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MICROSCOPICAL RESEARCHES

INTO THE

ACCORDANCE IN THE STRUCTURE AND GROWTH

OF

ANIMALS AND PLANTS.

TRANSLATED FROM THE GERMAN

OF

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CONTENTS.

SECTION III.

MICROSCOPICAL RESEARCHES,

&c. &c.

INTRODUCTION.

Although plants present so great a variety of external form, yet they are no less remarkable for the simplicity of their internal structure. This extraordinary diversity in figure is produced solely by different modes of junction of simple elementary structures, which, though they present various modifications, are yet throughout essentially the same, namely, *cells*. The entire class of the Cellular plants consists only of cells; many of them are formed solely of homogeneous cells strung together, some of even a single cell. In like manner, the Vascular plants, in their earliest condition, consist merely of simple cells; and the pollen-granule, which, according to Schleiden's discovery, is the basis of the new plant, is in its essential parts only a cell. In perfectly-developed vascular plants the structure is more complex, so that not long since, their elementary tissues were distinguished as cellular and fibrous tissue, and vessels or spiral-tubes. Researches on the structure, and particularly on the development of these tissues, have, however, shown that these fibres and spiral-tubes are but elongated cells, and the spiral-fibres only spiral-shaped depositions upon the internal surface of the cells. Thus the vascular plants consist likewise of cells, some of which only have advanced to a higher degree of development. The lactiferous vessels are the only structure not as yet reduced to cells; but further observations are required with respect to their development. According to Unger (Aphorismen zur Anatomie und Physiol. der Pflanzen, Wien, 1838, p. 14,) they in like manner consist of cells, the partition-walls of which become obliterated.

Animals, which present a much greater variety of external form than is found in the vegetable kingdom, exhibit also, and especially the higher classes in the perfectly-developed condition, a much more complex structure in their individual tissues. How broad is the distinction between a muscle and a nerve, between the latter and cellular tissue, (which agrees only in name with that of plants,) or elastic or horny tissue, and so on. When, however, we turn to the history of the development of these tissues, it appears, that all their manifold forms originate likewise only from cells, indeed from cells which are entirely analogous to those of vegetables, and which exhibit the most remarkable accordance with them in some of the vital phenomena which they manifest. *The design of the present treatise is to prove this by a series of observations.*

It is, however, necessary to give some account of the vital phenomena of vegetable cells. Each cell is, within certain limits, an Individual, an independent Whole. The vital phenomena of one are repeated, entirely or in part, in all the rest. These Individuals, however, are not ranged side by side as a mere Aggregate, but so operate together, in a manner unknown to us, as to produce an harmonious Whole. The processes which go forward in the vegetable cells, may be reduced to the following heads: 1, the production of new cells; 2, the expansion of existing cells; 3, the transformation of the cell-contents, and the thickening of the cell-wall; 4, the secretion and absorption carried on by cells.

The excellent researches of Schleiden, which throw so much light upon this subject, form the principal basis for my more minute observations on these separate vital phenomena. (See his "Beiträge zur Phytogenesis," in Müller's Archiv, 1838, p. 137, plates 3 and 4.)[1]

First, of the production of new cells. According to Schleiden, in Phænogamous plants, this process always (except as regards the cells of the Cambium,) takes place within the already mature cells, and in a most remarkable manner from out of the well-known cell-nucleus. On account of the importance of the

[1] [A translation of this paper forms part of this volume.—Trans.]

