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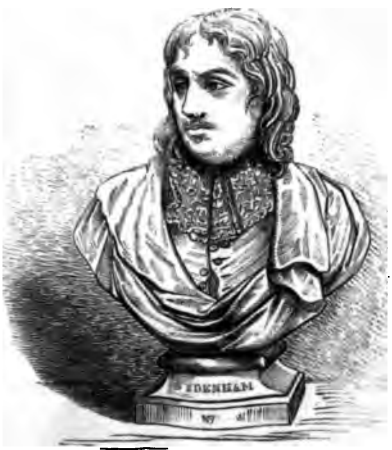

LONDON

MDCCCXLVII.

MICROSCOPICAL RESEARCHES

INTO THE

ACCORDANCE IN THE STRUCTURE AND GROWTH

OF

ANIMALS AND PLANTS.

TRANSLATED FROM THE GERMAN

OF

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AUTHOR'S PREFACE.

It is one of the essential advantages of the present age, that the bond of union connecting the different branches of natural science is daily becoming more intimate, and it is to the contributions which they reciprocally afford each other that we are indebted for a great portion of the progress which the physical sciences have lately made. This circumstance therefore renders it so much the more remarkable, that, notwithstanding the many efforts of distinguished men, the anatomy and physiology of animals and plants should remain almost isolated, though advancing side by side, and that the conclusions deducible from the one department should admit only of a remote and extremely cautious application to the other. Of late, the two sciences have for the first time begun to be more and more intimately allied. The object of the present treatise is to prove the most intimate connexion of the two kingdoms of organic nature, from the similarity in the laws of development of the elementary parts of animals and plants.

The principal result of this investigation is, that one common principle of development forms the basis for every separate elementary particle of all organised bodies, just as all crystals, notwithstanding the diversity of their figures, are formed according to similar laws. I have endeavoured to explain the design of such a comparison more fully in the commencement of the third section of this treatise, and will now lay before the reader those data which are of most importance in an historical point of view in reference to the development of this idea.

As soon as the microscope was applied to the investigation of the structure of plants, the great simplicity of their structure, as compared with that of animals, necessarily attracted attention. Whilst plants appeared to be composed entirely of cells, the elementary particles of animals exhibited the greatest variety, and for the most part presented nothing at all in common with cells. This, harmonised with the opinion long since current, that the growth of animals, whose tissues are furnished with vessels, differed essentially from that of vegetables. An independent vitality was ascribed to the elementary particles of vegetables growing without vessels, they were regarded to a certain extent as individuals, which composed the entire plant; whilst, on the other hand, no such a view was taken of the elementary parts of animals. An essential difference both in the mode and in the fundamental powers of growth was thus maintained.

It soon, however, appeared that animal tissues do also occur which grow without vessels; for instance, in the formation of the ovum, and the earlier stages of development of the embryo previous to the formation of the blood; and, secondly, certain tissues of the adult, the epidermis for example. With respect to the ovum, which manifested indubitable proofs of an actual vitality, all physiologists were agreed in ascribing to it a so-called *plant-like* growth. This resemblance to the plant had reference to a growth of the conspicuous parts of the ovum without vessels, and was in no way connected with the form and mode of growth of the elementary particles. No one, however, considered that the analogy of the ovum entitled him to infer the operation of a plant-like growth of the elementary particles in the non-vascular tissues of the matured animal; on the contrary, the opinion rather gained ground, that these tissues originated and grew by means of a secretion from the surface of the organised tissues. Such was supposed to be the case with the epithelium, the crystalline lens, &c. This opinion still maintained its ground, even when the structure of the tissues became more accurately known. Nor did the plant-like growth of the component parts of the ovum abolish the assumed essential difference of the growth of the vascular tissues.

A very important advance was made in the year 1837, when an actual growth of the elementary particles of epithelium was proved to take place without vessels. Henle (Symbolæ ad anatomiam vill. intest. Berol. 1837) showed that the cells in the superficial layers of epithelium are much more expanded than those in the deeper strata, a fact which leaves scarcely any doubt as to their true plant-like (i. e. non-vascular) growth. Henle[1] says (l. c. p. 9), "Hoc in loco (in planta pedis) cellularum (retis Malpighii) diametrum extrorsum augeri, sæpius repetita observatione pro re certa affirmare audeo. Quas retis cellulas non minus in fœtu suillo sensim increscentes transire in cellulas epidermidis, nunquam non inveni." Purkinje and Raschkow (Meletem. circa mammal. dentium evol. Vratisl. 1835) had made the following observations upon the development of the epidermis: "In primis evolutionis periodis—squamulæ—epithelii nondum ita conformatæ sunt ut in illa periodo, quæ partui præcedit, sed parenchyma plantarum cellulis simillimum ostendunt, cum quæque squamula, quæ postea talis apparet, tunc temporis tanquam cellula polyedrica e membrana tenacissima constans globosamque guttulam continens in conspectum veniat. Pressu applicato rumpebantur istæ cellulæ atque lymphaticum liquorem effundebant, quæ cellulæ, procedente evolutione, verisimile complanatæ in illas polyedricas squamas mutantur." Henle, when quoting this passage, adds (l. c. p. 9): "Hæc illa num vero sola compressio in causa esse possit, ut parva cellula

[1] Henle's observations are detailed at page 76 of this treatise. The researches of Turpin and Dumortier could not be quoted, as I only became acquainted with them at the conclusion of my work.

in tantam laminam extendatur, nondum satis mihi constat: certe principio increscere volumen cellulæ, nescio an imbibitione, constabit, nisi spes fallit, promotis disquisitionibus." The caution with which Henle (and, indeed, every good physiologist) expresses himself in this passage with reference to the true growth of non-vascular tissues, is the best illustration of the state of the question. There is another observation of Henle's, which is opposed to the epithelium being regarded as a lifeless substance secreted from the organised tissue; I allude to the passage (l. c. p. 22 et seq.) where he proves that the vibratile cilia, whose motion it is so difficult to explain by physical laws, stand upon little cylinders which are merely a modification of the epithelium.

Turpin (Annal. des Sciences natur. vii, p. 207) showed that the corpuscles, which Donné had found in vaginal discharges, and regarded as cast-off epithelium, were organised cells, and were in general oblong, and either pointed at one or both ends, or altogether irregular in figure, and that a new generation of spherical vesicles[1] took place in their interior. He then remarks (l. c. p. 210): "On ne peut s'empêcher, après avoir bien étudié les vésicules dont est formée la couche de mucus produite par la membrane muqueuse vaginale, d'y voir un tissu cellulaire bien organisé et composé comme tous les tissus cellulaires végétaux, d'un agglomérat, par simple contiguité, de vésicules distinctes et vivant *individuellement* chacune pour leur propre compte au dépens de l'eau muqueuse, qui les baigne de toutes parts." Turpin then compares this tissue of animal cells, presented under the appearance of mucus, with what he calls "*suppurations* végétales, excrétions muqueuses, qui semblent suinter sous forme de gouttelettes, de la surface des tissus vifs," and which is generally comprised under the

[1] May there not have been some confusion here with the nuclei of the epithelium-cells? At present, as far as regards Mammalia at least, we know of no formation of cells within cells in the epithelium.

name of cambium; and finally adds (l. c. p. 212), "En étendant la comparaison entre deux choses si comparables, on trouve que la forme variable des vésicules du tissu cellulaire du mucus de la membrane vaginale, leur allongement en pointe, leur flaccidité, toujours entretenue par l'humidité constante qui baigne les tissus animaux, et le développement dans leur intérieur, soit des granules, soit des vésicules sphériques, sont toutes choses qui s'observent également dans la composition de tous les tissus cellulaires végétaux mous et aqueux, et que l'on désigne par le nom de pulpe ou de parenchyme dans certaines tiges ou feuilles grasses et dans certains fruits mûrs ou blettes."

In the same year, Dumortier communicated researches into the development of the ova of snails. (Annal. des Sciences natur. viii, p. 129.) He observed, that in the mucus-globule, present in these ova, and from which the embryo is developed, there are generated cells, in the interior of which, secondary cells are formed, and so on, and that this tissue of cells becomes transformed into the liver, whilst the other tissues originate from a gelatinous mass, which exhibits myriads of points. In his conclusions, he says (l. c. p. 163), "En examinant l'évolution des Mollusques, nous avons démontré que les tissus animaux, quoique formés originairement de même par la solidification des surfaces, se développent de différentes manières: le tissu cellulaire par des productions médianes, le tissu dermo-musculaire par un feutré de canalicules centripètes. Ainsi, chez les animaux, les tissus ne se forment pas au dépens les uns des autres; il n'y existe pas un tissu générateur unique, mais bien plusieurs tissus originairement distincts.—Les belles observations de M. Mirbel ont prouvé que chez les végétaux il existe un seul tissu originel, le tissu cellulaire, qui par une suite de métamorphoses, se transforme en tissu vasculaire. Par conséquent, le règne végétal est caractérisé par l'unité originel, et le règne animal par la pluralité originelle des tissus." Vanbeneden and Windischmann give a different explanation to these observations of Dumortier, in as much as they regard the tissue consisting of cells as the yelk and not the liver. (Bulletin de l'Acad. royale de Bruxelles, tom. v, No. 5.)

