THE

SYDENHAM SOCIETY

INSTITUTED

MDCCCXLIII

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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PROFESSOR IN THE UNIVERSITY OF LOUVAIN,
ETC. ETC.

BY

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LONDON
PRINTED FOR THE SYDENHAM SOCIETY
MDCCCXLVII.

C. AND J. ADLARD, PRINTERS,
BARTHOLOMEW CLOSE.

TRANSLATOR'S PREFACE.

Any attempt on my part by way of introduction or commendation of Professor Schwann's work, must, I feel, be altogether misplaced and unnecessary. The treatise has now been seven years before the public, has been most acutely investigated by those best competent to test its value, and the first physiologists of our day have judged the discoveries which it unfolds as worthy to be ranked amongst the most important steps by which the science of physiology has ever been advanced. The Royal Society of London has evinced its sense of the great merit of the work by awarding to its Author the Copley Medal for the year 1845. The extensive reputation and fully-acknowledged value of the original work, then, forbid my presuming that any one of my readers can be altogether unacquainted with it and the general outlines of the Cell-Theory; I may, however, I trust, be permitted to add a few words respecting the edition which is now presented to the Subscribers of the Sydenham Society.

In the first place, I desire to tender my most unfeigned and unreserved apologies to the Council and Subscribers of the Society for the delay which has occurred in the issuing of this translation, and to assure the latter body that their

Council is in no degree responsible for its tardy appearance; when, nearly three years since, the Council did me the honour to accept an offer on my part to present to the Society a translation of Professor Schwann's treatise, I fully hoped to have proceeded with so pleasing a labour without interruption or hinderance; but various unforeseen circumstances, both of a professional and domestic nature, have occurred to prevent the accomplishment of my object until the present moment.

I am greatly indebted to the Author for the labour which he has expended in revising his work for this translation. Amongst the most important advantages which this edition has derived from his revision, I may mention the addition of many notes illustrative of the text, and the amalgamation of the two papers on Cartilage and Ossification, which, as they were originally written and printed at a considerable interval of time, led to some difficulty in the comprehension of the Author's precise views on that subject; and that circumstance is also to be received as explanatory of the appearance of some of the delineations of Cartilage in Plate III. It was originally intended to have added notes, which should bring down the history of the subject to the period of publication, but it was found that they would form a mass of material almost as large as the original text, and the idea was therefore abandoned.

In order that the reader might be in possession of the whole of the evidence upon which the Cell-Theory was originally based, I have appended a translation of Dr. SCHLEIDEN'S Monograph so frequently referred to by our Author.

It is to be feared that many of my readers may consider an apology to be necessary on my part for the style of the translation, and think that I might have followed the German less closely with advantage; the nature of the subject, however, involving as it does such very minute descriptions, and the constant repetition of the same terms, added to the impossibility of doing justice to the Author's close deductions in any other form than a literal translation, necessitated a much more rigid adherence to the original text, than I should have thought requisite under any other circumstances.

The Plates have been most faithfully copied from the originals by Mr. Henry Adlard.

HENRY SMITH.

HENRIETTA STREET, CAVENDISH SQUARE;
November 30th, 1847.

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.

CONTENTS.

SECTION III.

MICROSCOPICAL RESEARCHES,

&c. &c.

INTRODUCTION.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

SECTION I.

ON THE STRUCTURE AND GROWTH OF THE CHORDA DORSALIS AND CARTILAGE.

1. *Chorda Dorsalis.*

The Chorda Dorsalis in the larvæ of frogs and fishes lies in, or in some instances, under the bodies of the vertebræ, and is continued behind the coccyx, through the whole length of the tail. It is inclosed by a firm sheath, and forms a spindle-like, consistent, gelatiniform, transparent cord, which is thickest at the commencement of the tail, and thence gradually diminishes in each direction, both towards the skull and the point of the tail. It cannot well be separated entire in recently killed animals, but is best obtained from them in the form of delicate transverse sections. If the animal be placed in water for twenty-four hours or longer after death, and the tail then severed from the body at their point of junction, the chorda dorsalis may be entirely pressed out, by gently scraping along its course from the point of the tail, or from the head, towards the wound. As this does not succeed if the animal be allowed to lie out of water for the same period after death, the easier separableness appears to depend upon a penetration of the water between the chorda dorsalis and its sheath; the firmer connexion of it in the fresh condition, however, only upon a more close contact, or wedging in of the chorda dorsalis, and not upon a vascular connexion, for I do not suppose that it contains any vessels. Microscopically examined, it exhibits, as J. Müller has discovered in fishes, a cellular structure in its interior, surrounded externally by a proportionately thin cortical substance (rinde), which is beset with scattered granules. The interior exactly resembles the parenchymatous cellular tissue of plants. (See plate I, fig. 4.) It is readily seen, especially at the point of contact of three cells, that each one is surrounded by its own proper membrane. The cells vary much in size, being usually largest in the centre, and becoming somewhat smaller towards the outside. They have an irregular polyhedral shape, mostly with spherical surfaces, which are sometimes convex towards the outside, sometimes towards the cavity of the cell. Their walls are very thin, colourless, smooth, and almost completely transparent, firm, and slightly extensible. They dissolve readily in caustic potash. The rudiments of the chorda dorsalis in the conical interstices of the vertebræ of cartilaginous fishes are not dissolved by dilute or concentrated acetic acid. The chorda dorsalis of fishes according to J. Müller does not become converted into gelatine after long boiling. The cells of the chorda dorsalis of frog's larvæ contain in their interior a colourless, homogeneous, transparent fluid, which does not become cloudy at a boiling heat; the slight clouding observed in the chorda dorsalis after boiling, appears to be situated more in the cell-walls, which afterwards appear minutely granulated.

In the larva of Pelobates fuscus another formation occurs, inasmuch as by far the greater proportion of these cells contain a very distinct nucleus. It has the appearance of a somewhat yellowish-coloured small disc, of a roundish oval form, rather smaller than a blood-corpuscle of the frog, and almost as flat. (See plate I, fig. 4 *a*, where it is represented from the chorda dorsalis of Cyprinus erythrophthalmus.) In frog's larvæ the nucleus is nearly twice as large. It has a sharp, dark margin, and appears minutely granulated. In this little disc may be seen one, rarely two, and very seldom three dark, sharply circumscribed spots. It thus entirely resembles, both as a whole as well as in its modifications, the cytoblast of vegetable cells with its nucleolus, and microscopically, cannot at all be distinguished from it. Compare plate I, fig. 4 *a*, with plate I, fig. 1 *a*. But it also corresponds with it in its position in the cell. In very many cells, the vertical wall of which is viewed from above, it may be seen that the nucleus lies close on the inner surface of the wall of the cell, or even embedded in the wall. It appears then, as in plate I, fig. 1 *a′*, only still somewhat flatter. I have not, however, succeeded in observing that a lamella of the cell-wall passes over its internal surface, which is also but rarely seen in plants. If the external minutely granulated cortical substance of the chorda dorsalis of Pelobates fuscus be more accurately examined, it is found that the granules are oval, and furnished with a nucleolus, and that, with the exception of their being only about half as large, they entirely resemble the cell-nuclei. This cortical substance is not sharply separated from the proper tissue of the chorda dorsalis; and as the cells of the latter suddenly diminish very much towards the cortical substance, I think that these granules upon the latter are the cytoblasts of flattened cells which form it. Sometimes, although but indistinctly even with a very favorable light, very fine lines may be perceived in the intermediate spaces between these granules, where the cells come in contact, as in the common tabular (or scaly) epithelium. In the chorda dorsalis of the larva of Rana esculenta, where the nuclei in the cells are not distinct, these nuclei in the cortical substance are not seen; the tabular structure, however, is evident in them. One must be very cautious in denying the presence of the cytoblasts, when they are not immediately recognizable. They may in animals, as in plants, attain such a degree of transparency, as renders them very difficult of observation. Thus, I could not for a long time detect them in the rudiment of the chorda dorsalis, which is found in the conical intermediate spaces of the vertebræ, in a large Carp, until on a very clear day they appeared very pale but quite recognizable, and of precisely the form above described. They were somewhat more distinct in the Pike and Cyprinus erythrophthalmus. The delineation, plate I, fig. 4, is taken from the latter. They are however smaller in these fishes than in frog's larvæ.

To return to the larva of Pelobates fuscus. Here the cells of the chorda dorsalis lie so close to each other, that the walls of the two neighbouring cells are in immediate contact. Even when three or more cells are in contact, they are generally so close, that only the contiguous walls are observable. Sometimes, however, in such instances, a small intermediate space remains, which is larger than could be filled up by the unthickened cell-wall; and there is then seen, as in plants, a species (apparent or real?) of intercellular substance, or an intercellular canal. With regard to this latter (intercellular canal), occasionally, though rarely, in such an instance of close contiguity of three cells, upon making a transverse section, the cell-walls are observed sharply bounded, as well towards the cell as externally, and between the cells a small triangular interstice is seen, which is filled by a transparent fluid (not by air), or at least by a substance which refracts the light in a different manner from the cell-walls, just as it is represented in plate I, fig. 1 *c*, from the onion.

Young cells, which float free, form within the cells of the chorda dorsalis, as in plants. They are, however, in the larvæ of the frog so transparent, that very favorable light and good instruments are required to see them. The number of cells, also, in which new ones are formed in the larvæ is not great, at least in such as are to be had in the latter part of autumn. In the above-mentioned species of Cyprinus, and also in other fishes, they are, however, easy to be seen, and in greater number. Vesicles of very various sizes may be perceived in the cavities of many of these cells, and also in those of the larvæ of the frog, though they are more difficult of observation in the latter; a single one of these vesicles sometimes fills the greater part of the cavity; and occasionally several lie in one cell. (Pl. I, fig. 4, *b*, *b*, *c*.) They are commonly quite round; but not unfrequently two are in contact, and flattened against each other. That they lie free in the cell, follows from the fact, that they may be isolated without rupture. If, for instance, a small portion of the chorda dorsalis be torn into minute pieces, and a thin plate of glass with water be placed upon them, by moving this lightly backwards and forwards a few times, some such isolated vesicles may often be brought into the field of vision. They may then be made to roll about, and thus demonstrate their globular form. I have taken great pains to discover a nucleus in their walls, but without success. The young cells of the chorda dorsalis, also, in the larvæ so often mentioned, have often the appearance, so long as they are not isolated, of possessing a nucleus: but one may readily be deceived here, since such a nucleus may belong to a cell lying above or below them. Caution must also be used, not to confound a globular epithelial cell, which may have slipped into the chorda dorsalis in making the transverse section, with the true cells of that structure. I have not as yet been able, with certainty, to observe any nucleus, at least not of the characteristic form, in isolated young cells of the chorda dorsalis. In rare instances, a very small corpuscle, (*d*, *d*, of the figure,) lay in the inner surface of the young cell. It must remain a question whether the nucleus is really wanting, or whether it is only not visible in consequence of its translucency, or whether these corpuscles are developed into the nucleus. The chorda dorsalis accords with the vegetable cells, at least in this respect, that young cells are formed within the old ones.