latter in reference to animal organization, I here introduce an abridgment of Schleiden's description of it. A delineation is given in plate I, fig. 1, *a*, *a*, taken from the onion. This structure—named by R. Brown, Areola or cell-nucleus, by Schleiden, Cytoblast—varies in its outline between oval and circular, according as the solid which it forms passes from the lenticular into the perfectly spheroidal figure. Its colour is mostly yellowish, sometimes, however, passing into an almost silvery white; and in consequence of its transparency, often scarcely distinguishable. It is coloured by iodine, according to its various modifications, from a pale yellow to the darkest brown. Its size varies considerably, according to its age, and according to the plants, and the different parts of a plant in which it is found, from 0·0001 to 0·0022 Paris inch. Its internal structure is granular, without, however, the granules, of which it consists, being very clearly distinct from each other. Its consistence is very variable, from such a degree of softness as that it almost dissolves in water, to a firmness which bears a considerable pressure of the compressorium without alteration of form. In addition to these peculiarities of the cytoblast, already made known by Brown and Meyen, Schleiden has discovered in its interior a small corpuscle (see plate I, fig. 1, *b*,) which, in the fully-developed cytoblast, looks like a thick ring, or a thick-walled hollow globule. It appears, however, to present a different appearance in different cytoblasts. Sometimes only the external sharply-defined circle of this ring can be distinguished, with a dark point in the centre,—occasionally, and indeed most frequently, only a sharply circumscribed spot. In other instances this spot is very small, and sometimes cannot be recognized at all. As it will frequently be necessary to speak of this body in the following treatise, I will for brevity's sake name it the "*nucleolus*," (Kernkörperchen, "*nucleus-corpuscle*.") According to Schleiden, sometimes two, more rarely three, or, as he has personally informed me, even four such nucleoli occur in the cytoblast. Their size is very various, ranging from the semi-diameter of the cytoblast to the most minute point.

The following is Schleiden's description of the origin of the cells from the cytoblast. So soon as the cytoblasts have attained their full size, a delicate transparent vesicle, the young cell, rises upon their surface, and is placed upon the flat cytoblast like a watch-glass upon a watch. It is at this time so delicate that it dissolves in distilled water in a few minutes. It gradually expands, becomes more consistent, and at length so large, that the cytoblast appears only as a small body inclosed in one of the side walls. The portion of the cell-wall which covers the cytoblast on the inner side, is, however, extremely delicate and gelatinous, and only in rare instances to be observed; it soon undergoes absorption together with the cytoblast, which likewise becomes absorbed in the fully-developed cell. The cytoblasts are formed free within a cell, in a mass of mucus-granules, and the young cells lie also free in the parent cell, and assume, as they become flattened against each other, the polyhedral form. Subsequently the parent cell becomes absorbed. (See a delineation of young cells within parent cells, plate I, fig. 2, *b, b, b.*) It cannot at present be stated with certainty that the formation of new cells *always* takes place from a cystoblast, and *always* within the existing cells, for the Cryptogamia have not as yet been examined in this respect, nor has Schleiden yet expressed his views in reference to the Cambium. Moreover, according to Mirbel, a formation of new cells on the outside of the previous ones takes place in the intercellular canals and on the surface of the plant in the Phanerogamia. (See Mirbel on "Marchantia," in Annales du Musée, 1, 55; and the counter-observations of Schleiden, Müller's Archiv, 1838, p. 161.) A mode of formation of new cells, different from the above described, is exhibited in the multiplication of cells by division of the existing ones; in this case partition-walls grow across the old cell, if, as Schleiden supposes, this be not an illusion, inasmuch as the young cells might escape observation in consequence of their transparency, and at a later stage, their line of contact would be regarded as the partition wall of the parent cell.

The expansion of the cell when formed, is, either regular on all sides, in which case it remains globular, or it becomes polyhedral from flattening against the neighbouring cells, or it is irregular from the cell growing more vigorously in one or in several directions. What was formerly called the fibrous tissue, which contains remarkably elongated cells, is formed in this manner. These fibres also become branched, when different points of the cell-wall expand in different directions. This expansion of the cell-wall cannot be explained as a merely mechanical effect, which would continually tend to render the cell-membrane thinner. It is often even combined with a thickening of the cell-wall, and is probably effected by that process of nutrition called intus-susception. (See Hugo Mohl's "Erläuterung und Vertheidigung meiner Ansicht von der Structur der Pflanzen-substanzen," Tübingen, 1836.) The flattening of the cells may also be ascribed to the same cause.