Other instances of the resemblance in form between different animal tissues and those of vegetables had already been repeatedly pointed out. Thus it was frequently said, in reference to thickly-crowded animal cells, or even mere globules, that they presented an appearance resembling vegetable cellular-tissue; and Valentin (Nov. Act. N. C. xviii, P. 1, 96), after describing the nucleus of the epidermal cells, states that it reminded him of the nucleus which occurs in the vegetable kingdom, in the cells of the epidermis, the pistil, &c. Nothing, however, resulted from such comparisons, because they were mere similarities in figure, between structures which present the greatest variety of form.

Schleiden instituted researches into the mode of development of vegetable cells, which illustrated the process most excellently. This admirable work appeared subsequently in the second part of Müller's Archiv for 1838. He found, that in the formation of vegetable cells, small, sharply-defined granules are first generated in a granulous substance, and around them the cell-nuclei (cytoblasts) are formed, which appear like granulous coagulations around the granules. The cytoblasts grow for a certain time, and then a minute transparent vesicle rises upon them, the young cell, so that, in the first instance, it is placed upon the cytoblast, like a watch-glass upon a watch. It then becomes expanded by growth. Schleiden communicated the results of his investigations to me, previous to their publication in October, 1837. The resemblance in form, which the chorda dorsalis, to which J. Müller had already drawn attention, and the branchial cartilage of the tadpole present to vegetable cells, had previously struck me, but nothing resulted from it. The discoveries of Schleiden, however, led to more extended researches in another direction.

In the above-mentioned investigations of Henle, Turpin, and Dumortier, the resemblance which the animal tissues examined (epithelium and the liver or yelk of snails) bore to plants, lay, in the first place, in the circumstance, that their elementary particles grew without vessels, and in part, free in a fluid, or even inclosed in another cell; and in the second place, in that these elementary particles exhibiting a non-vascular growth, were furnished with a peculiar wall, like the cells of plants. When this coincidence was furnished, we were entitled to arrange these cells as near to the vegetable cells as the different kinds of animal cells, for instance, germinal vesicles, blood-corpuscles, and fat-cells, stand together, when regarded as different species comprised under the natural-history idea of cells.

The state of the matter, therefore, when I commenced my researches was as follows: The elementary particles of organised bodies presented the greatest variety of form; there was a resemblance between many of them, and, according to the greater or lesser degree of similarity, a group of fibres, of cells, of globules, and so on, might be distinguished, and in each of these divisions again there were different forms. As the cells taken collectively differed from the fibres, so also, only in a less degree, must the separate kinds of cells differ from each other, and the different kinds of fibres from each other. All those forms seemed to have nothing else in common, save that they grew by the addition of new molecules between those already existing, that they were living elements. So long as the epithelium-cells were regarded as a secretion of the organised substance, they could never, in that sense, be classed with the living elementary particles. There seemed to be no general rule with respect to the mode in which the molecules were joined together to form the living particles; here they united into one kind of cells, there into another, and at a third spot into a fibre, and so on. The principle of development appeared to be altogether different for such particles as differed in their physiological signification; and the diversity in the laws which it was necessary to assume in the development of a cell and a fibre, was also, only in a less degree, necessarily assumed between the different kinds of cells and the different sorts of fibres. Cells, fibres, &c. were therefore merely natural-history ideas, and no conclusion could be drawn from the mode of development of one kind of cell as to that of any other kind; and, in fact, no such deductions were made, although we were acquainted with some important points in the process of development of certain kinds of cells; for example, the blood-corpuscle (see p. 67 of this Treatise), and the ovum (see the Supplement, p. 217). Although the investigations quoted above determined the important fact of the non-vascular growth, they did not thereby effect any change in our views. The idea of proving the similarity of the principle of development for elementary particles which were physiologically different, by a comparison of animal cells with those of vegetables, was not contained in those researches, and with these, therefore, the investigators before mentioned might well come to a stand-still.

The discoveries of Schleiden made us more accurately acquainted with the process of development in the cells of plants. This process contained sufficient characteristic data to render a comparison of the animal cells in reference to a similar principle of development practicable. In this sense I compared the cells of cartilage and of the chorda dorsalis with vegetable cells, and found the most complete accordance. The discovery, upon which my inquiry was based, immediately lay in the perception of the principle contained in the proposition, that two elementary particles, physiologically different, may be developed in the same manner. For it follows, from the foregoing, that if we maintain the accordance of two kinds of cells in this sense, we are compelled to assume the same principle of development for all elementary particles, however dissimilar they may be, because the distinction between the other particles and a cell differs only in degree from that which exists between two cells; so also the principle of development in the latter can only then be similar, when it repeats itself in the rest of the elementary particles. I therefore quickly asserted this position also, so soon as I was convinced of the accordance between the cells of cartilage and those of plants in this sense.

It now became easy to accommodate the principle which I had laid down to the rest of the tissues, since the principle itself had already made me acquainted with the law of their development. Actual observation also completely confirmed the conclusion which had been drawn with respect to the rest of the tissues. It was not absolutely necessary that this principle should recur in the elementary particles of vascular tissues; for since no independent vitality of the elements, and therefore no diversity in the fundamental powers of growth, was assumed in their case, so, without prejudice to the principle, might they be subject to entirely different laws of development. But slight as was the probability at the commencement, that the principle could be carried out with respect to them, observation soon showed that vessels do not establish any essential difference in growth, but merely occasion some distinctions, which may be explained as the consequences of a more minute distribution of the nutrient fluid; of the change of material facilitated both by that means and by the circulation; and of a greater capacity of imbibition in the animal substance. Thus was the proposition firmly established by observation, that there is one common principle of development for the elementary particles of all organised bodies. It had already indeed been long known that all tissues were formed from a granulous mass; but that these granules bore some direct relation to the subsequent elementary particles, and what that relation might be was known in respect to but a few of the particles, and in them the mode of development appeared to differ so much, that unity neither was nor could be recognised in it; for the conformity of the principle of development consists chiefly in the similar origin of these granules themselves, and this circumstance was not known, indeed the term granules or granulous mass was sometimes used to denote the entire cells, sometimes the nuclei, and sometimes granulous substances which form to a certain extent as chemical precipitates, and have no direct connexion with the elementary cells of organised bodies.

I communicated a preliminary review of the results gained, and which already comprehended most of the tissues, in the beginning of the year 1838, in Froriep's 'Notizen,' Nos. 91, 103, and 112. The detailed description required a longer time; the first two portions of the present Treatise were placed before the Academy of Paris in August and December, 1838. J. Müller and Henle have already applied the theory to the most important pathological processes, and it now only requires to be extended to comparative anatomy, particularly amongst the lower animals.

At the conclusion of the Treatise I have attempted a theory of organisms, and for that purpose have excluded everything theoretical from the work itself, in order that facts might not be confused with hypothetical matter. The theory has at least this advantage, that by its aid any one may form a precise idea for himself of the organic processes, which may conduct to new researches; such a theory may therefore be of use, even if assumed to be decidedly false. It contains the principles of the organic phenomena, both of the healthy and diseased organism. It was my intention to have added an application of the theory to the several organic processes; but circumstances compelled me to bring the work to a conclusion. Perhaps at some future time I may find opportunity to fill up the deficiency.

Berlin, March 1839.

