of fresh molecules between those already present. Deposition goes on more vigorously at the outer part of this layer than at the inner. Frequently the entire layer, or in other instances the outer part of it only, becomes condensed to a membrane, which may continue to take up new molecules in such a manner that it increases more rapidly in superficial extent than in thickness, and thus an intervening cavity is necessarily formed between it and the nucleolus. A second layer (cell) is next precipitated around this first, in which precisely the same phenomena are repeated, with merely the difference that in this case the processes, especially the growth of the layer, and the formation of the space intervening between it and the first layer (the cell-cavity), go on more rapidly and more completely. Such were the phenomena in the formation of most cells; in some, however, there appeared to be only a single layer formed, while in others (those especially in which the nucleolus was hollow) there were three. The other varieties in the development of the elementary parts were (as we saw) reduced to these—that if two neighbouring

cells commence their formation so near to one another that the boundaries of the layers forming around each of them meet at any spot, a common layer may be formed enclosing the two incipient cells. So at least the origin of nuclei, with two or more nucleoli, seemed explicable, by a coalescence of the first layers (corresponding to the nucleus), and the union of many primary cells into one secondary cell by a similar coalescence of the second layers (which correspond to the cell). But the further development of these common layers proceeds as though they were only an ordinary single layer. Lastly, there were some varieties in the progressive development of the cells, which were referable to an unequal deposition of the new molecules between those already present in the separate layers. In this way modifications of form and division of the cells were explained. And among the number of the plastic phenomena in the cells we may mention, lastly, the formation of secondary deposits; for instances occur in which one or more new layers, each on the inner surface of the previous one, are deposited on the inner surface of a simple or of a secondary cell.

These are the most important phenomena observed in the formation and development of cells. The unknown cause, presumed to be capable of explaining these processes in the cells, may be called the plastic power of the cells. We will, in the next place, proceed to determine how far a more accurate definition of this power may be deduced from these phenomena.

In the first place, there is a power of attraction exerted in the very commencement of the cell, in the nucleolus, which occasions the addition of new molecules to those already present. We may imagine the nucleolus itself to be first formed by a sort of crystallization from out of a concentrated fluid. For if a fluid be so concentrated that the molecules of the substance in solution exert a more powerful mutual attraction than is exerted between them and the molecules of the fluid in which they are dissolved, a part of the solid substance must be precipitated. One can readily understand that the fluid must be more concentrated when new cells are being formed in it than when those already present have merely to grow. For if the cell is already partly formed, it exerts an attractive force upon the substance still in solution. There is then a cause for the deposition of this substance, which does not co-operate

when no part of the cell is yet formed. Therefore, the greater the attractive force of the cell is, the less concentration of the fluid is required; while, at the commencement of the formation of a cell, the fluid must be more than concentrated. But the conclusion which may be thus directly drawn, as to the attractive power of the cell, may also be verified by observation. Wherever the nutrient fluid is not equally distributed in a tissue, the new cells are formed in that part into which the fluid penetrates first, and where, consequently, it is most concentrated. Upon this fact, as we have seen, depended the difference between the growth of organized and unorganized tissues (see page 169). And this confirmation of the foregoing conclusion by experience speaks also for the correctness of the reasoning itself.

The attractive power of the cells operates so as to effect the addition of new molecules in two ways,—first, in layers, and secondly, in such a manner in each layer that the new molecules are deposited between those already present. This is only an expression of the fact; the more simple law, by which several layers are formed and the molecules are not all deposited between those already present, cannot yet be explained. The formation of layers may be repeated once, twice, or thrice. The growth of the separate layers is regulated by a law, that the deposition of new molecules should be greatest at the part where the nutrient fluid is most concentrated. Hence the outer part particularly becomes condensed into a membrane both in the layer corresponding to the nucleus and in that answering to the cell, because the nutrient fluid penetrates from without, and consequently is more concentrated at the outer than at the inner part of each layer. For the same reason the nucleus grows rapidly, so long as the layer of the cell is not formed around it, but it either stops growing altogether, or at least grows much more slowly so soon as the cell-layer has surrounded it; because then the latter receives the nutrient matter first, and, therefore, in a more concentrated form. And hence the cell becomes, in a general sense, much more completely developed, while the nucleus-layer usually remains at a stage of development, in which the cell-layer had been in its earlier period. The addition of new molecules is so arranged that the layers increase more