With regard to the changes which the cell-contents and cell-wall undergo during vegetation, I only take into consideration the thickening of the latter, as I have but a few isolated observations upon the transformations of the contents of animal cells, which however indicate analogous changes to those of plants. The thickening of the cell-walls takes place, either by the deposition from the original wall, of substances differing from, or more rarely, homogeneous with it, upon the internal surface of the cell, or by an actual thickening of the substance of the cell-wall. The first-mentioned form of deposition occurs in strata, at least this may be distinctly seen in many situations. (See Meyen's Pflanzen-Physiologie. Bd. 1, tab. I, fig. 4.) Very frequently,—according to Valentin, universally,—these depositions take place in spiral lines; this is very distinct, for example, in the spiral canals and spiral cells. The thickening of the cell-membrane itself, although more rare, appears still in some instances indubitable, for instance, in the pollen-tubes, (*e. g.* Phormium tenax.) Probably that extremely remarkable phenomenon of the motion of the fluid, which has now been observed in a great many cells of plants, is connected with the transformation of the cell-contents. In the Charæ, in which it is most distinct, a spiral motion may also be recognized in it. But, for the most part, the currents intersect each other in the most complex manner.

Absorption and Secretion may be classed as external operations of the vegetable cells. The disappearance of the parent cells in which young ones have formed, or of the cell-nucleus and of other structures, affords sufficient examples of absorption. Secretion is exhibited in the exudation of resin in the intercellular canals, and of a fluid containing sugar by the nectar-glands, &c. &c.

In all these processes each cell remains distinct, and maintains an independent existence. Examples, however, also occur in plants, where the cells coalesce, and this not merely with regard to their walls, but the cavities also. Schleiden has found that in the Cacti, the thickened walls of several cells unite to form a homogeneous substance, in which only the remains of the cell-cavities can be distinguished. Pl. I, fig. 3, represents such a blending of the cell-walls observed by Schleiden. The entire figure is a parent cell, with thickened walls, in which four young cells have formed, the walls of which are likewise thickened and have coalesced with each other, as well as with those of the parent cell; so that only the four cavities remain with their nuclei in a homogeneous substance. The spiral vessels, and, according to Unger, the lactiferous vessels also, afford examples of the union of the cavities of several cells by the absorption of the partition walls.