With regard to the thickening of the cell walls; these appear to remain always simple (unchanged) in the chorda dorsalis of the larva of the frog. But in the fully developed osseous fishes, in Cyprinus, for example, a thickening is exhibited in those cells which lie near the axis of the conical interspaces of the vertebræ. The cell-cavities always become smaller in consequence of this thickening of the walls. The thickened walls, or the intermediate substance between the cell cavities consist of closely cohering longitudinal fibres, between which very fine transverse fibres are also sometimes seen. The longitudinal fibres run uninterruptedly past several cells; and the primitive membrane of each cell can no longer be distinguished.

To sum up the researches upon the chorda dorsalis in a few words; it may be said to consist of polyhedral cells, which have, in or on the internal surface of their walls, a structure, according in its form and position with the nucleus of the cells of plants, namely, an oval flat disc containing one, two, or more rarely three nucleoli. The cells usually lie in close contact with each other; but sometimes at points where three or more cells meet together, a sort of intercellular substance, or an intercellular passage is seen. Young cells, which are at first round, and float free, are formed within parent cells. Nuclei of the characteristic form, are not distinctly observed in these young cells, but sometimes a small globule lies upon their inner surface. In those cells which undergo further development, the cell-membrane ceases to exist as a distinct structure, and the intermediate substance between the cell cavities consists for the most part of longitudinal fibres.

With the exception of the formation of these fibres, into the origin of which I have not yet examined, and the absence of the nucleus in the young cells, these cells entirely accord with the vegetable cells. It must remain undecided whether the nucleus is really wanting in these young cells, as it is not yet proved to exist in all plants, (for example in many acotyledonous plants,) or whether the little corpuscle, which presents itself on the inner surface of some young cells, is the nucleus which grows with the cell, as it is observed to do in some other animal cells; or whether the nucleus in the young cells is invisible in consequence of its translucency, since even fully-developed cells are met with, in which, although certainly present, it is, in consequence of its transparency, barely visible.

2. *Cartilage.*

The accordance of the structure of cartilage with the tissue of plants is of more importance in reference to animal organization. We have here to do not only with a more widely extended animal tissue, but also with one which, at least, in its subsequent stages of development, contains vessels, and therefore bears more decidedly the character of an animal tissue. The simplest form of cartilage is exhibited in the cartilages of the branchial rays of fishes. If, for example, a branchial ray of Cyprinus erythrophthalmus be loosened from the branchial arch, and the mucous membrane be removed by gentle scraping, the cartilage remaining presents the appearance of a little rod, which diminishes from the point of its insertion on the branchial arch towards its free end, its sides being somewhat compressed, and exhibiting on their margins some blunt prominences. The structure of this cartilage is very simple. At the point it perfectly resembles, in its whole appearance, the parenchymatous cellular tissue of plants. (See pl. I, fig. 5, from the above-mentioned Cyp. eryth.) Little polyhedral cell-cavities with rounded corners are seen lying closely together. The cell-cavities are separated from each other by extremely thin partition walls. The cell-contents are transparent, and a small pale round nucleus (*a*) may be seen in some cells when in the recent state, in others only after the action of water upon them. The structure of the lateral prominences of the cartilage is similar to that at the point, only that the cells are somewhat extended in length. Advancing from that point towards the middle, or still better from the point towards the root of the branchial ray, the partition walls of the cell-cavities are observed to become gradually thicker; and the cavities are here somewhat smaller. (Pl. I, fig. 6.) On the thickened cell-walls it may now also be seen that the intermediate substance of the cell-cavities is not a simple structure, but one composed of the walls peculiar to the contiguous cells: that is to say, each cell is surrounded with a thick ring, its peculiar wall, the external outline of which is more or less distinct. In the preparation from which the delineation is taken, it was in some parts quite as distinct as the internal. Between two cells these external outlines blend into one line, but separate again when the contact of the cell-walls ceases; there is thus often left between the cell-walls a three or four-cornered intermediate space (*c*), filled with a kind of intercellular substance. No other structure, no deposition of strata, or distinction between primary cell-membrane and secondary deposit can be observed in the thickened cell-walls. The cell-contents also remain clear after the thickening of the walls. At the base of the branchial ray, it is scarcely possible to distinguish between the different cells-walls, and the cartilage presents the appearance of a homogeneous substance, in which separate small cavities only are seen. (Pl. I, fig. 7.) Around some few only of the cell-cavities, a trace of the peculiar cell-walls may be seen in the form of a ring. This ring is usually somewhat thin, so that the entire intermediate substance of the cell-cavities cannot be formed of the cell-walls; but the intercellular substance, which was so small in quantity in the centre of the branchial ray, here contributes essentially to the formation of the cartilaginous substance, and often completely prevents the immediate contact of the cell-walls. This intercellular substance appears, however, to be homogeneous with that of the cell-walls, and in most situations coalesces with them. The cell-cavities, which are here transparent and without granulous contents, are now the cartilage-corpuscles.

The process of formation of this cartilage is as follows. It consists originally of cells, which lie in very close contact, but every one of which has its special, very thin cell-membrane. This follows, firstly, from the complete accordance in appearance, of cartilage in its earliest stage, with vegetable cellular tissue; secondly, from the presence of the nucleus in the young cells of cartilage, a structure which, as will subsequently be seen, occurs in almost all the cells proved to exist in other tissues; thirdly, from the fact, that a separation of the cell-walls is often distinctly perceptible in instances where they are thickened. These cell-walls lie either in close contact, or have only a trace of intercellular substance between them, or there is sufficient of that material to entirely prevent the contact of the different cells. Their walls, which are originally formed of a very thin membrane, become thickened. The cavities of the cells with thickened walls which are seen in the centre of the branchial ray, are smaller than those of the cells which lie nearer the surface, the walls of which are less dense; but, whether this is produced by a thickening of the cell-wall taking place from without inwards, or whether rather the cells were not smaller in their original formation, is a matter of uncertainty. No deposition of strata, nor any distinction from the primordial cell-membrane, can be recognized in these thickenings of the walls. The condensed cell-walls at length coalesce either with each other, or with the intercellular substance, to form one homogeneous mass, in which only the cell-cavities remain perceptible, presenting the appearance of small distinct excavations filled with a transparent substance; these cell-cavities are the cartilage-corpuscles.

In the foregoing description no error can arise from the great variety in form which the cartilage-corpuscles frequently present; for, on examining the branchial rays of a very large pike, the gradual transition may be traced, from the thin-walled almost globular cells to the most varied forms, in which the remains of the cell-cavities are so much extended in length as to give to the cartilage almost a fibrous appearance.

The same extremely simple process of formation (modified, however, in some important respects) is presented in all cartilages. These modifications, the fundamental type of which is already pointed out in the cartilages of the branchial rays of fishes above described, depend chiefly upon the share relatively contributed by the thickened cell-walls, or the intercellular substance, to form the intermediate substance of the cell-cavities, or cartilage-corpuscles. We have seen that this intermediate substance was formed almost entirely of the thickened cell-walls, with but a minimum amount of intercellular substance, in the centre of the branchial rays of fishes, whilst at their base, that is, in the earliest formed cartilage, the intercellular substance preponderated, and the less dense cell-walls contributed less to the formation of the true substance of the cartilage.

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The walls of the cells appear to contribute little or nothing to the formation of the substance of most of the ossifying cartilages,—those of the higher animals for example.

The cartilages of the branchial arches of the tadpole, like those of the branchial rays of fishes, consist of cells, which are, however, much larger than those of the fish, though smaller than the cells of the chorda dorsalis, with which they have, in every other respect, much similarity. The partition-walls of the cells are thicker than in the chorda dorsalis, but they may still be termed thin when compared with the cell-cavities. (See pl. III, fig. 1, which exhibits branchial cartilage from the young larva of Pelobates fuscus.) The cartilage intended to be used for investigation must be taken quite fresh from the living animal; for the structures become very indistinct if it be allowed to lie in water for any time after death, even though it be entire. After stripping off the mucous membrane, the cellular structure is readily recognized by the aid of the microscope. The cells vary much in size, and are more or less flattened against one another. The wall of each separate cell may be distinctly seen in the majority of instances, and its thickness might even be measured; that we cannot trace it so evidently in the smallest cells is probably referrible to the extreme thinness of their sides. The walls of the cells are for the most part in contact, but intercellular substance may be seen in many situations, and especially where several cells are contiguous. The surface of the cartilage, which is represented on the left and lower margin of the figure, (pl. III, fig. 1,) is formed in the first place of intercellular substance, which, in as much as the cells originate in it, may be called Cytoblastema.

This cartilage may, therefore, be described as consisting of intercellular substance, or cytoblastema, in which great numbers of cells are seen. The cell-contents are generally clear as water; but in the younger and smaller ones (for example, *c*,) the contained matter is less pellucid, and somewhat granulous. Each cell contains a spherical granulous nucleus, which lies upon the inner surface of the wall, and which again encloses a nucleolus. The size of the nucleus is not precisely alike in all the cells: it is somewhat larger in the large ones, but its size bears no proportion to the increased bulk of the cell; and again, the smaller cells are not much larger than the nucleus which they contain.

Nuclei, around which no cells have yet commenced to be developed, may be observed in the cytoblastema between the cells in some situations; for example, *a* and *b*. These likewise contain a nucleolus, and are somewhat less than the nuclei in the smaller cells.