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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 annot be explained as a merely mechanical effect, continually tend to render the cell-membrane is often even combined with a thickening of the d is probably effected by that process of nutrition susception. (See Hugo Mohl's "Erläuterung und ng meiner Ansicht von der Structur der Pflanzen-' Tübingen, 1836.) The flattening of the cells may bed to the same cause.

ard to the changes which the cell-contents and cell-o during vegetation, I only take into consideration ing of the latter, as I have but a few isolated obser-n the transformations of the contents of animal cells, ver indicate analogous changes to those of plants. ing of the cell-walls takes place, either by the depo-the original wall, of substances differing from, or , homogeneous with it, upon the internal surface of by an actual thickening of the substance of the cell-first-mentioned form of deposition occurs in strata, s 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 deposi-tions 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 in-stances indubitable, for instance, in the pollen-tubes, (*e. g.* Phormium tenax.) Probably that extremely remarkable phe-nomenon of the motion of the fluid, which has now been ob-served 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 ope-rations 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 intercel-lular 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 so large a quantity present, that the cells contained in it do not come into contact, as is the case in most cartilages. The chemical and physical properties of the cytoblastema are not the same in all parts. In cartilages it is very consistent, and ranks among the most solid parts of the body; in areolar tissue it is gelatinous; in blood quite fluid. These physical distinctions imply also a chemical difference. The cytoblastema of cartilage becomes converted by boiling into gelatine, which is not the case with the blood; and the mucus in which the mucus-cells are formed differs from the cytoblastema of the cells of blood and cartilage. The cytoblastema, external to the existing cells, appears to be subject to the same changes as the cell-contents; in general it is a homogeneous substance; yet it may become minutely granulous as the result of a chemical transformation, for instance, in areolar tissue and the cells of the shaft of the feather, &c. As a general rule, it diminishes in quantity, relatively with the development of the cells, though it seems that in cartilages there may be even a relative increase of the cytoblastema proportionate to the growth of the tissue. The physiological relation which the cytoblastema holds to the cells may be twofold: first, it must contain the material for the nutrition of the cells; secondly, it must contain at least a part of what remains of this nutritive material after the cells have withdrawn from it what they required for their growth. In animals, the cytoblastema receives the fresh nutritive material from the blood-vessels; in plants it passes chiefly through the elongated cells and vascular fasciculi; there are, however, many plants which consist of simple cells, so that there must also be a transmission of nutrient fluid through the simple cells; blood-vessels and vascular fasciculi are, however, merely modifications of cells.

Laws of the generation of new cells in the cytoblastema.— In every tissue, composed of a definite kind of cells, new cells of the same kind are formed at those parts only where the fresh nutrient material immediately penetrates the tissue. On this depends the distinction between organized or vascular, and unorganized or non-vascular tissues. In the former, the nutritive fluid, the liquor sanguinis, permeates by means of the vessels the whole tissue, and therefore new cells originate throughout its entire thickness. Non-vascular tissues, on the contrary, such as the epidermis, receive the nutritive fluid only from the tissue beneath; and new cells therefore originate only on their under surface, that is, at the part where the tissue is in connexion with organized substance. So also in the earlier period of the growth of cartilage, while it is yet without vessels new cartilage-cells are formed around its surface only, or at least in the neighbourhood of it, because the cartilage is connected with the organized substance at that part, and the cytoblastema penetrates from without. We can readily conceive this to be the case, if we assume that a more concentrated cytoblastema is requisite for the formation of new cells than for the growth of those already formed. In the epidermis, for instance, the cytoblastema below must contain a more concentrated nutritive material. When young cells are formed in that situation, the cytoblastema, which penetrates into the upper layers, is less concentrated, and may therefore serve very well for the growth of cells already formed, but not be capable of generating new ones. This constitutes the distinction which was formerly made between a growth by apposition and one by intussusception; "growth by apposition" is a correct term, if it be applied to the generation of new cells, and not to the growth of those already existing, the new cells in the epidermis for example, are formed only on its under surface, and are pushed upwards when other new ones are formed beneath them; but the new cells are generated throughout the entire thickness of the organized tissues. The cells, however, grow individually by intussusception in both instances. The bones occupy, to a certain extent, a middle position between the organized and unorganized tissues. The cartilage in the first instance has no vessels, and the new cells are, therefore, formed in the neighbourhood of the external surface only; at a subsequent period it receives vessels, which traverse the medullary or Haversian canals, the latter, however, are not sufficiently numerous to allow of the entire tissue becoming equably saturated with the fluid parts of the blood, a process which would be still further impeded by the greater firmness of cartilage and bone. According to the above law, then, the formation of new cytoblastema and new cells may take place partly upon the surface and partly around these medullary canals. Now, the structure of bone becomes most simple, if we assume that, in consequence of the firmness of the osseous substance, this process goes on in layers, which do not completely coalesce together. It must consist of a double system of layers, one being concentric to each of the medullary canals, and the other to the external surface of the bone. When the bone is hollow, the layers must also be concentric to the cavity; and when small medullary cavities exist in the place of canals, as in the spongy bones, the layers must also be concentric to them. The difference in the growth of animals and plants also rests upon the same law. In plants, the nutritive fluid is not so equably distributed throughout the entire tissues, as it is in the organized tissues of animals, but is conveyed in isolated fasciculi of vessels, widely separated from one another, more after the manner of bone. These fasciculi of vessels are also observed to be surrounded with small (most likely younger) cells, so that, in all probability, the formation of their new cells also takes place around these vessels, as it does in bones around the medullary canaliculi. In the stem of dicotyledonous plants the sap is conducted between the bark and the wood, and on that account the new cells are generated in strata concentric to the layers of the previous year. The variety in the mode of growth, as to whether the new cells are developed merely in separate situations in the tissue, or equally throughout its whole thickness, does not, therefore, constitute any primary distinction, but is the consequence of a difference in the mode in which their nutritive fluid is conveyed.

The generation of cells of a different character, such as fat-cells, in the interior of a non-vascular tissue (in cartilage which does not as yet contain vessels, for example), appears at first sight to form an exception to the law just laid down. But such is not really the case; the circumstance is capable of two explanations, either the cytoblastema for this kind of cells is furnished by the true cells of the tissue only when they have attained a certain stage of their development, or, the cytoblastema which penetrates into the depth of the tissue contains the nutritive material for the true cells of the tissue in a less concentrated state, whilst it is still sufficiently impregnated with the nutritive material for the other kind of cells.

According to Schleiden, new cells are never formed in the intercellular substance in plants; in animals, on the contrary, a generation of cells within cells is the less frequent mode, but this does occur, and in such a way, that a threefold or fourfold generation may take place in succession within one cell. Thus, according to R. Wagner's observations (see the Supplement), the Graafian vesicle appears to be an elementary cell; the ovum is developed within it in like manner as an elementary cell; within this, again, according at least to observations made upon the bird's egg, cells are generated, some of which contain young cells. It appears also, that a formation of true cartilage-cells can sometimes take place within those which already exist, and that young cells (fat-cells?) may be generated within them again. Several such examples might be brought forward; but by far the greater portion of the cells of cartilage are formed in the cytoblastema on the outside of the cells already present, and we never meet with a generation of cells within cells in the case of fibre, muscle, or nerve.

General phenomena of the formation of cells. Round corpuscles make their appearance after a certain time in the cytoblastema which, in the first instance, is structureless or minutely granulous. These bodies may either be cells in their earliest condition (and some may be recognized even at this stage), that is, hollow vesicles furnished with a peculiar structureless wall, cells without nuclei, or they may be cell-nuclei or the rudiments of cell-nuclei, round which cells will afterwards be formed.

The cells without nuclei, or, more correctly, the cells in which no nuclei have as yet been observed, occur only in the lower plants, and are also rare in animals. For the present, however, the following must be regarded as such, viz.: the young cells contained within others in the chorda dorsalis (see p. 13), the cells of the yelk-substance in the bird's egg (p. 50), the cells in the mucous layer of the germinal membrane of the bird's egg (p. 60), and some cells of the crystalline lens (p. 88). Pl. I, fig. 10, *c*, represents one of these cells without nuclei. Thus the mode of growth, in this instance, is similar to that of the nucleated cells, after the formation of their cell-membrane

By far the greater portion of the animal body, at least ninety-nine hundredths of all the elementary parts of the bodies of mammalia are developed from nucleated cells.

The cell-nucleus is a corpuscle, having a very characteristic form, by which it may in general be easily recognized. It is rather round or oval, spherical or flat. In the majority of fully-developed animal cells its average size would be about 0·0020-0·0030 Paris inch; but we meet with nuclei which are very much larger, and others, again, much smaller than this. The germinal vesicle of the bird's egg may be regarded as the largest cell-nucleus; the nuclei of the blood-corpuscles of warm-blooded animals afford examples of very small cell-nuclei. If the latter were but a very little smaller they would escape observation altogether, and the blood-corpuscles would then appear to be cells without nuclei. No other structure can be detected in these very small nuclei, nor can their characteristic form be further demonstrated. On the other hand, that of the larger blood-corpuscles may be distinctly recognized as a cell-nucleus.

The cell-nucleus is generally dark, granulous, often somewhat yellowish; but some occur which are quite pellucid and smooth. It is either solid, and composed of a more or less minutely granulated mass, or hollow. Most nuclei of animal cells exhibit more or less distinct trace of a cavity, at least, their external contour is generally somewhat darker, and the substance of the nucleus seems to be somewhat more compact at the circumference. The nucleus may often be traced through its progressive stages of development from a solid body to a perfect vesicle; this may be observed in the nuclei of the cartilage-cells in the branchial cartilages of tadpoles. The membrane of the cell-nucleus and its contents may be distinguished in those which are hollow. The membrane is smooth, structureless, and never of any remarkable thickness, that of the germinal vesicle being the thickest. The contents are either very minutely granulous, especially in the small hollow cell-nuclei, or pellucid, as in the germinal vesicle, and the larger nuclei in the cells of the branchial cartilages of the tadpole, or larger corpuscles may be subsequently formed in the interior of hollow nuclei, for instance, the innumerable corpuscles in the germinal vesicle of the fish, and fat-globules in the nucleus of the fat-cells in the cranial cavity of fishes.