After these preliminary remarks we pass on to animals. The similarity between some individual animal and vegetable tissues has already been frequently pointed out. Justly enough, however, nothing has been inferred from such individual points of resemblance. Every cell is not an analogous structure to a vegetable cell; and as to the polyhedral form, seeing that it necessarily belongs to all cells when closely compacted, it obviously is no mark of similarity further than in the circumstance of densely crowded arrangement. An analogy between the cells of animal tissues and the same elementary structure in vegetables can only be drawn with certainty in one of the following ways: either, 1st, by showing that a great portion of the animal tissues originates from, or consists of cells, each of which must have its particular wall, in which case it becomes probable that these cells correspond to the cellular elementary structure universally present in plants; or, 2dly, by proving, with regard to any one animal tissue consisting of cells, that, in addition to its cellular structure, similar forces to those of vegetable cells are in operation in its component cells; or, since this is impossible directly, that the phenomena by which the activity of these powers or forces manifests itself, namely, nutrition and growth, proceed in the same or a similar manner in them as in the cells of plants. I reflected upon the matter in this point of view in the previous summer, when, in the course of my researches upon the terminations of the nerves in the tail of the Larvæ of frogs (Medic. Zeitung, 1837), I not only saw the beautiful cellular structure of the Chorda Dorsalis in these larvæ, but also discovered the nuclei in the cells. J. Müller had already proved that the chorda dorsalis in fishes consists of separate cells, provided with distinct walls, and closely packed together like the pigment of the Choroid. The nuclei, which in their form are so similar to the usual flat nuclei of the vegetable cells that they might be mistaken for them, thus furnished an additional point of resemblance. As however the importance of these nuclei was not known, and since most of the cells of mature plants exhibit no nuclei, the fact led to no farther result. J. Müller had proved, with regard to the cartilage-corpuscles discovered by Purkinje and Deutsch in several kinds of cartilage, from their gradual transition into larger cells, that they were hollow, thus in a more extended sense of the word, cells; and Miescher also distinguishes an especial class of spongy cartilages of a cellular structure. Nuclei were likewise known in the cartilage-corpuscles. Müller, and subsequently Meckauer, having observed the projection of the cartilage-corpuscles at the edge of a preparation, it became very probable that at least some of them must be considered as cells in the restricted sense of the word, or as cavities inclosed by a membrane. Gurlt also, when describing one form of permanent cartilage, calls them vesicles. I next succeeded in actually observing the proper wall of the cartilage-corpuscles, first in the branchial cartilages of the frog's larvæ, and subsequently also in the fish, and also the accordance of all cartilage-corpuscles, and by this means in proving a cellular structure, in the restricted sense of the word, in all cartilages. During the growth of some of the cartilage-cells, a thickening of the cell-walls might also be perceived. Thus was the similarity in the process of vegetation of animal and vegetable cells still further developed. Dr. Schleiden opportunely communicated to me at this time his excellent researches upon the origin of new cells in plants, from the nuclei within the parent-cell. The previously enigmatical contents of the cells in the branchial cartilages of the frog's larvæ thus became clear to me; I now recognized in them young cells, provided with a nucleus. Meckauer and Arnold had already found fat-vesicles in the cartilage-corpuscles. As I soon afterwards succeeded in rendering the origin of young cells from nuclei within the parent-cells in the branchial cartilages very probable, the matter was decided. Cells presented themselves in the anima body having a nucleus, which in its position with regard to the cell, its form and modifications, accorded with the cytoblast of vegetable cells, a thickening of the cell-wall took place, and the formation of young cells within the parent-cell from a similar cytoblast, and the growth of these without vascular connexion was proved. This accordance was still farther shown by many details; and thus, so far as concerned these individual tissues, the desired evidence, that these cells correspond to the elementary cells of vegetables was furnished. I soon conjectured that the cellular formation might be a widely extended, perhaps a universal principle for the formation of organic substances. Many cells, some having nuclei, were already known; for example, in the ovum, epithelium, blood-corpuscles, pigment, &c. &c. It was an easy step in the argument to comprise these recognized cells under one point of view; to compare the blood-corpuscles, for example, with the cells of epithelium, and to consider these, as likewise the cells of cartilages and vegetables, as corresponding with each other, and as realizations of that common principle. This was the more probable, as many points of agreement in the progress of development of these cells were already known. C. H. Schultz had already proved the preexistence of the nuclei of the blood-corpuscles, the formation of the vesicle around the same, and the gradual expansion of this vesicle. Henle had observed the gradual increase in size of the epidermal cells from the under layers of the epidermis, towards the upper ones. The growth of the germinal vesicle, observed by Purkinje, served also at first as an example of the growth of one cell within another, although it afterwards became more probable that it had not the signification of a cell, but of a cell-nucleus, and thus furnished proof that everything having the cellular form does not necessarily correspond to the cells of plants. A precise term for these cells, which correspond to those of plants, should be adopted; either *elementary* cells, or *vegetative* cells (vegetations-zellen). By still further examination, I constantly found this principle of cellular formation more fully realized. The germinal membrane was soon discovered to be composed entirely of cells, and shortly afterwards cell-nuclei, and subsequently also cells were found in all tissues of the animal body at their origin; so that all tissues consist of cells, or are formed by various modes, from cells. The other proof of the analogy between animal and vegetable cells was thus afforded.

I shall follow the same course in communicating the separate observations, and shall speak, therefore, in the next place of the structure and growth of the chorda dorsalis and cartilage, and in the second section treat of the germinal membrane and the remaining tissues.

SECTION III.

REVIEW OF THE PREVIOUS RESEARCHES—THE FORMATIVE PROCESS OF CELLS—THE CELL THEORY.

THE two foregoing sections of this work have been devoted to a detailed investigation of the formation of the different tissues from cells, to the mode in which these cells are developed, and to a comparison of the different cells with one another. We must now lay aside detail, take a more extended view of these researches, and grasp the subject in its more intimate relations. The principal object of our investigation was to prove the accordance of the elementary parts of animals with the cells of plants. But the expression "plant-like life" (pflanzen-ähnliches Leben) is so ambiguous that it is received as almost synonymous with growth without vessels; and it was, therefore, explained at page 6 that in order to prove this accordance, the elementary particles of animals and plants must be shown to be products of the same formative powers, because the phenomena attending their development are similar; that all elementary particles of animals and plants are formed upon a common principle. Having traced the formation of the separate tissues, we can more readily comprehend the object to be attained by this comparison of the different elementary particles with one another, a subject on which we must dwell a little, not only because it is the fundamental idea of these researches, but because all physiological deductions depend upon a correct apprehension of this principle.