The above observations furnish us with a complete representation of the development of cartilage-cells, and show the accordance of that process with the development of vegetable-cells, inasmuch as they exhibit the simultaneous presence in the cytoblastema both of simple nuclei, and of cells containing a nucleus of similar shape and size upon the inner surface of their walls, and which may be observed in all stages of transition, from such as are scarcely larger than the nucleus they contain, to such as are many times its size. Simple nuclei are first present, developed in the cytoblastema. When these have arrived at a certain size, the cell is formed around and closely encompassing them. The cell gradually expands, whilst the nucleus remains lying on a point of the inner surface of its wall. The nucleus, also, increases somewhat in size, but not in proportion to the expansion of the cell. Now these three hypotheses may be assumed from the above facts; either the cell is first developed, and the nucleus subsequently, or both are developed simultaneously, or the nucleus is first developed, and then the cell around it. The first supposition, that the cells are developed earlier than the nuclei, is not possible, since in that case cells would be found at a certain period of development without nuclei. The simultaneous development of a cell, together with its nucleus, as two distinguishable structures, is equally impossible, for then we should observe a stage of development, at which as yet the cell and nucleus had not reached the size of the ordinary nucleus. In order to explain the above observations, we must, therefore, have recourse to the third supposition, viz. that the nucleus is first developed and then the cell around it.

The form of the young cells depends upon the space allotted them for expansion. They are, therefore, either round or angular, according as the neighbouring cells permit of, or limit their regular expansion. Two or more cells are often developed close together in one intercellular space, and thus compress those already formed, and the intercellular substance on the outside of them;

this fact explains the common appearance of two or four cells lying together in a group, being separated from one another by thin walls, whilst between such groups and the neighbouring cells we see much more intercellular substance.

The cells at first appear finely granulated, and not so transparent as in the more fully developed condition. The thickening of the cell-membrane takes place simultaneously with its expansion. One of the cells in pl. III, fig. 1, exhibits two nuclei, one of which, like those of all the other cells, has but one nucleolus, the other having two. It may be conjectured, that this second nucleus is destined to the formation of a young cell within the larger one.

In the intercellular substance at *e* in the same figure (pl. III, fig. 1,) may be seen a small corpuscle, surrounded by a granulous and indistinctly circumscribed mass, the rest of the intercellular substance being smooth and homogeneous. This is, perhaps, a nucleus in the act of formation, the nucleolus of which is already developed; and when the granulous mass surrounding that structure has obtained a defined external boundary, it will form a nucleus. If such be the case, we have here an instance of accordance of the development of the germ itself with the formation of the nucleus of vegetable-cells observed by Schleiden.

On examining the cartilage of the branchial arches of the tadpole in the more completely developed state, (pl. I, fig. 8,) we find the cells generally lying in groups, so that two, three, or four lie close together, separated from other groups by thicker partition walls. The special walls of the individual cells are less distinct, but at several spots where three or more cells are in contact, for example, at *a*, the separation of the walls may yet be seen, and a trace of intercellular substance is also present; the latter, however, is almost homogeneous with the cell-walls. It may also be observed that the cell-walls are thicker in these situations than they are represented in pl. III, fig. 1. Some parallel lines may be seen at various spots in these condensed cell-walls, and the thickening might, in such instances, be supposed to be really produced by a stratified deposition of the substance upon the internal surface of the cell-wall. But at the same time it must be remembered, that every partition-wall between two cells must consist of two layers, each of which corresponds to the wall of the corresponding cell. This appearance of strata, however, is observed only in the thick walls between two groups of cells, and as these groups probably originate by the formation of two or four cells within a parent cell, each half of the partition-wall between two groups must (presuming such to be the mode of their formation) consist again of two layers, the one of which corresponds to the wall of the parent cell, the other to that of the secondary cell, so that each partition-wall of two groups must consist of four layers. Although it does, indeed, appear that even a greater number of layers or strata are present, yet I must at the same time remark, that these observations are by no means sufficiently conclusive for the proof of a fact so important in reference to the process of nutrition, and that I am so far from regarding them as evidence of a stratified deposition of the substance, as not to hold such a thing to be even probable. The appearance is probably an optical deception. As before stated, no distinction was found between primary cell-membrane and secondary thickening in the cartilages of the branchial rays of fishes, but it seemed that the cell-membrane had actually become thickened; neither is there any such distinction to be observed in the branchial cartilages of the tadpole.

If the above described groups be assumed to have had their origin by the formation of secondary cells within a primary parent one, in that case, secondary cells which completely fill the parent one have not been developed in all the primary cells, for isolated cells occur in the branchial cartilages of Pelobates fuscus, which are somewhat larger than the secondary ones, but smaller than the other primary cells, and remarkable also, as will be seen immediately, from their contents.

The cells of the branchial cartilages of the larva of Pelobates fuscus just mentioned, contain within them one or more nuclei. (Pl. I, fig. 8, *d.*) These nuclei, which may be easily isolated, are either slightly oval, or perfectly globular, more or less granulous and yellowish, and apparently hollow. They contain one or two very distinct, round, dark nucleoli, which lie in their interior either close upon the wall, or very near to it. The nuclei (a portion of them at least) appear to lie free in the cell-cavity, for they may readily be isolated. The above mentioned primary cells of the larva of Pelobates fuscus in which none of these secondary cells, completely filling the parent one have been developed, contain very commonly several such nuclei, and also one or more young cells. Pl. I, fig. 8, *ff*, represents such young cells from the branchial cartilages of the larva of Rana esculenta. They are round vesicles containing a nucleus identical in form and size with those which lie free, but which is situated upon the internal surface of the wall, and never in the centre of the cell. This nucleus is never wanting in the young cells. The cells, however, vary much in size, some being scarcely larger than the nucleus they contain, others twice or thrice as large. From one to three such young cells, in various stages of development, are commonly found within the primary one, where they sometimes become flattened from want of space. As the figure represents, most of the *secondary* cells contain these young ones, and but few of them only simple nuclei (such as have no cell around them), in some of the young cells, indeed, a second somewhat paler nucleus appears. These young cells lie free within the primary cell, and may be isolated in the same manner as was described with regard to those of the chorda dorsalis. They appear in the first instance to be perfectly transparent; but gradually obtain a granulous yellowish aspect, and it is remarkable, that the earliest formation of this yellowish deposit takes place generally if not constantly, in the neighbourhood of the nucleus.

It will thus be seen that these young cells, (fat cells?) which are formed within the true cartilage-cells, furnish us with a series of observations as regards their development, similar to that observed in the formation of the cartilage-cells themselves: namely, simple nuclei, cells closely encompassing those nuclei, and all the stages of transition up to the largest cells; but never have we met with these young cells without nuclei. So that the same conclusions might be arrived at with respect to the mode of their development, as were before with regard to that of the cartilage-cells, namely, that the nuclei are first formed, and around them the cells, precisely as in plants. The nucleus in these young cells, however, does not appear to increase in growth after the cell has once formed around it. The accordance in form between these and the young cells of vegetables is shown by comparing Plate I, fig. 8, with fig. 2, *b*.

The nucleus of the true cartilage-cells like that of vegetable-cells is subsequently absorbed. After the cartilages of the branchial rays of fishes have been exposed to the action of water, it is only in the young cells that the nuclei are visible; they are much more rarely seen in those cells of which the walls are already very much thickened. In many cells of the branchial cartilages of the tadpole, a small nucleus with a ragged outline may be observed, which is probably the cytoblast of the cell in the act of undergoing absorption. These cytoblasts (nuclei) of the true cartilage-cells always lie in the cell-cavity, even when its wall is thickened, and it is impossible to distinguish whether they lie free or are still connected with the cell-wall. A twofold explanation is here possible: either the cytoblast separates from the wall after the formation of the cell-membrane is perfected, and falls free into the cavity (as occurs in plants), and at such period a secondary deposition of substance upon the cell-wall first commences; or the thickening of the wall is due to an actual increase of the original cell-membrane, and in that manner the nucleus is pushed inwards, and may remain in connexion with the wall. If a secondary deposition of substance took place before the nucleus was disengaged from the cell-membrane, that body must be enclosed in the wall, and would not lie in the cell-cavity. As both these explanations are possible, it will be seen that no conclusion can be drawn from the position of the nucleus, as to whether the thickening of the cell-wall be a secondary deposition, or an actual growth of the cell-membrane. Sometimes a cartilage-cell presents more than one nucleus; when in such a case the original nucleus of the cell is absorbed, all those observed are probably the germs of new cells, which have not as yet commenced their development. The same fact is frequently observed in plants. The nuclei in the branchial cartilages of the tadpole have for the most part the same size; some, however, which are probably not as yet perfectly formed, are smaller than others. It also often occurs that a nucleus is seen expanded to three or four times the usual size; such instances might be mistaken for young cells without nuclei, but they may be readily recognized by their general aspect. They are more transparent and delicate, and exhibit one or two nucleoli, which are easily detected; when two are present they are widely separated from one another. According to

Schleiden, a similar enlargement of the nucleus also occurs in plants, thus affording a remarkable accordance in what seems a very unimportant circumstance. It appears to be a kind of abortion; for I have never yet seen a cell formed around such a nucleus.

The cranial cartilages of the tadpole (Plate I, fig. 9) are distinguished from the branchial by the smaller size of the cell-cavities, and the increased strength of the firm intermediate substance. The walls of the separate cells cannot now be traced, they appear to have coalesced with the intercellular substance, which is present in greater quantity. The cells lie in groups of two or four together, and it is very probable, that in this cartilage, each group is formed of cells, which have been developed in a parent cell; for some may be seen, for example at *c*, which do not as yet quite fill the original cell. Such an instance, however, is rarely so very distinct as not to admit of a doubt. There is a very striking similarity between the group *a*, fig. 9, and fig. 3, which represents four young vegetable cells developed in a parent cell, and the thickened walls of which have coalesced with one another and with those of the parent cell, so that the four cavities only remain in an homogeneous substance. That portion of the cell-cavities which is still visible is filled with a granulous yellowish substance, in which lie one or more nuclei, or young cells provided with a nucleus: these remains of the cell-cavities are the cartilage-corpuscles discovered by Purkinje.

The intercellular substance is universally much more prominent in the cartilages of mammalia than it is in those hitherto described, and in them it forms the principal part of the firm mass of the cartilage. There is not, however, any essential difference either between the structure of the several kinds of cartilage of mammalia, or between these and the cartilage of lower animals, the only distinction being that it is a little more difficult to prove the existence of the special walls of the cartilage-cells in the former.