considerably in superficial extent than in thickness; and thus an intervening space is formed between each layer and the one preceding it, by which cells and nuclei are formed into actual hollow vesicles. From this it may be inferred that the deposition of new molecules is more active between those which lie side by side along the surface of the membrane, than between those which lie one upon the other in its thickness. Were it otherwise, each layer would increase in thickness, but there would be no intervening cavity between it and the previous one, there would be no vesicles, but a solid body composed of layers.

Attractive power is exerted in all the solid parts of the cell. This follows, not only from the fact that new molecules may be deposited everywhere between those already present, but also from the formation of secondary deposits. When the cavity of a cell is once formed, material may be also attracted from its contents and deposited in layers; and as this deposition takes place upon the inner surface of the membrane of the cell, it is probably that which exerts the attractive influence. This formation of layers on the inner surface of the cell-membrane is, perhaps, merely a repetition of the same process by which, at an earlier period, nucleus and cell were precipitated as layers around the nucleolus. It must, however, be remarked that the identity of these two processes cannot be so clearly proved as that of the processes by which nucleus and cell are formed; more especially as there is a variety in the phenomena, for the secondary deposits in plants occur in spiral forms, while this has at least not yet been demonstrated in the formation of the cell-membrane and the nucleus, although by some botanical writers the cell-membrane itself is supposed to consist of spirals.

The power of attraction may be uniform throughout the whole cell, but it may also be confined to single spots; the deposition of new molecules is then more vigorous at these spots, and the consequence of this uneven growth of the cell-membrane is a change in the form of the cell.

The attractive power of the cells manifests a certain form of election in its operation. It does not take up all the substances contained in the surrounding cytoblastema, but only particular ones, either those which are analogous with the substance

already present in the cell (assimilation), or such as differ from it in chemical properties. The several layers grow by assimilation, but when a new layer is being formed, different material from that of the previously-formed layer is attracted: for the nucleolus, the nucleus and cell-membrane are composed of materials which differ in their chemical properties.

Such are the peculiarities of the plastic power of the cells, so far as they can as yet be drawn from observation. But the manifestations of this power presuppose another faculty of the cells. The cytoblastema, in which the cells are formed, contains the elements of the materials of which the cell is composed, but in other combinations: it is not a mere solution of cell-material, but it contains only certain organic substances in solution. The cells, therefore, not only attract materials from out of the cytoblastema, but they must have the faculty of producing chemical changes in its constituent particles. Besides which, all the parts of the cell itself may be chemically altered during the process of its vegetation. The unknown cause of all these phenomena, which we comprise under the term metabolic phenomena of the cells, we will denominate the *metabolic power*.

The next point which can be proved is, that this power is an attribute of the cells themselves, and that the cytoblastema is passive under it. We may mention vinous fermentation[1]

[1] I could not avoid bringing forward fermentation as an example, because it is the best known illustration of the operation of the cells, and the simplest representation of the process which is repeated in each cell of the living body. Those who do not as yet admit the theory of fermentation set forth by Cagniard-Latour, and myself, may take the development of any simple cells, especially of the spores, as an example; and we will in the text draw no conclusion from fermentation which cannot be proved from the development of other simple cells which grow independently, particularly the spores of the inferior plants. We have every conceivable proof that the fermentation-granules are fungi. Their form is that of fungi; in structure they, like them, consist of cells, many of which enclose other young cells. They grow, like fungi, by the shooting forth of new cells at their extremities; they propagate like them, partly by the separation of distinct cells, and partly by the generation of new cells within those already present, and the bursting of the parent-cells. Now, that these fungi are the cause of fermentation, follows, first, from the constancy of their occurrence during the process; secondly, from the cessation of fermentation under any influences by which they are known to be destroyed, especially boiling heat, arseniate of potass, &c.; and, thirdly, because the principle which excites the process of fermentation must be a substance which is again generated and increased by the

as an instance of this. A decoction of malt will remain for a long time unchanged; but as soon as some yeast is added to it, which consists partly of entire fungi and partly of a number of single cells, the chemical change immediately ensues. Here the decoction of malt is the cytoblastema; the cells clearly exhibit activity, the cytoblastema, in this instance even a boiled fluid, being quite passive during the change. The same occurs when any simple cells, as the spores of the lower plants, are sown in boiled substances.