When organic nature, animals and plants, is regarded as a Whole, in contradistinction to the inorganic kingdom, we do not find that all organisms and all their separate organs are compact masses, but that they are composed of innumerable small particles of a definite form. These elementary particles, however, are subject to the most extraordinary diversity of figure, especially in animals; in plants they are, for the most part or exclusively, cells. This variety in the elementary parts seemed to hold some relation to their more diversified physiological function in animals, so that it might be established as a principle, that every diversity in the physiological signification of an organ requires a difference in its elementary particles; and, on the contrary, the similarity of two elementary particles seemed to justify the conclusion that they were physiologically similar. It was natural that among the very different forms presented by the elementary particles, there should be some more or less alike, and that they might be divided, according to their similarity of figure, into fibres, which compose the great mass of the bodies of animals, into cells, tubes, globules, &c. The division was, of course, only one of natural history, not expressive of any physiological idea, and just as a primitive muscular fibre, for example, might seem to differ from one of areolar tissue, or all fibres from cells, so would there be in like manner a difference, however gradually marked between the different kinds of cells. It seemed as if the organism arranged the molecules in the definite forms exhibited by its different elementary particles, in the way required by its physiological function. It might be expected that there would be a definite mode of development for each separate kind of elementary structure, and that it would be similar in those structures which were physiologically identical, and such a mode of development was, indeed, already more or less perfectly known with regard to muscular fibres, blood-corpuscles, the ovum (see the Supplement), and epithelium-cells. The only process common to all of them, however, seemed to be the expansion of their elementary particles after they had once assumed their proper form. The manner in which their different elementary particles were first formed appeared to vary very much. In muscular fibres they were globules, which were placed together in rows, and coalesced to form a fibre, whose growth proceeded in the direction of its length. In the blood-corpuscles it was a globule, around which a vesicle was formed, and continued to grow; in the case of the ovum, it was a globule, around which a vesicle was developed and continued to grow, and around his again a second vesicle was formed.

The formative process of the cells of plants was clearly explained by the researches of Schleiden, and appeared to be the same in all vegetable cells. So that when plants were regarded as something special, as quite distinct from the animal kingdom, one universal principle of development was observed in all the elementary particles of the vegetable organism, and physiological deductions might be drawn from it with regard to the independent vitality of the individual cells of plants, &c. But when the elementary particles of animals and plants were considered from a common point, the vegetable cells seemed to be merely a separate species, co-ordinate with the different species of animal cells, just as the entire class of cells was co-ordinate with the fibres, &c., and the uniform principle of development in vegetable cells might be explained by the slight physiological difference of their elementary particles.

The object, then, of the present investigation was to show, that the mode in which the molecules composing the elementary particles of organisms are combined does not vary according to the physiological signification of those particles, but that they are everywhere arranged according to the same laws; so that whether a muscular fibre, a nerve-tube, an ovum, or a blood-corpuscle is to be formed, a corpuscle of a certain form, subject only to some modifications, a cell-nucleus, is universally generated in the first instance; around this corpuscle a cell is developed, and it is the changes which one or more of these cells undergo that determine the subsequent forms of the elementary particles; in short, that there is one common principle of development for all the elementary particles of organisms.

In order to establish this point it was necessary to trace the progress of development in two given elementary parts, physiologically dissimilar, and to compare them with one another. If these not only completely agreed in growth, but in their mode of generation also, the principle was established that elementary parts, quite distinct in a physiological sense, may be developed according to the same laws. This was the theme of the first section of this work. The course of development of the cells of cartilage and of the cells of the chorda dorsalis was compared with that of vegetable cells. Were the cells of plants developed merely as infinitely minute vesicles which progressively expand, were the circumstances of their development less characteristic than those pointed out by Schleiden, a comparison, in the sense here required, would scarcely have been possible. We endeavoured to prove in the first section that the complicated process of development in the cells of plants recurs in those of cartilage and of the chorda dorsalis. We remarked the similarity in the formation of the cell-nucleus, and of its nucleolus in all its modifications, with the nucleus of vegetable cells, the pre-existence of the cell-nucleus and the development of the cell around it, the similar situation of the nucleus in relation to the cell, the growth of the cells, and the thickening of their wall during growth, the formation of cells within cells, and the transformation of the cell-contents just as in the cells of plants. Here, then, was a complete accordance in every known stage in the progress of development of two elementary parts which are quite distinct, in a physiological sense, and it was established that the principle of development in two such parts may be the same, and so far as could be ascertained in the cases here compared, it is really the same.