The intercellular substance in some cartilages of mammalia is at first so soft, that the cells fall apart under slight pressure, and float free in the fluid. If, for example, a thin lamella be cut off from the cartilage at the angle of the lower jaw of a fœtal pig of three and a half inches in length (a period when the cartilage is about to become, but is not as yet, ossified), and placed under the compressorium, the cells will be seen to lie so closely in it, that the space occupied by them may be estimated at three fourths, and that of the intercellular substance at one fourth of the whole volume. Many of the cells which have become separated by the process of cutting, float already in the fluid; and on slightly compressing the preparation many more become loose, and flow out in streams from the intercellular substance into the surrounding fluid. The intercellular substance is too soft to prevent the separation, but at a subsequent period of development this cannot be effected. According to Meckauer the cartilage-corpuscles may also be isolated by boiling. I once succeeded in crushing one of these young cartilage-cells while still in connexion with the preparation. The first effect of the compressorium was to produce an extension of breadth; it then suddenly shrank together, whilst a clear fluid streamed out, thus proving the contents of the cell to be fluid and transparent. Now, inasmuch as these cells present in different instances a more or less granulous appearance, it follows that the cells of ossifying cartilage must have a peculiar investing membrane, which is granulous, and thus that they are actual elementary cells, in our sense of the word, and neither mere excavations in the substance, nor perfectly solid corpuscles. The appearance of the cells which float about entirely accords also with this view, for while their contents seem to be clear, the cells look granulated. All of them contain a very beautiful oval or circular, not flattened cell-nucleus, situate upon the internal surface of the wall, and this nucleus encloses one or two very distinct nucleoli; in short, they in every respect accord with the elementary cells of most of the other tissues. By the aid of acetic acid we may also frequently succeed in rendering the cell-walls visible upon a thin lamella of cartilage, and as the cell-contents are at the same time dissolved by the acid, it has the additional advantage of bringing the nucleus into view, which is sometimes indistinct in consequence of the granulous nature of the contents. Plate III, fig. 2, exhibits a portion of cartilage so treated with acetic acid; it is taken from the as yet unossified portion of the ilium of an embryo pig of five inches in length. The cell-walls, with their double outlines, may be seen, and both the illuminated and dark side in the thickness of the walls distinguished. The delineation, at the same time, proves how important a share is taken by the intercellular substance in the formation of the firm structure of cartilage.

The cartilages of the fœtus do not altogether accord in chemical constitution with those of the adult, since we can obtain from them by boiling but a small quantity of a gelatinous substance, and that only with great difficulty, and they afford no true gelatine (capable of forming a jelly). I boiled some unossified cartilages, consisting of apophyses of the femur and cartilaginous portions of the scapulæ, taken from several embryo pigs, measuring three and a half inches in length. After twelve hours' boiling, they entirely crumbled into very small scales, which gave a variegated appearance to water in which they were stirred about, and appeared under the microscope extremely thin and granulous. The fluid, when filtered and evaporated almost to dryness, did not coagulate. Alcohol produced a copious precipitate, which was dried, afterwards dissolved in boiling water, and then evaporated almost to dryness; still no coagulation took place. Alum, however, clouded the fluid, and acetic acid had the same effect, but in a much slighter degree. As the quantity of cartilage made use of in the foregoing experiment was too small, I made a further investigation with cartilage which had already become ossified, from the same embryos, namely, the frontal and parietal bones, scapulæ, humerus, femur, and some ribs. The unossified parts were removed as cleanly as possible from all the bones. The earthy matter was withdrawn by hydrochloric acid; the cartilages were then washed with water, and boiled for twenty-four hours. Under this process they fell to pieces very slowly, meanwhile numerous little glittering scales appeared in the fluid, which, after being dried, resembled very minute fish-scales, and exhibited a beautiful play of colours. They were, perhaps, the lamellæ described by Deutsch, which surround the minute medullary canaliculi. The form of most of the pieces of cartilage remained perfectly recognizable, and was but slightly altered. They looked of a yellowish-white colour, and not at all gelatinous, as substances usually do when about to be transformed into gelatine. The fluid was filtered from these little scales and pieces of cartilage, and then evaporated almost to dryness. It did not exhibit any trace of coagulation after standing twenty-four hours. After being dried, it was again dissolved in boiling water, on which occasion, however, a portion remained undissolved. It was, therefore, filtered; the fluid was copiously precipitated by alum, and the precipitate was, for the most part, although not entirely, dissolved, on the addition of alum in excess. Acetic acid likewise rendered the fluid very turbid, and an excess of acid did not entirely remove the cloudiness. It was copiously precipitated by tincture of gall-nuts, and acetic acid removed this precipitate again, leaving a very slight turbidness. (Acetic acid likewise completely dissolves the precipitate obtained from glue by tincture of gall-nuts, therefore glue, when dissolved in acetic acid, will not be precipitated by the tincture.) According to these reactions, the gelatinous substance obtained appears to be chondrin, notwithstanding that it was obtained from ossified cartilage. The question, therefore, arises—does the cartilaginous substance which is connected with earthy matter in the fœtus really yield chondrin instead of the gelatine of bone, or was there much unossified cartilage still contained in what appeared to be ossified, and was that the sole source of the chondrin? The point is, at all events, worthy of renewed investigation. It is surprising that the fœtal cartilages should exhibit so great a resistance to the action of boiling water, and that although they yield a small quantity of a gelatinous substance, they do not afford any which has the property of *gelatinizing*.

The formative processes of cartilage hitherto described, proceed, as it appears, without the presence of vessels in the structure; such at least is the case in thin cartilages, to which probably the fluid parts of the blood can penetrate from the vessels of the neighbouring tissues. In the branchial rays of the fish, for example, I could not find any space in which vessels could have existed; throughout the structure masses of cartilage and cartilage-corpuscles were to be seen, but no canals which could have been traversed by vessels.

The manner in which ossification proceeds now becomes an interesting object of inquiry. The investigation is best pursued by making very fine sections with a razor, from the half-ossified cartilages of the extremities, vertebræ, or coccyx, of the larva of Pelobates fuscus. The little cartilage-cells, which are not enclosed one within another, and are for the most part furnished with a nucleus, are readily recognized in the true cartilaginous substance of the unossified cartilages. I am not prepared to state whether this substance is formed by thickening of the cell-walls, or by the intercellular substance. The earthy matter is first deposited in the true cartilaginous substance. It first appears in the form of isolated, extremely minute granules, by which an indistinct appearance of arched striæ is sometimes produced. At other points, these little granules of earthy matter lie collected together into larger irregular heaps. I do not know whether these little collections are depositions of pure earthy matter which has not as yet united with the cartilage, and therefore merely provisional deposits which subsequently are distributed equally in the cartilaginous substance (which is not probable), or whether this earthy matter is already united with the cartilage, and that the regular aspect which the structure presents when ossified may be accounted for by the gradual union of the earthy matter with it after the same mode. I saw no such deposition of earthy matter in heaps in the incompletely ossified parietal bones of the same larva, but the whole cartilaginous substance contained it equably distributed without any perceptible granules. In both instances, however, when dilute hydrochloric acid is applied to the object under the microscope, the boundary denoting the solution of the earthy matter, and the consequent transparency of the cartilage, may be distinctly seen advancing in the form of a sharply-defined line from the edge of the preparation towards the interior, proving that, in the cartilages first mentioned, there was earthy matter equably united with the substance, in addition to the heaps and isolated granulous deposits. For this boundary line cannot be produced by the mere progressive imbibition of the acid without a solution of the earthy salts; at least neither an unossified cartilage, nor one from which the earthy matter had been previously withdrawn and the acid again washed from it, exhibited the phenomenon of such a line advancing towards the interior. During the early period of ossification, when this line arrives at a cell-cavity, it becomes indented proportionally to the size of the cavity, because it does not come in contact with any earthy matter there; the cell-cavities, in the first instance, being free from earthy salts. The reverse, however, is the case in the more completely ossified parts; there the cell-cavity remains behind, forming a dark indentation in the line, which as it advances renders the tissue transparent, and leaves the cavity a black spot, from which dark fibres, similar to those of the corpuscles of bone, issue in a stellated form. Shortly afterwards the fibres disappear, then the corpuscle gradually diminishes, and at last vanishes also, leaving a pale spot. Such an appearance could not be due to an air-bubble in the cell-cavity; for in that case, I think, the course of its exit might be followed. It is probably a more compact mass of earthy matter, which does not become dissolved so quickly as that contained in the substance of the cartilage. After this has become impregnated with earthy matter, the cell-cavities are also filled, and when so filled they are the osseous corpuscles. Similar observations might be instituted on the ossified cartilages of mammalia, in which the identity of osseous and cartilage-corpuscles was rendered more certain by Miescher's researches. The next question which presents itself concerns the nature of those minute fibres which proceed in a stellated form from the osseous corpuscles. After the earthy matter has been withdrawn the corpuscles may still be seen, though rendered very pale by that process; the fibres, however, are not at all visible, although a formation corresponding to them is certainly present in the cartilaginous substance, and their extraordinary minuteness sufficiently explains the invisibility. The same formation might also exist before ossification, but be invisible from the like cause. As these fibres and the cell-cavities become filled with earthy matter simultaneously, and at a later period than the cartilaginous substance, and since they contain the earthy salts in a more compact and less easily soluble mass, it is probable that they are hollow tubes, that is, canaliculi which proceed from the cell-cavities, spreading out into the cartilaginous substance. According, therefore, to the view which we take respecting the cartilage-corpuscles, according as we consider them to be the cavities of cells, the walls of which have become thickened and blended, not only with one another but with the intercellular substance, so as to form the cartilaginous substance; or as we take them for the entire cells, and the intermediate substance of the cell-cavities as only intercellular substance, so must these tubes be viewed either as canaliculi which penetrate from the cell-cavity into the thickened cell-walls, or as hollow prolongations of the cells into the intercellular substance. In the first case, they might be compared to the porous canals of vegetable cells; in the second, they would correspond with prolongations of cells, such as we shall often again meet with in the progress of this work. Meanwhile, for an example of those cells which are extended out on all sides into canals, and which I have called stellated cells, the reader is referred to plate II, figs. 8 and 9, where those transformations are delineated from pigment-cells. I decidedly give the preference to the latter explanation of the canaliculi, because they pass through the entire thickness of the firm cartilaginous substance, a fact which, in order to be consistent with the first view, requires for its explanation that the substance between the cell-cavities should be formed of the thickened cell-walls, which is certainly not the case in the cartilages of mammalia, as is seen in plate III, fig. 2. The osseous corpuscles, with their canaliculi, would therefore be the cartilage-cells transformed into stellated cells, and filled with earthy matter. We shall return to this metamorphosis of round into stellated cells when treating of the pigment. The resemblance between stellated pigment-cells and osseous corpuscles is sometimes very striking, as is shown, for example, by the pigment-cell which lies to the extreme right in plate II, fig. 9. The compact bony substance is intercellular substance; it is, however, probable that the walls of the stellated osseous cells form some, if only a very small part, of it.