In the cells themselves again, it appears to be the solid parts, the cell-membrane and the nucleus, which produce the change. The contents of the cell undergo similar and even more various changes than the external cytoblastema, and it is at least probable that these changes originate with the solid parts composing the cells, especially the cell-membrane, because the secondary deposits are formed on the inner surface of the cell-membrane, and other precipitates are generally formed in the first instance around the nucleus. It may therefore, on the whole, be said that the solid component particles of the cells possess the power of chemically altering the substances in contact with them.

The substances which result from the transformation of the

process itself, a phenomenon which is met with only in living organisms. Neither do I see how any further proof can possibly be obtained otherwise than by chemical analysis, unless it can be proved that the carbonic acid and alcohol are formed only at the surface of the fungi. I have made a number of attempts to prove this, but they have not as yet completely answered the purpose. A long test-tube was filled with a weak solution of sugar, coloured of a delicate blue with litmus, and a very small quantity of yeast was added to it, so that fermentation might not begin until several hours afterwards, and the fungi, having thus previously settled at the bottom, the fluid might become clear. When the carbonic acid (which remained in solution) commenced to be formed, the reddening of the blue fluid actually began at the bottom of the tube. If at the beginning a rod were put into the tube, so that the fungi might settle upon it also, the reddening began both at the bottom, and upon the rod. This proves, at least, that an undissolved substance which is heavier than water gives rise to fermentation; and the experiment was next repeated on a small scale under the microscope, to see whether the reddening really proceeded from the fungi, but the colour was too pale to be distinguished, and when the fluid was coloured more deeply no fermentation ensued; meanwhile, it is probable that a reagent upon carbonic acid may be found which will serve for microscopic observation, and not interrupt fermentation. The foregoing inquiry into the process by which organized bodies are formed, may perhaps, however, serve in some measure to recommend this theory of fermentation to the attention of chemists.

contents of the cell are different from those which are produced by change in the external cytoblastema. What is the cause of this difference, if the metamorphosing power of the cell-membrane be limited to its immediate neighbourhood merely? Might we not much rather expect that converted substances would be found without distinction on the inner as on the outer surface of the cell-membrane? It might be said that the cell-membrane converts the substance in contact with it without distinction, and that the variety in the products of this conversion depends only upon a difference between the convertible substance contained in the cell and the external cytoblastema. But the question then arises, as to how it happens that the contents of the cell differ from the external cytoblastema. If it be true that the cell-membrane, which at first closely surrounds the nucleus, expands in the course of its growth, so as to leave an interspace between it and the cell, and that the contents of the cell consist of fluid which has entered this space merely by imbibition, they cannot differ essentially from the external cytoblastema. I think therefore that, in order to explain the distinction between the cell-contents and the external cytoblastema, we must ascribe to the cell-membrane not only the power in general of chemically altering the substances which it is either in contact with, or has imbibed, but also of so separating them that certain substances appear on its inner, and others on its outer surface. The secretion of substances already present in the blood, as, for instance, of urea, by the cells with which the urinary tubes are lined, cannot be explained without such a faculty of the cells. There is, however, nothing so very hazardous in it, since it is a fact that different substances are separated in the decompositions produced by the galvanic pile. It might perhaps be conjectured from this peculiarity of the metabolic phenomena in the cells, that a particular position of the axes of the atoms composing the cell-membrane is essential for the production of these appearances.

Chemical changes occur, however, not only in the cytoblastema and the cell-contents, but also in the solid parts of which the cells are composed, particularly the cell-membrane. Without wishing to assert that there is any intimate connexion between the metabolic power of the cells and galvanism, I may yet, for the sake of making the representation of the process