The nucleus, in most instances, contains one or two, more rarely three or four small dark corpuscles, *the nucleoli.* Their size varies from that of a spot which is scarcely discernible to that of Wagner's spot (*macula germinativa*) in the germinal vesicle. Nucleoli cannot be distinctly recognized in all cell-nuclei. They may be distinguished from the larger corpuscles, which are sometimes developed in certain hollow nuclei, from the circumstance of their being formed at a much earlier period; they exist, indeed, before the cell-nucleus. They are placed eccentrically in the round nuclei, and in the hollow ones are distinctly seen to lie upon the internal surface of the wall. It is very difficult to ascertain their nature; it may also vary very much in different cells. They sometimes appear to be capable of considerable enlargement, as in the nuclei of the fat-cells in the cranial cavity of the fish, and in such instances often have the appearance of fat. According to Schleiden, hollow nucleoli also frequently occur in plants.

Most cell-nuclei agree in the peculiarity of not being dissolved, or rendered transparent by acetic acid, at least not rapidly so, whilst the cell-membrane of animal cells is in most cases very sensitive to its action. Some cells, (such as those of the yelk-cavity of the egg, plate II, fig. 3,) which have no perceptible nucleus of the ordinary form, exhibit a globule having the appearance of a fat-globule, which grows as the cell expands, though not in the same proportion, and was probably formed previous to the cell. Whether such a globule have the signification of a nucleus or not, must remain an undecided question.

The formation of the cell-nucleus. In plants, according to Schleiden, the nucleolus is first formed, and the nucleus around it. The same appears to be the case in animals. According to the observations of R. Wagner on the development of ova in the ovary of Agrion virgo,[1] the germinal spot is first

[1] See Wagner, Beiträge zur Geschichte der Zeugung und Entwickelung; Erster Beitrag., tab. II, fig. 1.

formed, and around that the germinal vesicle, which is the nucleus of the ovum-cell, Eizelle.[1] The youngest germinal vesicle there represented by Wagner, appears to be hollow. This is not generally the case, however, in the formation of cell-nuclei. Plate III, fig. 1, *e*, appears to be a cell-nucleus of a cartilage-cell in the act of forming. A small round corpuscle is there seen, surrounded by some minutely granulous substance, whilst the rest of the cytoblastema is homogeneous. This granulous substance is gradually lost around the object; at a subsequent period it begins to be sharply defined, and then exhibits the form of a cell-nucleus, which continues to grow for a certain period. (See pl. III, fig. 1, *a*, *b*.) Such a nucleus usually appears solid in the first instance, and many nuclei remain in this condition; in others, on the contrary, the portion of the substance situated nearest to the external surface continually becomes darker, and not unfrequently at last forms a distinctly perceptible membrane, so that the nucleus is hollow in such instances. The formative process of the nucleus may, accordingly, be conceived to be as follows: A nucleolus is first formed; around this a stratum of substance is deposited, which is usually minutely granulous, but not as yet sharply defined on the outside. As new molecules are constantly being deposited in this stratum between those already present, and as this takes place within a precise distance of the nucleolus only, the stratum becomes defined externally, and a cell-nucleus having a more or less sharp contour is formed. The nucleus grows by a continuous deposition of new molecules between those already existing, that is, by intussusception. If this go on equably throughout the entire thickness of the stratum, the nucleus may remain solid; but if it go on more vigorously in the external part, the latter will become more dense, and may become hardened into a membrane, and such are the hollow nuclei. The circumstance of the layer generally becoming more dense on its exterior, may be explained by the fact that the nutritive fluid is conveyed to it from the outside, and is therefore more concentrated in that situation. Now if the deposition of the new

[1] See the Supplement.

molecules between the particles of this membrane takes place in such a manner that more molecules are deposited between those particles which lie side by side upon its surface than there are between those which lie one beneath another in its thickness, the expansion of the membrane must proceed more vigorously than its increase in thickness, and therefore a constantly increasing space must be formed between it and the nucleolus, whereby the latter remains adherent to one side of its internal surface.

I have made no observations on the formation of nuclei with more than one nucleolus. But it is easy to comprehend how it may occur, if we conceive that two nucleoli may lie so close together that the layers which form around them become united before they are defined externally, and that by the progressive deposition of new molecules, the external limitation is so effected that two corpuscles are enclosed by it at the same time, and then the development proceeds as though only one nucleolus were present.

When the nucleus has reached a certain stage of development, the cell is formed around it. The following appears to be the process by which this takes place. A stratum of substance, which differs from the cytoblastema, is deposited upon the exterior of the nucleus. (See pl. III, fig. 1, *d.*) In the first instance this stratum is not sharply defined externally, but becomes so in consequence of the progressive deposition of new molecules. The stratum is more or less thick, sometimes homogeneous, sometimes granulous; the latter is most frequently the case in the thick strata which occur in the formation of the majority of animal cells. We cannot at this period distinguish a cell-cavity and cell-wall. The deposition of new molecules between those already existing proceeds, however, and is so effected that when the stratum is thin, the entire layer—and when it is thick, only the external portion—becomes gradually consolidated into a membrane. The external portion of the layer may begin to become consolidated soon after it is defined on the outside; but, generally, the membrane does not become perceptible until a later period, when it is thicker and more defined internally; many cells, however, do not exhibit any appearance of the formation of a cell-membrane, but they seem to be solid, and all that can be remarked is that the external portion of the layer is somewhat more compact.

Immediately that the cell-membrane has become consolidated, its expansion proceeds as the result of the progressive reception of new molecules between the existing ones, that is to say, by virtue of a growth by intussusception, while at the same time it becomes separated from the cell-nucleus. We may therefore conclude that the deposition of the new molecules takes place more vigorously between those which lie side by side upon the surface of the membrane, than it does between those which lie one upon another in its thickness. The interspace between the cell-membrane and cell-nucleus is at the same time filled with fluid, and this constitutes the cell-contents. During this expansion the nucleus remains attached to a spot on the internal surface of the cell-membrane. If the entire stratum, in which the formation of the cell commenced, have become consolidated into a cell-membrane, the nucleus must lie free upon the cell-wall; but if only the external portion of the stratum have become consolidated, the nucleus must remain surrounded by the internal part, and adherent to a spot upon the internal surface of the cell-membrane. It would seem that the portion of the stratum which remains may be disposed of in two ways: either it is dissolved and forms a part of the cell-contents, in which case the nucleus will lie free upon the cell-wall as before; or it gradually becomes condensed into a substance similar to the cell-membrane, and then the nucleus appears to lie in the thickness of the cell-wall. This explains the variety in the position of the nucleus with respect to the cell-membrane. According to Schleiden, it sometimes lies in the thickness of the membrane in plants, so that its internal surface, which is directed towards the cell-cavity, is covered by a lamella of the cell-wall. In animals it also sometimes appears to be slightly sunk in the cell-membrane; but I have never observed a lamella passing over its inner surface; on the contrary, in almost all instances it lies quite free, adherent only to the internal surface of the cell-membrane.

The particular stage of development of the nucleus at which the cell commences to be formed around it varies very much. In some instances the nucleus has already become a distinct vesicle ere it occurs; the germinal vesicle, for example; in others, and this is the most common, the nucleus is still solid, and its development into a vesicle does not take place until a later period, or perhaps the change never occurs at all. When the cell is developed, the nucleus either remains stationary at its previous stage of development, or its growth proceeds, but not in proportion to the expansion of the cell, so that the intermediate space between it and the cell-membrane, the cell-cavity, is also constantly becoming relatively larger. If the growth of a cell is impeded by the neighbouring cells, or if the new molecules added between the existing particles of the cell-membrane are applied to the thickening of the cell-wall instead of to its expansion, it may occur that the nucleus becomes more vigorously expanded than the cell, and gradually fills a larger portion of the cell-cavity. An example of this was brought forward at page 23, from the branchial cartilages of the tadpole; on the whole, however, such instances are very rare. As the nuclei, in the course of their development, and especially in such instances as that just mentioned, continually lose their granulous contents and become pellucid, and as in some cases, the germinal vesicle for example, other corpuscles, such as fat-globules, &c., may be developed in these contents of the nucleus (a circumstance which never occurs with respect to the cell-cavities) it is often difficult to distinguish such enlarged nuclei from young cells. The presence of two nucleoli is often sufficient to enable us to distinguish such an enlarged hollow nucleus. The observation of the stages of transition, between the characteristic form of the cell-nucleus and these nuclei which so much resemble cells, will also aid us in obtaining the information desired. As in the case of the germinal vesicle, however, a positive decision can only be obtained by demonstrating that such a nucleus has precisely the same relation to the cell that an ordinary cell-nucleus has; that is to say, that such a nucleus is formed before the cell, that the latter is formed as a stratum around it, and that the nucleus is afterwards surrounded by the cell. Whether the nucleus undergoes any further development, as the expansion of the cell proceeds, or not, the usual result is that it becomes absorbed. This does not take place, however, in all cases, for, according to Schleiden, it remains persistent in most cells in the Euphorbiaceæ, and the blood-corpuscles may be quoted as an example to the same effect in animals.