When ossification takes place, the earthy matter is first deposited in this intercellular substance, and probably at a subsequent period also in the cell-cavities. The deposition often causes the substance to assume a darkish granulous appearance in the first instance, which it afterwards loses, becoming more equally dark. If we assume, what is extremely probable, that the earthy matter is contained in bones in combination with the cartilaginous substance, in a manner analogous to a chemical union, and not in the form of minutely-divided granules, the mode in which the union with the earthy salts takes place may then be explained in two ways: either the earthy matter combines with a particle of cartilaginous substance in such a manner that each smallest atom receives in the first instance a minimum of salts, and gradually more and more, until the whole portion of cartilage obtains its due quantity; or, the earthy matter unites at first with some only of the smallest atoms of the cartilage, combining, however, with these to the full proportion which their capacity of saturation requires; the remaining atoms then gradually and successively receive their due portion of the salts, so that each atom does not chemically combine with them until it can become completely saturated. The latter explanation, from the analogy with inorganic combinations, and from the above-mentioned granulous appearance which cartilage exhibits when undergoing ossification, appears to me by far the more probable. For, according to the first view, the medullary canaliculi, in the neighbourhood of which the deposition of earthy matter first commences, ought to be surrounded, not by a granulous appearance, but by a dark shadow which should gradually fade away to a pale edge.

I conceive the formation of the medullary canaliculi in ossifying cartilage to be similar to that of the capillary vessels, which will be examined hereafter. We shall return to them again, as also to the origin of the concentric laminæ of bone.

We will now briefly sum up the observations upon cartilage, and refer to the phenomena of vegetable life, which either accord with or are dissimilar to them. Cartilage originates from cells, every one of which has its special, and, in the first instance, very thin wall; precisely like those of vegetables. These cells either lie closely together, and on that account are flattened against one another, like those of plants (see pl. I, figs. 5 and 6), or, there is intercellular substance present, and this again either in so very small a quantity as to be visible only in situations where three or four cells are in contact (see fig. 6, *c*), or in so much greater quantity, as to prevent the contiguity of the different cell-walls (pl. I, fig. 7; and pl. III, fig. 1.) Most of the cells, at their earliest period of development (and perhaps constantly) contain a nucleus, that is, a round or oval, and sometimes hollow corpuscle (pl. I, fig. 5, *a*; and pl. III, figs. 1 and 2), which again generally encloses one or two nucleoli. The cartilage-cells originate in the first place by the formation of the nucleus in the cytoblastema, around which the cell is afterwards formed, so that the latter at first closely encompasses the nucleus. The nucleus advances slightly in growth after the formation of the cell, but in a much lower proportion. It is subsequently absorbed; frequently, however, not before ossification. This is precisely what occurs in vegetables. The walls of the cartilage-cells become thickened (compare figs. 6 and 7 with fig. 5), which is also the case with many vegetable-cells. No distinction, however, between primary cell-membrane and secondary deposit can be observed in cartilage-cells, and such a deposition in strata as is often distinctly seen in thickened cells of plants cannot be made out here with sufficient certainty. The cell-nucleus in the meantime, when not absorbed, remains lying upon the inside of the thickened wall. An instance of actual thickening of the cell-membrane without a stratified deposit, does not, however, appear to be wanting in plants, *e. g.* the pollen-tube of Phormium tenax. (See the Introduction.) But it seems, that a thickening of the walls of the cartilage-cells does not take place universally, it does not for instance in the ossifying cartilages; the true cartilage substance may also be formed entirely, or at least chiefly of the intercellular substance. The condensed cell-walls subsequently coalesce with one another, or with the intercellular substance, so that at last only the cell-cavities remain in an homogeneous substance. Whether the walls of those cartilage-cells which do not undergo any thickening become blended with the intercellular substance or not, remains uncertain. An analogous instance of coalescence of the cell-walls is afforded by vegetables, for Schleiden has observed such a blending in the layer of bark which lies immediately beneath the cuticle of the Cacti.

The cartilage-cells often contain either simple nuclei (i. e. without cells around them), or young cells with such nuclei. These young cells are formed free within the parent-cell, without vascular connexion. Their nucleus is first formed, and afterwards the cell around it, just as in the true cartilage-cell. This is one of the most important instances of accordance between animal and vegetable cells, for the latter, according to Schleiden, are developed in like manner from the nucleus, and likewise within a parent-cell. (See the Introduction.) We may therefore confidently compare the nucleus of these young cells, as also that of the true cartilage-cell, to the cytoblast of vegetable cells. Their shape and the eccentric position of their nucleus, placed as it is upon the internal surface of the cell-wall, also accord with the young cells of plants. Compare plate I, fig. 8, *ff*, with fig. 2. The form of the nucleus likewise corresponds with that of many vegetable cells. In these young cells of cartilage, it is presented to the observer as a small oval or perfectly spherical corpuscle, having, in many instances, a granulous and somewhat yellowish appearance, and containing one or two nucleoli. (Compare this with the description of the nucleus of vegetable cells in the Introduction.) The nucleus of the cartilage-cell appears to be hollow, a fact which has not been observed with regard to the cytoblast of vegetable cells,[1] and the nucleoli lie close upon, or in the neighbourhood of the internal surface of its wall, whilst, according to Schleiden, they lie deep in the cytoblast of vegetable cells.

The cartilage-cells, when once formed, appear to be endued with the capacity to grow throughout the entire mass of the structure. The case is different with regard to the formation of new cells. This takes place in certain situations only, on the surface of the cartilage, for instance, or between the last formed cells. We have already seen that in the branchial rays of fishes, the least developed cells lay at the point, and lateral margins. The little rod, which the branchial ray represents, does not increase in size by the formation of new cells between the original ones throughout its entire length, but its extension in the longitudinal direction is produced by the development of new cells in the neighbourhood of the point, and it increases in breadth by the same process going on in the neighbourhood of the side walls. It is a familiar fact, that the cylindrical bones grow chiefly upon the surface and at the end of the shaft. The formation of new cartilage-cells usually takes place only in the neighbourhood of the surface which is in contact with the organized substance, (I refer throughout this passage to that period alone, at which the cartilage does not contain any vessels of its own,) but it is not exclusively confined to that situation, it may also proceed in the intercellular substance between the last-formed cells.

At the period of ossification, the earthy matter is first deposited in the cell-walls, or in the true cartilage-substance, the

[1] In a letter which I have received from Schleiden, he informs me that he has also found hollow nuclei in plants.

remains of the cell-cavities also become filled with it at a subsequent period, and at the same time the stellated canaliculi issuing from them make their appearance. The formation of these canaliculi probably takes place by the transformation of round cartilage-cells into a stellated form, after the manner of the pigment-cells at plate II, figs. 8 and 9.

The above detailed investigation of the chorda dorsalis and cartilage, has conducted us to this result,—that the most important phenomena of their structure and development accord with corresponding processes in plants, that some anomalies and differences may indeed still remain unexplained, but that they are not of sufficient importance to disturb the main conclusion, viz. that these tissues originate from cells, which must be considered to correspond in every respect to the elementary cells of vegetables. Thus then are we furnished with the first of the proofs required in the Introduction; that is to say, we have shown with regard to a certain tissue, that it not only originates from cells, but that these cells in the process of their development manifest phenomena analogous to those of the cells of plants. We have now thrown down a grand barrier of separation between the animal and vegetable kingdoms, viz. diversity of structure. We have become acquainted with the signification of the individual parts of the animal tissues as compared with the vegetable cells, and know that cells, cell-membrane, cell-contents, nuclei, and nucleoli in the former are in every respect analogous to the parts having similar names in the cells of plants. We have already observed several modifications both of the nucleus and cell. The former presented itself as a corpuscle having either an oval or circular outline, spherical in figure, or very much flattened, sometimes hollow, and often scarcely perceptible, in consequence of its transparency, but generally granulous and yellowish, and containing in its interior from one to three nucleoli. This nucleus lay within, and fast adhering to the wall of the cell, but never in its centre. The fundamental form of the cell appeared to be that of a round vesicle, but we have also observed the flattening of the cells against one another, the presence of intercellular substance between them in greater or less quantity, and lastly, the thickening of the cell-walls.

We have seen the generation of cells within cells, and the formation both of the young cells in cartilage, and of the true cartilage-cells themselves, was proved to take place around the nucleus, in the same manner as that described by Schleiden in vegetable cells. The other proof for the accordance of animal and vegetable structure (see Introduction, p. 6) yet remains to be supplied, viz. that most or all animal tissues are developed from cells. If this proof only were furnished, the analogy of such cells to the elementary cells of plants would at once become extremely probable; we may now assert that analogy so much the more firmly, since the cells of two distinct tissues have been proved in detail to correspond with those of plants.

SECTION II.

ON CELLS AS THE BASIS OF ALL TISSUES OF THE ANIMAL BODY.