But regarding the subject from this point of view we are compelled to prove the universality of this principle of development, and such was the object of the second section. For so long as we admit that there are elementary parts which originate according to entirely different laws, and between which and the cells which have just been compared as to the principle of their development there is no connexion, we must presume that there may still be some unknown difference in the laws of the formation of the parts just compared, even though they agree in many points. But, on the contrary, the greater the number of physiologically different elementary parts, which, so far as can be known, originate in a similar manner, and the greater the difference of these parts in form and physiological signification, while they agree in the perceptible phenomena of their mode of formation, the more safely may we assume that all elementary parts have one and the same fundamental principle of development. It was, in fact, shown that the elementary parts of most tissues, when traced backwards from their state of complete development to their primary condition are only developments of cells, which so far as our observations, still incomplete, extend, seemed to be formed in a similar manner to the cells compared in the first section. As might be expected, according to this principle the cells, in their earliest stage, were almost always furnished with the characteristic nuclei, in some the pre-existence of this nucleus, and the formation of the cell around it was proved, and it was then that the cells began to undergo the various modifications, from which the diverse forms of the elementary parts of animals resulted. Thus the apparent difference in the mode of development of muscular fibres and blood-corpuscles, the former originating by the arrangement of globules in rows, the latter by the formation of a vesicle around a globule, was reconciled in the fact that muscular fibres are not elementary parts co-ordinate with blood-corpuscles, but that the globules composing muscular fibres at first correspond to the blood-corpuscles, and are like them, vesicles or cells, containing the characteristic cell-nucleus, which, like the nucleus of the blood-corpuscles, is probably formed before the cell. The elementary parts of all tissues are formed of cells in an analogous, though very diversified manner, so that it may be asserted, *that there is one universal principle of development for the elementary parts of organisms, however different, and that this principle is the formation of cells.* This is the chief result of the foregoing observations.

The same process of development and transformation of cells within a structureless substance is repeated in the formation of all the organs of an organism, as well as in the formation of new organisms; and the fundamental phenomenon attending the exertion of productive power in organic nature is accordingly as follows: *a structureless substance is present in the first instance, which lies either around or in the interior of cells already existing; and cells are formed in it in accordance with certain laws, which cells become developed in various ways into the elementary parts of organisms.*

The development of the proposition, that there exists one general principle for the formation of all organic productions, and that this principle is the formation of cells, as well as the conclusions which may be drawn from this proposition, may be comprised under the term *cell-theory*, using it in its more extended signification, whilst in a more limited sense, by theory of the cells we understand whatever may be inferred from this proposition with respect to the powers from which these phenomena result.

But though this principle, regarded as the direct result of these more or less complete observations, may be stated to be generally correct, it must not be concealed that there are some exceptions, or at least differences, which as yet remain unexplained. Such, for instance, is the splitting into fibres of the walls of the cells in the interior of the chorda dorsalis of osseous fishes, which was alluded to at page 14. Several observers have also drawn attention to the fibrous structure of the firm substance of some cartilages. In the costal cartilages of old persons for example, these fibres are very distinct. They do not, however, seem to be uniformly diffused throughout the cartilage, but to be scattered merely here and there. I have not observed them at all in new-born children. It appears as if the previously structureless cytoblastema in this instance became split into fibres; I have not, however, investigated the point accurately. Our observations also fail to supply us with any explanation of the formation of the medullary canaliculi in bones, and an analogy between their mode of origin and that of capillary vessels, was merely suggested hypothetically. The formation of bony lamellæ around these canaliculi, is also an instance of the cytoblastema assuming a distinct form. But we will return presently to an explanation of this phenomenon that is not altogether improbable. In many glands, as for instance, the kidneys of a young mammalian fœtus, the stratum of cells surrounding the cavity of the duct, is enclosed by an exceedingly delicate membrane, which appears to be an elementary structure, and not to be composed of areolar tissue. The origin of this membrane is not at all clear, although we may imagine various ways of reconciling it with the formative process of cells. (These gland-cylinders seem at first to have no free cavity, but to be quite filled with cells. In the kidneys of the embryos of pigs, I found many cells in the cylinders, which were so large as to occupy almost the entire thickness of the canal. In other cylinders, the cellular layer, which was subsequently to line their walls, was formed, but the cavity was filled with very pale transparent cells, which could be pressed out from the free end of the tube.)