The fact that many nuclei are developed into hollow vesicles, and the difficulty of distinguishing some of these hollow nuclei from cells, forms quite sufficient ground for the supposition that a nucleus does not differ essentially from a cell; that an ordinary nucleated cell is nothing more than a cell formed around the outside of another cell, the nucleus; and that the only difference between the two consists in the inner one being more slowly and less completely developed, after the external one has been formed around it. If this description were correct, we might express ourselves with more precision, and designate the nuclei as cells of the first order, and the ordinary nucleated cells as cells of the second order. Hitherto we have decidedly maintained a distinction between cell and nucleus; and it was convenient to do so as long as we were engaged in merely describing the observations. There can be no doubt that the nuclei correspond to one another in all cells; but the designation, "cells of the first order," includes a theoretical view of the matter which has yet to be proved, namely, the identity of the formative process of the cell and the nucleus. This identity, however, is of the greatest importance for our theory, and we must therefore compare the two processes somewhat more closely. The formation of the cell commenced with the deposition of a precipitate around the nucleus; the same occurs in the formation of the nucleus around the nucleolus. The deposit becomes defined externally into a solid stratum: the same takes place in the formation of the nucleus. The development proceeds no farther in many nuclei, and we also meet with cells which remain stationary at the same point. The further development of the cells is manifested either by the entire stratum, or only the external part of it becoming consolidated into a membrane; this is precisely what occurs with the nuclei which undergo further development. The cell-membrane increases in its superficies, and often in thickness also, and separates from the nucleus, which remains lying on the wall; the membrane of the hollow cell-nuclei grows in the same manner, and the nucleolus remains adherent to a spot upon the wall. A transformation of the cell-contents frequently follows, giving rise to a formation of new products in the cell-cavity. In most of the hollow cell-nuclei, the contents become paler, less granulous, and in some of them fat-globules, &c., are formed. (See pages 173, 4.) We may therefore say that the formation of cells is but a repetition around the nucleus of the same process by which the nucleus was formed around the nucleolus, the only difference being that the process is more intense and complete in the formation of cells than in that of nuclei.

According to the foregoing, then, the whole process of the formation of a cell consists in this, that a small corpuscle (the nucleolus) is the earliest formation, that a stratum (the nucleus) is first deposited around it, and then subsequently a second stratum (substance of the cell) around this again. The separate strata grow by the reception of new molecules between the existing ones, by intussusception, and we have here an illustration of the law, in deference to which the deposition takes place more vigorously in the external part of each stratum than it does in the internal, and more vigorously in the entire external stratum than in the internal. In obedience to this law it often happens that only the external part of each stratum becomes condensed into a membrane (membrane of the nucleus and membrane of the cell), and the external stratum becomes more perfectly developed to form a cell, than the nucleus does. When the nucleoli are hollow, which, according to Schleiden, is the case in some instances in plants, perhaps a threefold process of the kind takes place, so that the cell-membrane forms the third, the nucleus the second, and the nucleolus the first stratum. Probably merely a single stratum is formed around an immeasurably small corpuscle in the case of those cells which have no nuclei.

Varieties in the development of the cells in different tissues. Although, as we have just seen, the formative process of the cells is essentially the same throughout, and dependent upon a formation of one or many strata, and upon a growth of those strata by intussusception, the changes, on the other hand, which the cells, when once formed, undergo in the different tissues, are, in their phenomena at least, much more varied. They may be arranged in two classes according as the individuality of the original cell is retained (independent cells), or as it is more or less completely lost (coalescing cells, and cells which undergo division).

The varieties which occur amongst the independent cells, are partly of a chemical nature, and partly have reference to a difference in the growth of the cell-membrane, by which means a change in the form of the cell may be produced.

The cell-membrane differs in respect to its chemical qualities in different kinds of cells. That of the blood-corpuscles, for instance, is dissolved by acetic acid, whilst that of the cartilage-cell is not. The chemical composition of the cell-membrane differs even in the same cell according to its age, so that a transformation of the substance of the membrane itself takes place in plants; for, according to Schleiden, the cell-membrane of the youngest cells dissolves in water, the fully-developed cells not being acted upon by that fluid. The simple cells are still more remarkable for their cell-contents. One cell forms fat, another pigment, a third etherial oil; and here also a transformation of the cell-contents takes place. A granulous precipitate is seen to form gradually in what was in the first instance a pellucid cell, and this usually takes place first around the cell-nucleus; or, *vice versâ,* during incubation, the granulous (fatty) contents of the cells of the yelk-substance gradually undergo partial solution. According to Schleiden, this transformation of the substance of the cell-contents proceeds in accordance with a certain rule; I have not made any investigations upon the subject in animals.

We should also include under this head the formation of the secondary deposits upon the internal surface of the cell-membrane, so very frequently met with in plants. If a firm cohering substance be formed from the cell-contents, it may be deposited upon the internal surface of the cell-membrane. In plants this deposition generally takes place in layers, a stratum being formed in the first instance upon the internal surface of the cell-membrane, upon the internal surface of that one a second, and so on until at last the entire cavity may be almost filled by them. According to Valentin, these surrounding deposits always take place in spiral lines which are subject to great varieties in their arrangement, for there may be one or many of them, and they may either completely cover the internal surface of the cell-membrane, or not be in contact with each other at all. I have not observed any such secondary stratified depositions in animals.

The variations which may occur in the growth of the cell-membrane in simple cells, depend upon the circumstance as to whether or not the addition of new molecules takes place equably at all parts of the cell-membrane. In the first case the form of the cell remains unchanged, and the only other distinction possible would be grounded upon the fact as to whether the greater part of the new molecules were deposited between the particles which lay side by side upon the superficies of the cell-membrane, or between those which lay one behind another in its thickness. The first mode of growth produces an expansion of the cell-membrane, the effect of the second is more especially to thicken it. Both modes are generally combined, but in such a manner that the expansion of the cell-membrane prevails in most instances.

A great variety of modifications in the form of the cells may be produced by the irregular distribution of the new molecules. The globular, which is their fundamental form, may be converted into a polyhedral figure, or the cells may become flattened into a round or oval or angular tablet, or the expansion of the cells may take place on one or on two opposite sides, so as to form a fibre, and these fibres again may either be flat, being at the same time in some instances serrated, or lastly, the expansion of the cells into fibres may take place on different sides so as to give them the stellate form. Some of these changes of form are, no doubt, due to mechanical causes. Thus, for example, the polyhedral form is produced by the close crowding of the spherical cells, and these, when separated from one another, sometimes assume their round figure again; such is the case with the yelk-cells. Some of the other changes would seem to be capable of explanation by exosmosis. If, for example, the contents of a round cell be so changed, that a fluid is generated in it which is less dense than the surrounding fluid, the cell will lose some of its contents by exosmosis, and must, therefore, collapse, and may become flattened into a table as in the blood-corpuscles. Such explanations, however, are unsatisfactory in by far the greatest number of instances, and we are compelled to assume, that the growth does not necessarily proceed equably on all sides, but that the new molecules may be deposited in greater abundance in certain situations. Let us take the instance of a round cell, the cell-membrane of which is already developed, and suppose the deposition of new molecules to be confined to one particular part of the cell-membrane, that part would become expanded, and so a hollow fibre would grow forth from the cell, the cavity of which would communicate with the cell-cavity. The same result would take place, but more easily, if the new molecules were disposed unequally previous to the period when the external stratum of the precipitate, which is formed around the nucleus, had become condensed into a distinctly perceptible cell-membrane. The hollowing out of the fibre would then be less perfect, and the growth of the fibre must advance, particularly as regarded its thickness, before any manifest distinction between wall and cavity could be perceived.

The cause of this irregular disposition of the new molecules may, in some instances, be due to circumstances altogether external to the cell. If, for instance, a cell lay in such a position that one side of it was in contact with a concentrated nutritive material, one could conceive that side of the cell growing more vigorously, even though the force, which produces the growth of the cell, should operate equably throughout the entire cell. Such an explanation cannot, however, be received at all in most instances, but we must admit modifications in the principle of development of the cells, of such a nature, as that the force, which affects the general growth of the cells, is enabled to occasion an equable disposition of new molecules in one cell, and an unequal one in another.