The young cells contained within the cartilage-cells (see plate I, fig. 8, *ff*) may be regarded as the elementary form of the tissues previously considered, and may be described as round cells having a characteristic nucleus, firmly attached to the internal surface of the wall. As the above were proved to correspond with the vegetable cells, it follows, that it is only necessary to trace back the elementary structure of the rest of the tissues to the same formation, in order to show their analogy also with the cells of plants. In some tissues this proof is easy, and immediately afforded; in others, however, it is obtained with much difficulty, and it would frequently be altogether impossible to demonstrate the cellular nature of some, if the connexion between the different steps in this investigation were lost sight of. The difficulty arises from the following circumstances: 1st. The minuteness of the cells; in consequence of which it is not only necessary to use a power magnifying from 400 to 500 diameters, but it is also frequently, indeed generally found impossible to press out their contents. 2dly. The delicate nature of the cell-membrane. When this has a certain density, its external as well as internal outline may be recognized, and the distinction between it and the cell-contents may thus be placed beyond a doubt. But if the cell-membrane be very delicate, the two outlines meet together in one line, and this may readily be regarded as the boundary line of a globule, not enclosed by a special enveloping membrane. 3dly. The similar power of refraction possessed by the cell-wall and cell-contents, in consequence of which the internal outline of the former cannot be observed. 4thly. The granulous nature of the cell-membrane, which when the contents are also granulous, cannot be distinguished from them. Lastly, the variety of form presented by the cells, for they may be flattened even to the total disappearance of the cavity, or elongated into cylinders and fibres. From these circumstances, many of the cells which now come before us for consideration, have been described as mere globules, or granules, terms which do not express their true signification, and even when they were spoken of as cells, or cells furnished with a nucleus, the description rested only upon a slight analogy, since but very few of them (for example, the pigment-cells), were proved to be actually hollow cells. But—as the precise signification of the nucleus is unknown, and as the cell-membrane is not proved to be anything essential to those cells (and this follows from their accordance with vegetable cells), upon the analogy with which the proof of the cellular nature of the rest of the globules provided with a nucleus will be based,—there is no contradiction involved in the supposition that a nucleus may be contained in a solid globule as well as in a cell.

From the difficulties of this investigation above detailed, it will be seen that a given object may really be a cell, when even the common characteristics of that structure, namely, the perceptibility of the cell-membrane, and the flowing out of the cell-contents, cannot be brought under observation. The possibility that an object may be a cell, does not, however, advance us much; the presence of positive characteristics is necessary in order to enable us to regard it as such. In many instances these difficulties do not present themselves, and the cellular nature of the object is immediately recognized; in others, the impediments are not so great but that the distinction between cell-membrane and cell-contents is at least indicated, and in such cases other circumstances may advance that supposition to a certainty. The most important and abundant proof as to the existence of a cell is the presence or absence of the nucleus. Its sharp outline and dark colour render it in most instances easily perceptible; its characteristic figure, especially when it encloses nucleoli, and remarkable position in the globule under examination, (being within it, but eccentrical, and separated from the surface only by the thickness of the assumed cell-wall,) all combine to prove it the cell-nucleus, and render its analogy with the nucleus of the young cells contained in cartilage, and with those of vegetables, as also the analogy between the globules under examination, in which it lies, and those cells, consequently the existence of a spherical cell-membrane in the globules, extremely probable. More than nine tenths of the globules in question present such a nucleus; in many the special cell-membrane is indubitable, in most it is more or less distinct. Under such circumstances, we may be permitted to conclude that all those globules which present a nucleus of the characteristic form and position, have also a cell-membrane, although, from the causes before specified, it may not be perceptible. The different tissues will also afford us many instances of other circumstances which tend to prove the existence of an actual cell-membrane. An example of what is referred to would be afforded by an instance, in which a certain corpuscle (furnished with a nucleus), about the cellular nature of which a doubt existed, could be proved to be only a stage of development, or modification in form, of an indubitable cell. The cell-nuclei and their distance from each other when scattered in a tissue, also serve as indications, when the outlines of the cells have to be sought for. They likewise serve to guide conjecture as to the earlier existence of separate cells, in instances where they have coalesced in the progress of development. When a globule does not exhibit a nucleus during any one of the stages of its development, it is either not a cell, or may at least be preliminarily rejected, if there be no other circumstances to prove it such. Fortunately, these cells devoid of nuclei are rare.

In addition, however, to the cellular nature of the elementary structures of animal tissues, there are yet other points of accordance between them and the cells of plants, which may generally be shown in the progress of their development, and which give increased weight to the evidence tending to prove that these elementary structures are cells. The exceedingly frequent, if not absolutely universal presence of the nucleus, even in the latest formed cells, proves its great importance for their existence. We cannot, it is true, at present assert that, with regard to all cells furnished with a nucleus, the latter is universally the primary and the cell the secondary formation, that is to say, that in every instance the cell is formed around the previously existing nucleus. It is probable, however, that such is the case generally, for we not only meet with separate nuclei in most of the tissues, distinct from those which have cells around them, but we also find that the younger the cells are, the smaller they are in proportion to the nucleus. The ultimate destiny also of the nucleus is similar to that of the vegetable cells. As in the last named, so in most animal cells it is subsequently absorbed, and remains as a permanent structure in some few only. In plants, according to Schleiden, the young cells are always developed within parent cells, and we have also seen such a development of new cells within those already formed in the chorda dorsalis and cartilage. If, however, any doubt existed as to whether the primary cells of these tissues were formed within previously existing parent cells, none such can arise in reference to many of the tissues next to be considered. We shall indeed frequently meet with a formation of young cells within older ones, but it is not the rule, and does not occur at all with regard to many of them.

The following admits of universal application to the formation of cells; there is, in the first instance, a *structureless*[1] substance present, which is sometimes quite fluid, at others more or less gelatinous. This substance possesses within itself, in a greater or lesser measure according to its chemical qualities and the degree of its vitality, a capacity to occasion the production of cells. When this takes place the nucleus usually appears to be formed first, and then the cell around it. The formation of cells bears the same relation to organic nature that crystallization does to inorganic. The cell, when once formed, continues to grow by its own individual powers, but is at the same time directed by the influence of the entire organism in such manner, as the design of the whole requires. This is the fundamental phenomenon of all animal and vegetable vegetation. It is alike equally consistent with those instances in which young cells are formed within parent cells, as with those in which the formation goes on

[1] [Strukturlos.—I have ventured to translate this word as above, although I am aware it is open to objection. The idea intended to be conveyed by the author is that of a substance in which no definite structure can be detected. As the word will be frequently used in the following pages, the reader is requested to assign this signification to it invariably.—Trans.]

outside of them. The generation of the cells takes place in a fluid, or in a structureless substance in both cases. We will name this substance in which the cells are formed, cell-germinating material (Zellenkeimstoff), or cytoblastema. It may be figuratively, but only figuratively, compared to the mother-lye from which crystals are deposited.

We shall refer to this point at greater length hereafter, and only anticipate our subject with this result of the investigation, in order to facilitate the comprehension of what follows.

In the previous section of this work we have discussed in detail the course of development of some of the animal cells, having taken the chorda dorsalis and cartilage for our examples. We are now required to prove, as far as is possible, that all the tissues either originate from, or consist of cells. We separate this investigation into two divisions. The first treats of the Ovum and Germinal membrane, in so far as they form the common basis of all the subsequent tissues. The second division embraces the permanent tissues of the animal body, with the omission of the two already described.

FIRST DIVISION.

On the Ovum and Germinal Membrane.

The ovum of Mammalia lies, as is known, within the Graafian vesicle. I have not made any investigation as to whether that vesicle may be considered to have the signification of a cell. It is indeed a cell in the general sense of the word, being a cavity in the substance of the ovary, it has even a special membrane; but as we here only receive the word cell as signifying an elementary part of animals and plants, it becomes necessary to inquire whether this membrane may not be a secondary formation resulting from the junction of other structures which are elementary. The history of the development of the Graafian vesicle must show whether that be the case, or whether it originate by the mere growth of a cell furnished with a structureless cell-membrane, which cell may formerly, perhaps, have had a nucleus.[1] Within this vesicle lies the ovum or vesicle of Baer, embedded in a layer of granules. When these granules are examined with a magnifying power of 450, they are readily recognized to be cells, that is, round vesicles containing a nucleus, which is situated upon the internal surface of the wall. The nucleus being granulous and darker than the rest of the object falls under observation first. It encloses one or two nucleoli. The cell surrounding it varies in size, being in the average about half as large again in diameter, but some are much larger. The cells are for the most part extremely delicate, and round, when separated from one another. When in connexion, they often flatten against one another, and assume a polyhedral form. In addition to these cells, isolated nuclei appear also to be present within the Graafian vesicle, perhaps as the germs of new cells. The production of these cells proceeds according to the fundamental law mentioned at page 39, within the fluid of the Graafian vesicle, that being their germinative material or cytoblastema. Whether this fluid is to be regarded as cell-contents, and the cells produced in it as being formed within a parent cell, must depend upon the solution of the question, as to whether the Graafian vesicle be an elementary cell or not; but the decision of this point is not essential, for the rule that cells originate within others is not universal. When the independent vitality of cells is borne in mind, we can readily conceive how these, when they (after the bursting of the vesicle) arrive with the ovum in the uterus, may be further developed into other structures (the chorion according to Krause.) Within this granulous or rather cellular disc then the ovum or vesicle of Baer lies embedded, (see the representation, plate II, fig. 1, taken from Krause.) The first object which attracts observation is the dark spherical yelk, surrounded by a transparent space, (zona pellucida of Baer, chorion of Wagner.) Krause found (Müller's Archiv, 1837, p. 27) that the yelk is surrounded by a peculiar membrane, *d* (vitelline membrane), and that the transparent space is enclosed externally

[1] According to the researches of Martin Barry (Phil. Trans. Part II, 1838, p. 305, &c.), both cases appear to occur, so that a cell composed of a structureless membrane is first formed, (the ovisac of Barry,) and subsequently an external vascular covering of cellular tissue. On the relation of this follicle to the mode of development of the ovary itself, see Valentin in Müller's Archiv, 1838, p. 526.

by a very delicate pellicle, the albumen-membrane, *b*, also that the transparent substance itself (albumen) is sufficiently fluid to permit of such a degree of displacement of the yelk as to allow of its coming into contact even with the albumen-membrane. Although I have never yet succeeded in observing this pellicle, and though in my researches the transparent membrane, on the bursting of the yelk, always tore with smooth edges like a solid substance, yet the observations of the respected discoverer are too precise to admit of a doubt upon it. It is also supported by the analogy of most of the ova of other classes of animals, in which chorion and vitelline membrane may generally be distinguished, notwithstanding that they sometimes lie close upon each other. The albumen-membrane has probably the signification of a cell-membrane, in which case the albumen will be the cell-contents, and the yelk a young cell. According to Wharton Jones, the transparent areola (zona pellucida) of the ovum, or the albuminous layer in the fecundated ovum of mammalia, becomes considerably expanded in the tubes, a fact which would be readily explained by the inherent energy of the albumen-membrane when regarded as a cell. In such case, however, the mode of formation of the albumen would be very different from the corresponding process in the bird's egg, where, according to Purkinje, it is secreted by the oviduct, and a membrane (chorion) is formed around it subsequently, which cannot therefore have the signification of a cell-membrane, and is moreover not simple in structure, but composed of fibres. Meanwhile an investigation might be made, as to whether the albumen in the egg may not also be first surrounded and formed by an equally thin pellicle, around which a secondary external membrane may subsequently be produced. According to Purkinje, however, this is not the case, and I could not discover any such pellicle upon the inner surface of the shell-membrane of the excluded egg. I have not made any inquiry as to whether the chorion of fishes is a cell-membrane or not. It is covered internally with a very beautiful epithelium, which is made up of more or less flat hexagonal cells, each of which has its nucleus.