These and similar phenomena may remain for a time unexplained. Although they merit the greatest attention and require further investigations, we may be allowed to leave them for a moment, for history shows that in the laying down of every general principle, there are almost always anomalies at first, which are subsequently cleared up.

The elementary particles of organisms, then, no longer lie side by side unconnectedly, like productions which are merely capable of classification in natural history, according to similarity of form; they are united by a common bond, the similarity of their formative principle, and they may be compared together and physiologically arranged in accordance with the various modifications under which that principle is exhibited. In the foregoing part of this work, we have treated of the tissues in accordance with this physiological arrangement, and have compared the different tissues with one another, proving thereby, that although different, but similarly formed, elementary parts may be grouped together in a natural-history arrangement, yet such a classification does not necessarily admit of a conclusion with regard to their physiological position, as based upon the laws of development. Thus, for example, the natural-history division, "cells," would, in a general sense, become a physiological arrangement also, inasmuch as most of the elementary parts comprised under it have the same principle of development; but yet it was necessary to separate some from this division; as, for instance, the germinal vesicle, all hollow cell-nuclei, and cells with walls composed of other elementary parts, although the germinal vesicle is a cell in the natural-history sense of the term. It does not correspond to an epithelium-cell, but to the nucleus of one. The difference in the two modes of classification was still more remarkable in respect to fibres. The mode of their origin is most varied, for, as we saw, a fibre of areolar tissue is essentially different from a muscular fibre; while, on the other hand, a whole primitive muscular fasciculus is identical in its mode of origin with a nervous fibre, and so on. The existence of a common principle of development for all the elementary parts of organic bodies lays the foundation of a new section of general anatomy, to which the term *philosophical* might be applied, having for its object—firstly, to prove the general laws by which the elementary parts of organisms are developed; and, secondly, to point out the different elementary parts in accordance with the general principle of development, and to compare them with one another.

SURVEY OF CELL-LIFE.

The foregoing investigation has conducted us to the principle upon which the elementary parts of organized bodies are developed, by tracing these elementary parts, from their perfected condition, back to the earlier stages of development. Starting now from the principle of development, we will reconstruct the elementary parts as they appear in the matured state, so that we may be enabled to take a comprehensive view of the laws which regulate the formation of the elementary particles. We have, therefore, to consider—1, the cytoblastema; 2, the laws by which new cells are generated in the cytoblastema; 3, the formative process of the cells themselves; 4, the very various modes in which cells are developed into the elementary parts of organisms.

Cytoblastema.—The cytoblastema, or the amorphous substance in which new cells are to be formed, is found either contained within cells already existing, or else between them in the form of intercellular substance. The cytoblastema, which lies on the outside of existing cells, is the only form of which we have to treat at present, as the cell-contents form matter for subsequent consideration. Its quantity varies exceedingly, sometimes there is so little that it cannot be recognized with certainty between the fully-developed cells, and can only be observed between those most recently formed; for instance, in the second class of tissues; at other times there is

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 more clear, remark that the chemical changes produced by a galvanic pile are accompanied by corresponding changes in the pile itself.

The more obscure the cause of the metabolic phenomena in the cells is, the more accurately we must mark the circumstances and phenomena under which they occur. One condition to them is a certain temperature, which has a maximum and a minimum. The phenomena are not produced in a temperature below 0° or above 80° R.; boiling heat destroys this faculty of the cells permanently; but the most favorable temperature is one between 10° and 32° R. Heat is evolved by the process itself.

Oxygen, or carbonic acid, in a gaseous form or lightly confined, is essentially necessary to the metabolic phenomena of the cells. The oxygen disappears and carbonic acid is formed, or *vice versa*, carbonic acid disappears, and oxygen is formed. The universality of respiration is based entirely upon this fundamental condition to the metabolic phenomena of the cells. It is so important that, as we shall see further on, even the principal varieties of form in organized bodies are occasioned by this peculiarity of the metabolic process in the cells.