Amongst the changes which more or less completely deprive the original cells of their individuality, are to be classed, in the first place, the coalescence of the cell-walls with one another, or with the intercellular substance; secondly, the division of one cell into several; and, thirdly, the coalescence of several primary cells to form a secondary one.

A coalescence of the cell-membrane with the intercellular substance, or with a neighbouring cell-wall, appears to take place in some cartilages for example. At first the cell-membrane has a sharply-defined external contour, by degrees the boundary line becomes paler, and at last is no longer perceptible with the microscope. We cannot, at present, lay down any general law respecting the circumstances under which such a coalescence occurs; it presupposes that the cell-membrane and intercellular substance are homogeneous structures, and may perhaps always take place when such a state exists.

As regards the subdivision of the cells, we have already seen how a jutting out of the cell-membrane may be produced by its more vigorous growth in certain situations. But a jutting inwards into the cavity of the cell may also result from the very same process. Now, if we imagine this jutting inwards to take place in a circular form around a cell, as the consequence of a partial increase in the force of its growth, it may proceed to such an extent, that one cell may be separated into two, connected together only by a short peduncle, which may afterwards be absorbed. This would illustrate the most simple form of subdivision in a cell. In the animal cells, however, which undergo subdivision, that is, the fibre-cells, the process is more complicated; firstly, because when an elongated cell subdivides, it splits into many fibres; and, secondly, because the cells are so very minute. The process, therefore, cannot for these reasons be accurately traced, and the following is all that we can detect: a cell becomes elongated on two opposite sides into several fibres; from the angle, which the fibres on either side form with each other, a striated appearance gradually extends over the body of the cell; this formation of striæ becomes more and more distinct, until the body of the cell splits entirely into fibres.

The coalescence of several primary cells to form a secondary cell is, to a certain extent, the opposite process to the last. Several primary cells, of muscle for instance, are arranged close together in rows, and coalesce into a cylinder, in the thickness of which lie the nuclei of the primary cells. This cylinder is hollow and not interrupted by septa, and the nuclei lie upon the internal surface of its wall. These are the facts of the process, so far as they have as yet been observed. One can form a conception of so much as is yet required to render them complete. If two perfectly-developed cells coalesce together, their walls must first unite at the point of contact, and then the partition-wall between the cavities must be absorbed. Nature, however, does not by any means require that these acts should occur at precisely defined periods. The coalescence may take place before the cell-wall and cell-cavity exist as distinct structures, somewhat in the following manner: the nuclei are formed first, around them a new stratum of substance is deposited, the external portion of which, in accordance with the course of formation of an ordinary simple cell, would become condensed into a cell-membrane. But in this instance the nuclei lie so close together, that the strata forming around them and corresponding to the cells, flow together, to form a cylinder, the external portion of which becomes condensed into a membrane, just in the same manner as in simple cells, where merely the external portion of the stratum formed around the nucleus, becomes hardened on the outside into a membrane, in consequence of the reception of new molecules. There is, therefore, nothing in this which differs so very materially from the course of development of a simple cell; indeed, we seemed to be compelled to assume a similar process for the formation of the nuclei furnished with two or more nucleoli. (See page 176.) It is possible that there may be stages of transition between the ordinary simple cell and these secondary cells. It has been already mentioned at pages 117-118, that fat-cells occur in the cranial cavity of fishes, many of which contain two nuclei. It is possible that only one of them is the cytoblast of the cell, and that the second is a nucleus which has formed subsequently; but they resemble one another so completely in their characteristic position on the cell-membrane (see pl. III, fig. 10,) that perhaps they may both be cytoblasts of a cell which has been formed around both nuclei, in consequence of the external stratum of the precipitate having become condensed in such a manner that the membrane enclosed both nuclei. Meanwhile observation affords no demonstrative proof on the subject, and the similarity in the position of these two nuclei may be explained in another way. Fat thrusts all bodies which have imbibed water towards the outside of the cell, in order that it may assume its own globular form. If now a second nucleus should form in one of these fat-cells, it will be thrust towards the outside, and must gradually raise the cell-membrane into a prominence. It may also be observed, that opportunities of demonstrating the actual absorption of the fully-developed partition-wall between two cells do occur in the spiral vessels of plants.

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

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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 and crystals, are, as we have observed, very different, even if we regard merely the plastic phenomena of the cells, and leave their metabolic power (which may possibly arise from some other peculiarity of organic substance) for a time entirely out of the question.

Is it, however, possible that these distinctions are only secondary, that the power of crystallization and the plastic power of the cells are identical, and that an original difference can be demonstrated between the substance of cells and that of crystals, by which we may perceive that the substance of cells must crystallize as cells according to the laws by which crystals are formed, rather than in the shape of the ordinary crystals? It may be worth while to institute such an inquiry.

In seeking such a distinction between the substance of cells and that of crystals, we may say at once that it cannot consist in anything which the substance of cells has in common with those organic substances which crystallize in the ordinary form. Accordingly, the more complicated arrangement of the atoms of the second order in organic bodies cannot give rise to this difference; for we see in sugar, for instance, that the mode of crystallization is not altered by this chemical composition.

Another point of difference by which inorganic bodies are distinguished from at least some of the organic bodies, is the faculty of imbibition. Most organic bodies are capable of being infiltrated by water, and in such a manner that it penetrates not so much into the interspaces between the elementary tissues of the body, as into the simple structureless tissues, such as areolar tissue, &c.; so that they form an homogeneous mixture, and we can neither distinguish particles of organic matter, nor interspaces filled with water. The water occupies the infiltrated organic substances, just as it is present in a solution, and there is as much difference between the capacity for imbibition and capillary permeation, as there is between a solution and the phenomena of capillary permeation. When water soaks through a layer of glue, we do not imagine it to pass through pores, in the common sense of the term; and this is just the condition of all substances capable of imbibition. They possess, therefore, a double nature, they have a definite form like solid bodies; but like fluids, on the other hand, they are also permeable by anything held in solution. As a specifically lighter fluid poured on one specifically heavier so carefully as not to mix with it, yet gradually penetrates it, so also, every solution, when brought into contact with a membrane already infiltrated with water, bears the same relations to the membrane, as though it were a solution. And crystallization being the transition from the fluid to the solid state, we may conceive it possible, or even probable, that if bodies, capable of existing in an intermediate state between solid and fluid could be made to crystallize, a considerable difference would be exhibited from the ordinary mode of crystallization. In fact, there is nothing, which we call a crystal, composed of substance capable of imbibition; and even among organized substances, crystallization takes place only in those which are capable of imbibition, as fat, sugar, tartaric acid, &c. The bodies capable of imbibition, therefore, either do not crystallize at all, or they do so under a form so different from the crystal, that they are not recognized as such.

Let us inquire what would most probably ensue, if material capable of imbibition crystallized according to the ordinary laws, what varieties from the common crystals would be most likely to show themselves, assuming only that the solution has permeated through the parts of the crystal already formed, and that new molecules can therefore be deposited between them. The ordinary crystals increase only by apposition; but there may be an important difference in the mode of this apposition. If the molecules were all deposited symmetrically one upon another, we might indeed have a body of a certain external form like a crystal; but it would not have the structure of one, it would not consist of layers. The existence of this laminated structure in crystals presupposes a double kind of apposition of their molecules; for in each layer the newly-deposited molecules coalesce, and become continuous with those of the same layer already present; but those molecules which form the adjacent surfaces of two layers do not coalesce. This is a remarkable peculiarity in the formation of crystals, and we are quite ignorant of its cause. We cannot yet perceive why the new molecules, which are being deposited on the surface of a crystal (already formed up to a certain point), do not coalesce and become continuous with those already deposited, like the molecules in each separate layer, instead of forming, as they do, a new layer; and why this new layer does not constantly increase in thickness, instead of producing a second layer around the crystal, and so on. In the meantime we can do no more than express the fact in the form of a law, that the coalescing molecules are deposited rather along the surface beside each other, than in the thickness upon one another, and thus, as the breadth of the layer depends upon the size of the crystal, so also the layer can attain only a certain thickness, and beyond this, the molecules which are being deposited cannot coalesce with it, but must form a new layer.

If we now assume that bodies capable of imbibition could also crystallize, the two modes of junction of the molecules should be shown also by them. Their structure should also be laminated, at least there is no perceptible reason for a difference in this particular, as the very fact of layers being formed in common crystals shows that the molecules need not be all joined together in the most exact manner possible. The closest possible conjunction of the molecules takes place only in the separate layers. In the common crystals this occurs by apposition of the new molecules on the surface of those present and coalescence with them. In bodies capable of imbibition, a much closer union is possible, because in them the new molecules may be deposited by intussusception between those already present. It is scarcely, therefore, too bold an hypothesis to assume, that when bodies capable of imbibition crystallize, their separate layers would increase by intussusception; and that this does not happen in ordinary crystals, simply because it is impossible.