Within the transparent areola, or, according to Krause, the albuminous layer, lies the vesicle of Baer, or the yelk; which, from Krause's statement, is enclosed by a peculiar structureless membrane, the double outline of which he recognised, (plate II, fig. 1, *d.*) It is thus highly probable that the yelk of the mammalian ovum is a cell. Even if, as Wagner intimates, the vitelline membrane in other animals should sometimes be formed only secondarily within the chorion, it would not materially interfere with our purpose, since in that case the chorion would be the cell-membrane. The ovum universally possesses an external closed membrane (whether it be chorion or vitelline membrane), which is structureless, and not generated from other elementary structures, and therefore is the ovum always a cell. The yelk-cell encloses the vitelline substance as its cell-contents, and upon its internal surface lies the germinal vesicle, or vesicle of Purkinje, (fig. 1, *f.*) This, as is known, is a very transparent thin-walled vesicle, containing a pellucid fluid, according to Wagner coagulable by spirits of wine. It encloses almost universally (Wagner cites but very few exceptions) upon the internal surface of its wall, a corpuscle, called by the discoverer, R. Wagner, germinal spot, or germinal disc, (fig. 1, *g.*) In mammalia it is generally flat. In many instances several of these spots are present, their number, however, is said by Wagner to bear proportion to the age of the ovum, they being fewer and much more firmly attached to the wall of the germinal vesicle in young ova. I have frequently observed in osseous fishes (where they are often present in such numbers as to prevent the fluid in the vesicle from being seen) that when one of these corpuscles, after the bursting of the germ-vesicle, passed through a narrow space, it first became considerably elongated, and then drawn out in the centre to a thin thread, which soon broke. The two ends afterwards retracted, and thus two round globules were produced from one corpuscle, in a similar manner to what we may observe in the drops of fat upon soup. They appear, therefore, to be composed of a tenacious substance which is not miscible with water. Purkinje states that the germinal vesicle in birds is firmly fixed to the vitelline membrane, but Baer and Wagner describe it as lying in the centre of the yelk at first, and rising to the surface at a subsequent period.

The decision of the question, as to the precise signification of the germinal vesicle, now becomes of great importance. Is it a young cell generated within the yelk-cell, or is it the nucleus of the yelk-cell? If the former, it is in all probability the most essential rudiment of the embryo; but if it be the nucleus of the yelk-cell its importance vanishes with the formation of the yelk-cell, and according to the analogy of most cell-nuclei, it must either become absorbed altogether at a subsequent period, or continue for a time simply rudimentary, without forming any important new structure. The following is the ordinary career of a simple cell: a nucleus is present in the first instance; around it a cell is formed; the nucleus at first often increases in size as the cell grows, but their growth is by no means proportionate, that of the cell being much more rapid; the cell-contents are at first transparent; a firm precipitate or new formation next commences in the cell, and this occurs immediately around the nucleus, which is at first enclosed by it; the nucleus then either becomes entirely absorbed, or continues only rudimentary and (with the following exception) I have never observed it to give origin to any other essential formation. One or more oil-globules once appeared to me to be formed during the absorption of the nucleus in the adipose cells within the cranial cavity of a young carp. The importance of the decision of this question in reference to the germinal vesicle thus becomes very obvious. Unfortunately, however, neither the observations upon the subsequent relations of the germ-vesicle, nor those on the origination of the ovum, are sufficiently extensive or certain for the purpose.

We shall next proceed to analyse both views of the question more minutely, and afterwards compare them with the observations. If the germ-vesicle be a young cell, in the first place, it is absolutely necessary that the yelk-cell should first exist, and that the germ-vesicle should afterwards be developed within it; 2dly, the germ-vesicle must not be connected with the vitelline-membrane, but must be developed free at some chosen spot within the cavity of the yelk; 3dly, the germ-vesicle may be regarded either as a cell without a nucleus, and in that case the spots of Wagner belong to the cell-contents, or Wagner's spot, when it is single, is the nucleus; when there are several present, the others either differ essentially from *one* particular spot, and pertain to the cell-contents, or they are nuclei of young cells afterwards to be developed within the germ-vesicle. Before the spot can be considered to be the nucleus, it is necessary that it should, in the first instance at least, be connected with the wall of the vesicle. If, however, the germinal vesicle be the nucleus of the yelk-cell, it is essential, in the first place, that it should, in all probability, be present before the yelk-cell; at all events, that in proportion as the ovum is younger, should the vesicle be larger in relation to the cell; 2dly, it must, at first, lie upon the vitelline-membrane, and be more or less intimately connected with it; 3dly, the germinal-vesicle, when regarded as a nucleus, either has no nucleoli, or Wagner's spots are to be considered to represent them; in the first case they form the contents of the nucleus. In the enumeration of these points, no regard is had to the relations of the germ-vesicle subsequent to impregnation, because it is desirable to determine its ultimate destiny, to a certain extent *a priori*, from its signification, and thus to be enabled at the least to afford a guide to the much more difficult observation of the fecundated ovum. If the researches were complete, the distinctions above cited would be sufficient for the correct determination of the question at issue, the decision of the first point indeed would of itself be ample evidence.

When we take into consideration the first point raised on either side, we should be compelled to decide in favour of the latter view, and regard the germ-vesicle as a nucleus, if it were proved to be first present, and also that the yelk-cell is formed around it as a simple cell, narrowly encompassing it in the first instance, and becoming gradually expanded. In the next place, it is certain that at an early period the germ-vesicle is much larger in proportion to the yelk-cell, and that it at first grows *pari passu* with the yelk-cell, but that subsequently the latter increases in size in a much greater ratio, whilst the vesicle remains stationary; and these are precisely the relations in which the vesicle should stand in order to be regarded as a nucleus. But these facts are not entirely irreconcilable with the first view. A young cell, the germ-vesicle, might be imagined to form within the yelk-cell at a very early period of its growth, which young cell might at first increase in size more rapidly than the original one, but cease to do so earlier, whilst the parent-cell might continue to be developed in size. Such a circumstance is, however, very rare, and the weight of evidence before us is much in favour of the second view; but in order to determine this point, it is necessary to inquire whether the vesicle exist before the cell. That such is the case is not yet proved, although Baer and Purkinje suppose it to be so, and an observation of Wagner's favours the supposition. (Prodromus Physiologiæ Generationis, p. 9, fig. xviii, *a*.) He found the posterior extremity of the oviduct of Acheta campestris full of germinal vesicles, which became gradually expanded in their progress through the oviduct. The oviduct becomes dilated in its further course; globules are observed in it, which Wagner regards as yelk-globules, and between them lie the germ-vesicles; then "each vesicle becomes surrounded by its yelk and chorion, and thus the individual ova become separated." He does not state, however, in what manner the vitelline-membrane is produced. Is it formed as a cell, at first narrowly encompassing the germ-vesicle, and then gradually expanding; or does it at the same time enclose a quantity of the surrounding yelk-globules? It is difficult to conceive the latter mode of formation; but if the former be the correct one, the globules surrounding the germ-vesicles in the oviduct cannot be yelk-globules. Fresh researches are therefore necessary, which, if they should be confirmatory of the first view, will also be decisive for considering the germ-vesicle as a cell-nucleus.[1]

With regard to the second point,—namely, as to whether the germ-vesicle be more or less intimately connected with the membrane of the yelk-cell at an early period, or lie free within it,—any evidence afforded by its solution would be comparatively inconclusive. According to Baer and Wagner, the vesicle in the first instance lies in the centre of the yelk-cell, and only rises to its wall at a later period. Baer quotes the ova of frogs as examples in which it lies for a long time in the centre of the yelk. The germ-vesicle is generally found on the wall of the cell; and in birds, according to Purkinje, it is frequently so intimately connected with it, that it tears in the attempt to

[1] See the Supplement. The observations of Wagner upon the ova of insects which are there quoted, and the recent researches of Barry on those of mammalia and birds, (l. c. p. 308,) prove the germinal vesicle to be first formed, and then the vitelline membrane round it.

separate them. Although the position of the vesicle in the middle of the yelk-cell affords evidence rather in favour of its being regarded as a young cell, yet it is not altogether inconsistent with its character as a nucleus; for it is only during the earliest formation of the cell that the nucleus is required to be connected with it; it is frequently disconnected at a later period, and lies loose in the cell. At that stage of development, however, in which the vitelline-membrane closely encompasses the germ-vesicle, it is impossible to decide whether it lie in the middle or on the wall of the cell. This point, therefore, is of more ideal than practical importance for the prosecution of the investigation.