Each cell is not capable of producing chemical changes in every organic substance contained in solution, but only in particular ones. The fungi of fermentation, for instance, effect no changes in any other solutions than sugar; and the spores of certain plants do not become developed in all substances. In the same manner it is probable that each cell in the animal body converts only particular constituents of the blood.

The metabolic power of the cells is arrested not only by powerful chemical actions, such as destroy organic substances in general, but also by matters which chemically are less uncongenial; for instance, concentrated solutions of neutral salts. Other substances, as arsenic, do so in less quantity. The metabolic phenomena may be altered in quality by other substances, both organic and inorganic, and a change of this kind may result even from mechanical impressions on the cells.

Such are the most essential characteristics of the fundamental powers of the cells, so far as they can as yet be deduced from the phenomena. And now, in order to comprehend distinctly in what the peculiarity of the formative process of a cell, and therefore in what the peculiarity of the essential phenomenon in the formation of organized bodies consists, we will compare this process with a phenomenon of inorganic nature as nearly as possible similar to it. Disregarding all that is specially peculiar to the formation of cells, in order to find a more general definition in which it may be included with a process occurring in inorganic nature, we may view it as a process in which a solid body of definite and regular shape is formed in a fluid at the expense of a substance held in solution by that fluid. The process of crystallization in inorganic nature comes also within this definition, and is, therefore, the nearest analogue to the formation of cells.

Let us now compare the two processes, that the difference of the organic process may be clearly manifest. First, with reference to the plastic phenomena, the forms of cells and crystals are very different. The primary forms of crystals are simple, always angular, and bounded by plane surfaces; they are regular, or at least symmetrical, and even the very varied secondary forms of crystals are almost, without exception, bounded by plane surfaces. But manifold as is the form of cells, they have very little resemblance to crystals; round surfaces predominate, and where angles occur, they are never quite sharp, and the polyhedral crystal-like form of many cells results only from mechanical causes. The structure too of cells and of crystals is different. Crystals are solid bodies, composed merely of layers placed one upon another; cells are hollow vesicles, either single, or several inclosed one within another. And if we regard the membranes of these vesicles as layers, there will still remain marks of difference between them and crystals; these layers are not in contact, but contain fluid between them, which is not the case with crystals; the layers in the cells are few, from one to three only; and they differ from each other in chemical properties, while those of crystals consist of the same chemical substance. Lastly, there is also a great difference between crystals and cells in their mode of growth. Crystals grow by apposition, the new molecules are set only upon the surface of those already deposited, but cells increase also by intussusception, that is to say, the new molecules are deposited also between those already present.

But greatly as these plastic phenomena differ in cells and in crystals, the metabolic are yet more different, or rather they are quite peculiar to cells. For a crystal to grow, it must be already present as such in the solution, and some extraneous cause must interpose to diminish its solubility. Cells, on the contrary, are capable of producing a chemical change in the surrounding fluid, of generating matters which had not previously existed in it as such, but of which only the elements were present in another combination. They therefore require no extraneous influence to effect a change of solubility; for if they can produce chemical changes in the surrounding fluid, they may also produce such substances as could not be held in solution under the existing circumstances, and therefore need no external cause of growth. If a crystal be laid in a pretty strong solution, of a substance similar even to itself, nothing ensues without our interference, or the crystal dissolves completely: the fluid must be evaporated for the crystal to increase. If a cell be laid in a solution of a substance, even different from itself, it grows and converts this substance without our aid. And this it is from which the process going on in the cells (so long as we do not separate it into its several acts) obtains that magical character, to which attaches the idea of Life.

From this we perceive how very different are the phenomena in the formation of cells and of crystals. Meanwhile, however, the points of resemblance between them should not be overlooked. They agree in this important point, that solid bodies of a certain regular shape are formed in obedience to definite laws at the expense of a substance contained in solution in a fluid; and the crystal, like the cell, is so far an active and positive agent as to cause the substances which are precipitated to be deposited on itself, and nowhere else. We must, therefore, attribute to it as well as to the cell a power to attract the substance held in solution in the surrounding fluid. It does not indeed follow that these two attractive powers, the power of crystallization—to give it a brief title—and the plastic power of the cells are essentially the same. This could only be admitted, if it were proved that both powers acted according to the same laws. But this is seen at the first glance to be by no means the case: the phenomena in the formation of cells