Let us then imagine a portion of the crystal to be formed: new molecules continue to be deposited, but do not coalesce with the portion of the crystal already formed; they unite with one another only, and form a new layer, which, according to analogy with the common crystals, may invest either the whole or a part of the crystal. We will assume that it invests the entire crystal. Now, although this layer be formed by the deposition of new molecules between those already present instead of by apposition, yet this does not involve any change in the law, in obedience to which the deposition of the coalescing molecules goes on more vigorously in two directions, that is, along the surface, than it does in the third direction corresponding to the thickness of the layer; that is to say, the molecules which are deposited by intussusception between those already present, must be deposited much more vigorously between those lying together along the surface of the layer than between those which lie over one another in its thickness. This deposition of molecules side by side is limited in common crystals by the size of the crystal, or by that of the surface on which the layer is formed; the coalescence of molecules therefore ceases as regards that layer, and a new one begins. But if the layers grow by intussusception in crystals capable of imbibition, there is nothing to prevent the deposition of more molecules between those which lie side by side upon the surface, even after the lamina has invested the whole crystal; it may continue to grow without the law by which the new molecules coalesce requiring to be altered. But the consequence is, that the layer becomes, in the first instance more condensed, that is, more solid substance is taken into the same space; and afterwards it will expand and separate from the completed part of the crystal so as to leave a hollow space between itself and the crystal; this space fills with fluid by imbibition, and the first-formed portion of the crystal adheres to a spot on its inner surface. Thus, in bodies capable of imbibition, instead of a new layer attached to the part of the crystal already formed, we obtain a hollow vesicle. At first this must have the shape of the body of the crystal around which it is formed, and must, therefore, be angular, if the crystal is angular. If, however, we imagine this layer to be composed of soft substance capable of imbibition, we may readily comprehend how such a vesicle must very soon become round or oval. But the first formed part of the crystal also consists of substance capable of imbibition, so that it is very doubtful whether it must have an angular form at all. In common crystals atoms of some one particular substance are deposited together, and we can understand how a certain angular form of the crystal may result if these atoms have a certain form, or if in certain axes they attract each other differently. But in bodies capable of imbibition, an atom of one substance is not set upon another atom of the same substance, but atoms of water come between; atoms of water, which are not united with an atom of solid substance, so as to form a compound atom, as in the water of crystallization, but which exist in some other unknown manner between the atoms of solid substance. It is not possible, therefore, to determine whether that part of the crystal which is first formed must have an angular figure or not.

An ordinary crystal consists of a number of laminæ; when so small as to be but just discernible, it has the form which the whole crystal afterwards exhibits, at least as far as regards the angles; we must therefore suppose that the first layer is formed around a very small corpuscle, which is of the same shape as the subsequent crystal. We will call this the primitive corpuscle. It is doubtful what may be the shape of this corpuscle in the crystals which are capable of imbibition. The first layer, then, is formed around the corpuscle in the way mentioned; it grows by intussusception, and thus forms a hollow, round or oval vesicle, to the inner surface of which the primitive corpuscle adheres. As all the new molecules that are being deposited may be placed in this layer without any alteration being required in the law which regulates the coalescence of the molecules during crystallization, we must conclude that it remains the only layer, and becomes greatly expanded, so as to represent all the layers of an ordinary crystal. It is, however, a question whether there may not exist some reasons why several layers can be formed. We can certainly conceive such to be the case. The quantity of the solid substance that must crystallize in a given time, depends upon the concentration of the fluid; the number of molecules that may, in accordance with the law already mentioned, be deposited in the layer in a given time depends upon the quantity of the solution which can penetrate the membrane by imbibition during that time. If in consequence of the concentration of the fluid there must be more precipitated in the time than can penetrate the membrane, it can only be deposited as a new layer on the outer surface of the vesicle. When this second layer is formed, the new molecules are deposited in it, and it rapidly becomes expanded into a vesicle, on the inner surface of which the first vesicle lies with its primitive corpuscle. The first vesicle now either does not grow at all, or at any rate much more slowly, and then only when the endosmosis into the cavity of the second vesicle proceeds so rapidly that all that might be precipitated while passing through it, is not deposited. The second vesicle, when it is developed at all, must needs be developed relatively with more rapidity than the first; for as the solution is in the most concentrated state at the beginning, the necessity for the formation of a second layer then occurs sooner; but when it is formed, the concentration of the fluid is diminished, and this necessity occurs either later or not at all. It is possible, however, that even a third, or fourth, and more, may be formed; but the outermost layer must always be relatively the most vigorously developed; for when the concentration of the solution is only so strong, that all that *must* be deposited in a certain time, *can* be deposited in the outermost layer, it is all applied to the increase of this layer.

Such, then, would be the phenomena under which substances capable of imbibition would probably crystallize, if they did so at all. I say probably, for our incomplete knowledge of crystallization and the faculty of imbibition, does not as yet admit of our saying anything positively *a priori*. It is, however, obvious that these are the principal phenomena attending the formation of cells. They consist always of substance capable of imbibition; the first part formed is a small corpuscle, not angular (nucleolus), around this a lamina is deposited (nucleus), which advances rapidly in its growth, until a second lamina (cell) is formed around it. This second now grows more quickly and expands into a vesicle, as indeed often happens with the first layer. In some rarer instances only one layer is formed; in others, again, there are three. The only other difference in the formation of cells is, that the separate layers do not consist of the same chemical substance, while a common crystal is always composed of one material. In instituting a comparison, therefore, between the formation of cells and crystallization, the above-mentioned differences in form, structure, and mode of growth fall altogether to the ground. If crystals were formed from the same substance as cells, they would probably, in *these* respects, be subject to the same conditions as the cells. Meanwhile the metabolic phenomena, which are entirely absent in crystals, still indicate essential distinctions.

Should this important difference between the mode of formation of cells and crystals lead us to deny all intimate connexion of the two processes, the comparison of the two may serve at least to give a clear representation of the cell-life.

The following may be conceived to be the state of the matter: the material of which the cells are composed is capable of producing chemical changes in the substance with which it is in contact, just as the well-known preparation of platinum converts alcohol into acetic acid. This power is possessed by every part of the cell. Now, if the cytoblastema be so changed by a cell already formed, that a substance is produced which cannot become attached to that cell, it immediately crystallizes as the central nucleolus of a new cell. And then this converts the cytoblastema in the same manner. A portion of that which is converted may remain in the cytoblastema in solution, or may crystallize as the commencement of new cells; another portion, the cell-substance, crystallizes around the central corpuscle. The cell-substance is either soluble in the cytoblastema, and crystallizes from it, so soon as the latter becomes saturated with it; or else it is insoluble, and crystallizes at the time of its formation, according to the laws of crystallization of bodies capable of imbibition mentioned above, forming in this manner one or more layers around the central corpuscle, and so on. If we conceive the above to represent the mode of the formation of cells, we regard the plastic power of the cells as identical with the power by which crystals grow. According to the foregoing description of the crystallization of bodies capable of imbibition, the most important plastic phenomena of the cells are certainly satisfactorily explained. But let us see if this comparison agrees with all the characteristics of the plastic power of the cells. (See above, p. 194 et seq.)

The attractive power of the cells does not always operate symmetrically; the deposition of new molecules may be more vigorous in particular spots, and thus produce a change in the form of the cell. This is quite analogous to what happens in crystals; for although in them an angle is never altered, there may be much more material deposited on some surfaces than on others; and thus, for instance, a quadrilateral prism may be formed out of a cube. In this case new layers are deposited on one, or on two opposite sides of a cube. Now, if one layer in cells represent a number of layers in a common crystal, it may be easily perceived that instead of several new layers being formed on two opposite surfaces of a cell, the one layer would grow more at those spots, and thus a round cell would be elongated into a fibre; and so with the other changes of form. Division of the cells can have no analogue in common crystals, because that which is once deposited is incapable of any further change. But this phenomenon may be made to accord with the representation of crystals capable of imbibition, just as well as the coalescence of numerous cells in the manner described at page 184 does. And if we ascribe to a layer of a crystal capable of imbibition the power of producing chemical changes in organic substances, we can very well understand also the origin of secondary deposits on its inner surface as they occur in cells. For if, in accordance with the laws of crystallization, the lamina has become expanded into a vesicle, and its cavity has become filled by imbibition with a solution of organic substance, there may be materials formed by means of the converting influence of the lamina, which cannot any longer be held in solution. These may, then, either crystallize within the vesicle, as new crystals capable of imbibition under the form of cells; or if they are allied to the substance of the vesicle, they may so crystallize as to form part of the system of the vesicle itself: the latter may occur in two ways, the new matters may be applied to the increase of the vesicle, or they may form new layers on its inner surface from the same cause which led to the first formation of the vesicle itself as a layer. In the cells of plants these secondary deposits have a spiral arrangement. This is a very important fact, though the laws of crystallization do not seem to account for the absolute necessity of it. If, however, it could be mathematically proved from the laws of the crystallization of inorganic bodies, that under the altered circumstances in which bodies capable of imbibition are placed, these deposits must be arranged in spiral forms, it might be asserted without hesitation that the plastic power of cells and the fundamental powers of crystals are identical.

We come now, however, to some peculiarities in the plastic power of cells, to which we might, at first sight, scarcely expect to find anything analogous in crystals. The attractive power of the cells manifests a certain degree of election in its operation; it does not attract every substance present in the cytoblastema, but only particular ones; and here a muscle-cell, there a fat-cell, is generated from the same fluid, the blood. Yet crystals afford us an example of a precisely similar phenomenon, and one which has already been frequently adduced as analogous to assimilation. If a crystal of nitre be placed in a solution of nitre and sulphate of soda, only the nitre crystallizes; when a crystal of sulphate of soda is put in, only the sulphate of soda crystallizes. Here, therefore, there occurs just the same selection of the substance to be attracted.

We observed another law attending the development of the plastic phenomena in the cells, viz. that a more concentrated solution is requisite for the first formation of a cell than for its growth when already formed, a law upon which the difference between organized and unorganized tissues is based. In ordinary crystallization the solution must be more than saturated for the process to begin. But when it is over, there remains a mother lye, according to Thénard, which is no longer saturated at the same temperature. This phenomenon accords precisely with the cells; it shows that a more concentrated solution is requisite for the commencement of crystallization than for the increase of a crystal already formed. The fact has indeed been disputed by Thomson; but if, in the undisputed experiment quoted above, the crystal of sulphate of soda attracts the dissolved sulphate of soda rather than the dissolved nitre, and *vice versâ*, the crystal of nitre attracts the dissolved nitre more than the dissolved sulphate of soda, it follows that a crystal does attract a salt held in solution, because the experiment proves that there are degrees of this attraction. But if there be such an attraction exerted by a crystal, then the introduction of a crystal into a solution of a salt, affords an efficient cause for the deposition of this salt, which does not exist when no crystal is introduced. The solution must therefore be more concentrated in the latter case than in the former, though the difference be so slight as not to be demonstrable by experiment. It would not, however, be superfluous to repeat the experiments. In the instance of crystals capable of imbibition, this difference may be considerably augmented, since the attraction of molecules may increase perhaps considerably by the penetrating of the solution between those already deposited.

We see then how all the plastic phenomena in the cells may be compared with phenomena which, in accordance with the ordinary laws of crystallization, would probably appear if bodies capable of imbibition could be brought to crystallize. So long as the object of such a comparison were merely to render the representation of the process by which cells are formed more clear, there could not be much urged against it; it involves nothing hypothetical, since it contains no explanation; no assertion is made that the fundamental power of the cells really has something in common with the power by which crystals are formed. We have, indeed, compared the growth of organisms with crystallization, in so far as in both cases solid substances are deposited from a fluid, but we have not therefore asserted the identity of the fundamental powers. So far we have not advanced beyond the data, beyond a certain simple mode of representing the facts.

The question is, however, whether the exact accordance of the phenomena would not authorize us to go further. If the formation and growth of the elementary particles of organisms have nothing more in common with crystallization than merely the deposition of solid substances from out of a fluid, there is certainly no reason for assuming any more intimate connexion of the two processes. But we have seen, first, that the laws which regulate the deposition of the molecules forming the elementary particles of organisms are the same for all elementary parts; that there is a common principle in the development of all elementary parts, namely, that of the formation of cells; it was then shown that the power which induced the attachment of the new molecules did not reside in the entire organism, but in the separate elementary particles (this we called the plastic power of the cells); lastly, it was shown that the laws, according to which the new molecules combine to form cells, are (so far as our incomplete knowledge of the laws of crystallization admits of our anticipating their probability) the same as those by which substances capable of imbibition would crystallize. Now the cells do, in fact, consist only of material capable of imbibition; should we not then be justified in putting forth the proposition, that the formation of the elementary parts of organisms is nothing but a crystallization of substance capable of imbibition, and the organism nothing but an aggregate of such crystals capable of imbibition?

To advance so important a point as absolutely true, would certainly need the clearest proof; but it cannot be said that even the premises which have been set forth have in all points the requisite force. For too little is still known of the cause of crystallization to predict with safety (as was attempted above) what would follow if a substance capable of imbibition were to crystallize. And if these premises were allowed, there are two other points which must be proved in order to establish the proposition in question: 1. That the metabolic phenomena of the cells, which have not been referred to in the foregoing argument, are as much the necessary consequence of the faculty of imbibition, or of some other peculiarity of the substance of cells, as the plastic phenomena are. 2. That if a number of crystals capable of imbibition are formed, they must combine according to certain laws so as to form a systematic whole, similar to an organism. Both these points must be clearly proved, in order to establish the truth of the foregoing view. But it is otherwise if this view be adduced merely as an hypothesis, which may serve as a guide for new investigations. In such case the inferences are sufficiently probable to justify such an hypothesis, if only the two points just mentioned can be shown to accord with it.

With reference to the first of these points, it would certainly be impossible, in our ignorance as to the cause of chemical phenomena in general, to prove that a crystal capable of imbibition must produce chemical changes in substances surrounding it; but then we could not infer, from the manner in which spongy platinum is formed, that it would act so peculiarly upon oxygen and hydrogen. But in order to render this view tenable as a possible hypothesis, it is only necessary to see that it *may* be a consequence. It cannot be denied that it may: there are several reasons for it, though they certainly are but weak. For instance, since all cells possess this metabolic power, it is more likely to depend on a certain position of the molecules, which in all probability is essentially the same in all cells, than on the chemical combination of the molecules, which is very different in different cells. The presence, too, of different substances on the inner and the outer surface of the cell-membrane (see above, page 199) in some measure implies that a certain direction of the axes of the atoms may be essential to the metabolic phenomena of the cells. I think, therefore, that the cause of the metabolic phenomena resides in that definite mode of arrangement of the molecules which occurs in crystals, combined with the capacity which the solution has to penetrate between these regularly deposited molecules (by means of which, presuming the molecules to possess polarity, a sort of galvanic pile will be formed), and that the same phenomena would be observed in an ordinary crystal, if it could be rendered capable of imbibition. And then perhaps the differences of quality in the metabolic phenomena depend upon their chemical composition.

In order to render tenable the hypothesis contained in the second point, it is merely necessary to show that crystals capable of imbibition can unite with one another according to certain laws. If at their first formation all crystals were isolated, if they held no relation whatever to each other, the view would leave entirely unexplained how the elementary parts of organisms, that is, the crystals in question, become united to form a whole. It is therefore necessary to show that crystals do unite with each other according to certain laws, in order to perceive, at least, the possibility of their uniting also to form an organism, without the need of any further combining power. But there are many crystals in which a union of this kind, according to certain laws, is indisputable; indeed they often form a whole, so like an organism in its entire form, that groups of crystals are known in common life by the names of flowers, trees, &c. I need only refer to the ice-flowers on the windows, or to the lead-tree, &c. In such instances a number of crystals arrange themselves in groups around others, which form an axis. If we consider the contact of each crystal with the surrounding fluid to be an indispensable condition to the growth of crystals which are not capable of imbibition, but that those which are capable of imbibition, in which the solution can penetrate whole layers of crystals, do not require this condition, we perceive that the similarity between organisms and these aggregations of crystals is as great as could be expected with such difference of substance. As most cells require for the production of their metabolic phenomena, not only their peculiar nutrient fluid, but also the access of oxygen and the power of exhaling carbonic acid, or *vice versâ*; so, on the other hand, organisms in which there is no circulation of respiratory fluid, or in which at least it is not sufficient, must be developed in such a way as to present as extensive a surface as possible to the atmospheric air. This is the condition of plants, which require for their growth that the individual cells should come into contact with the surrounding medium in a similar manner, if not in the same degree as occurs in a crystal tree, and in them indeed the cells unite into a whole organism in a form much resembling a crystal tree. But in animals the circulation renders the contact of the individual cells with the surrounding medium superfluous, and they may have more compact forms, even though the laws by which the cells arrange themselves are essentially the same.

The view then that organisms are nothing but the form under which substances capable of imbibition crystallize, appears to be compatible with the most important phenomena of organic life, and may be so far admitted, that it is a possible hypothesis, or attempt towards an explanation of these phenomena. It involves very much that is uncertain and paradoxical, but I have developed it in detail, because it may serve as a guide for new investigations. For even if no relation between crystallization and the growth of organisms be admitted in principle, this view has the advantage of affording a distinct representation of the organic processes; an indispensable requisite for the institution of new inquiries in a systematic manner, or for testing by the discovery of new facts a mode of explanation which harmonizes with phenomena already known.