The third point relates to the signification which attaches to the individual parts of the germ-vesicle. It may be hollow consistently with both views. Although we are not as yet acquainted with any hollow nuclei in plants,[1] we have nevertheless found nuclei in cartilages which were hollow, and decidedly to be regarded as cytoblasts. The question now arises, what are Wagner's spots or spot? If the germ-vesicle be considered to be a young cell, *one* of them may be its nucleus, and the rest cell-contents, or nuclei of young cells, which will be developed afterwards; if it be regarded as nucleus, the spots may either be nucleoli, or merely its contents. It is a fact in favour of the former view, that only one spot is present in most instances, the others being usually produced at a later period. Wagner has sometimes observed one or more minute points in this single spot, and has delineated them from Alcedo hispida, Lepus cuniculus, Ovis aries, &c.; I have also sometimes met with small points of this kind which gave the spot, in some degree, the appearance of a nucleus adhering to the wall of the cell, and containing within it these little points as its nucleoli. Meanwhile, their presence is too inconstant, and they are generally too indefinite, to permit of our attributing any importance to them in the decision of the present question. The extraordinary number in which they frequently occur is opposed to their being regarded as nucleoli within the germ-vesicle, presuming it to be a cell-nucleus, for in fishes they sometimes fill the entire vesicle, at least, being closely crowded, they cover

[1] See Note, p. 33.

the internal surface of it. Three is the largest number of nucleoli which I have observed in other nuclei, and Schleiden has in some very rare instances seen four in plants. If, however, they are only the contents of the nucleus, and not nucleoli, it must be allowed that they differ very much from the contents of almost all other nuclei, which are generally yellowish, and made up of extremely minute granules. The only exception which I have met with was that already mentioned respecting the nucleus of the adipose cells in the cranial cavity of a young carp. This last point seems therefore rather in favour of the germ-vesicle being regarded as a young cell.[1]

When the whole of the above detailed evidence is reflected upon in connexion, it will be seen that it is as yet impossible to decide the question as to whether the germinal vesicle be cell or nucleus. The opinion that the vesicle is to be regarded as a cell-nucleus, seems for the present to have the ascendancy, inasmuch as the observations upon the first and most important point, viz. the prior existence of the germ-vesicle to that of the yelk-cell appear to be in favour of that view.[2] The sub-

[1] Since in vegetable cells the nucleolus is the primary formation, and the nucleus a secondary one around it, and as the same has been shown to be most probably the case in animal cells, (see page 20, on the production of the nucleus of cartilage-cells,) so also in this case the signification to be assigned to Wagner's spot depends upon the history of the development of the germ-vesicle. The observations of Wagner, quoted in the Supplement, show, however, that the single germinal spot of the ova of insects is first formed, and the germinal vesicle afterwards around it. The former must then be considered as nucleolus to the vesicle, which corresponds to the nucleus. When several of Wagner's spots occur, their signification is totally different from that of the *first one*, and they are to be regarded only as secondary formations in the interior of the germ-vesicle. In fact, the younger the ova of fishes and frogs, the fewer spots are observed in them.

[2] The following is the probable course of formation of the ovum, according to the researches now before us; the ovisac (Eisach, ovisac of Barry, internal membrane of the Graafian vesicle) is first developed. In this (according to analogy with Wagner's observations on the ova of insects) a germinal spot is generated, as nucleolus to the ovum. Around that spot the germinal vesicle is formed as nucleus to the ovum; and round this again the ovum-cell (Eizelle.) Martin Barry, indeed, (l. c. p. 308,) conjectures that the germ-vesicle is formed previously to the ovisac; but my respected friend expresses himself with great caution on the question; and it would in fact be difficult to determine whether a given vesicle were a germinal vesicle, around which no ovisac had as yet formed, or an ovisac within which no germ-vesicle had as yet formed. The occurrence also in the lower ani-

sequent relations of the vesicle seem also to afford evidence in its favour. The disc, for instance, is formed around it, and this perhaps corresponds to the granulous precipitate which

mals of several ova in one ovicapsule is difficult of explanation by Barry's view. In the further investigation of this subject, attention must continue to be fixed upon the possible, and even probable, existence of a nucleus to the ovicapsule. Wagner saw certain follicles in the mole, in which he could not detect a trace of any enclosed body.

Wagner expresses himself in his new work (Lehrbuch der Physiologie, Leipzig, 1839, p. 34) as being doubtful whether the vesicles met with in his observations on the preformation of the germinal vesicle in the ova of insects, were actually vesicles or not. The observations of Barry on the ova of mammalia and birds, are, however, in favour of the explanation of the ovum of the insect originally given by the first-named highly respected investigator, and therefore also of that which represents the germ-vesicle as nucleus of the ovum-cell. It is true it might be said, that, regarding the germ-vesicle as a cell, a second one, the ovum-cell was formed around it; but as opposed to that view, it must be remembered that no example of a second cell being formed around the first is afforded amongst all the other cells which exhibit a nucleus of the decidedly characteristic form. The point in dispute, as to the interpretation to be placed upon the germ-vesicle, loses, however, somewhat of its importance if the theory which I shall propose (see the conclusion of the treatise) be received, inasmuch as I shall there endeavour to prove the formation of the cell around the nucleus to be merely a repetition of the process by which the nucleus is formed around the nucleolus, and that the whole process of development of the cell may be reduced to a single or many times repeated formation of strata. The germinal-vesicle accordingly is the first stratum, or a cell of the first order; the yelk-cell the second stratum, or a cell of the second order. As above stated at page 47, a minute point was observed in the germinal spot by Wagner, and subsequently by myself also; and my respected colleague Vanbeneden lately found germinal spots in the ova of certain polypes (Genus Zoanthus), and also in ova of Anodonta, which had not as yet left the ovary, that appeared granulous, but at the same time seemed to be hollow, and some of which distinctly contained a very small round corpuscle. This observation accords most completely with the theory which regards the cells as produced by a stratified formation. This small corpuscle, which may be called a secondary nucleolus, would here be the primordial formation; the germinal spot would be the first stratum around it, that having in this instance become developed into a vesicle, in a manner likewise to be explained hereafter by the Cell-Theory; the germinal vesicle would be the second, and the yelk-cell the third stratum. The formation of even a fourth stratum, the albumen membrane, around the yelk-cell, would involve nothing contradictory to the theory; but in such case we certainly could not avoid regarding it as a second cell, which had become formed around a previously existing one: for the yelk-cell cannot well be considered to be a nucleus. The mode of formation of this albumen membrane must, however, in the first instance, be ascertained by investigation.

usually takes place around the nucleus in other cells; and again, the germ-vesicle disappears, precisely as the nucleus of other cells is generally absorbed. There is then no evidence that the fluid of the germinal vesicle exercises a fructifying influence; but if it be the cell-nucleus, it disappears, because it has completed its office,—the formation of the yelk-cell. The disc, which has formed around it, becomes developed into the germinal membrane, and it is uncertain whether the remains of the germ-vesicle also take part in that formation.

We shall next proceed to the consideration of the other contents which the yelk-cell includes in addition to the germ-vesicle, making use of the bird's egg for the purpose. Setting aside some points of distinction of slighter importance, the globules, well known as present in the yelk of the hen's egg when laid, may be divided into two principal classes: *a*, the globules of the yelk-cavity; and *b*, those of the true yelk-substance. The former (*a*) are not only present in the yelk-cavity, but occur also in the canal leading from it to the germinal membrane, and in the little prominence, called by Pander the nucleus of the tread (Kern des Hahnentritts). When many of them lie close together, they exhibit a white colour, whilst the true yelk-globules in such circumstances appear yellow. They may also be distinguished from the latter globules under the microscope, (see pl. II, fig. 2.) They are perfectly round globules, with quite smooth edges, each enclosing a smaller one, which is also perfectly spherical, and looks like an oil-globule, being rendered very distinct by its sharp outline.

The remaining space in the large globules is usually transparent, and not granulous. But some may be observed which have granulous contents, and they then completely resemble the true yelk-globules, except that the latter do not generally contain any smaller ones with such dark outlines. Sometimes also, the globules of the yelk-cavity contain two or more such smaller ones. The common yelk-globules (*b*), that is, those of the true yelk-substance, may be distinguished from the above-described by the following characteristics: they are upon the whole larger, they have all granulous contents, and, for the most part, do not enclose any smaller globules. They are very sensitive to the action of water, which causes them to fall to pieces, and then the granules enclosed within them becoming free, give a milk-white colour to the fluid. These granules, which are of various size, resemble milk-globules, and, as has been frequently remarked by others, exhibit also like them a brisk molecular motion. In consequence of the speedy action of water upon these globules, they must be examined in albumen or a weak solution of common salt, which preserves them better. These fluids also do not impart a white colour to the surface of a yelk which is opened in them, as water does. The globule, when crushed under the compressorium, tears somewhat suddenly on one side, the other margins remaining smooth, and then, without any increase of the pressure, a large quantity of the globules contained in it flow slowly forth. This fact indicates an external membrane belonging to the globules, but it must be a very soft and delicate one. Baer, who distinguishes four kinds of them, believes that he has also sometimes seen such a membrane in the yelk-globules of immature ovarian eggs. The yelk-globules when isolated are round, but, in their natural position in the yelk, they flatten against one another into angular shapes, in which manner the crystal-like bodies observed by Purkinje in the boiled yelk are produced. These bodies generally make up the whole of the true yelk-substance of a fresh egg, so that, with the exception of the contents of the yelk-globules, we do not usually meet with any free granulous substance in the yelk. The minutely granulous substance which is observed in addition to the yelk-globules, particularly after the action of water upon them, appears in most instances, and on the external layers of the yelk invariably, to be produced solely by the destruction of the yelk-globules. In the vicinity of the yelk-cavity of a boiled egg, however, we frequently find a coagulated substance composed of granules similar to those contained in the yelk-globules, and which appears to be actually free yelk substance not enclosed within globules.

It is necessary to examine the eggs while still contained in the ovary, if we wish to become acquainted with the process of formation of these two kinds of globules (those of the yelk-cavity and yelk-substance), and the mode of production of the yelk-cavity and its canal. The younger eggs, having a diameter of one or two lines, have a grayish-white colour, but are not yellow; if such an one be cut through the centre, under water, it is found to contain a thick, semi-fluid, grayish-white mass, part of which flows slowly out. Around this mass lies a more consistent, cohering, membrane-like stratum, which lines the cavity of the little egg. When a portion of this mass is examined under the microscope, a great many round and very transparent vesicles or cells are observed in it, each of which encloses a dark corpuscle resembling an oil-globule. Many such globules float about free, and in addition to them there is also a good deal of minutely granulous substance present. In order, however, to examine this mass in a perfectly natural condition, the use of water must be avoided; one of the little eggs, of from half a line to a line in diameter, should be placed upon the dry object plate, and then pierced, a drop of its contents being allowed to flow out. This drop will be found to consist entirely of very pale cells, most variable in size, each one containing a round globule, the size of which is about proportionate to that of the cell. This globule or nucleus resembles an oil-globule, in consequence of its dark outline, (see pl. II, fig. 3.) Many of these cells with their nuclei are so small, that, when lying close together, they might be regarded as a merely granulous substance; the cells may, however, be recognised with a favorable light. Some of the larger ones occasionally contain two or three of the globules or nuclei before mentioned. The contents of the cells are usually quite transparent, but some isolated ones are seen, in which a minutely granulous precipitate has formed. These cells are enclosed within the egg, in a small quantity of transparent fluid. In order to explain the somewhat variable appearance which the contents of the egg assume after contact with water, a small one should be placed upon a glass with a drop of that fluid, and some of its contents pressed out whilst under the microscope. A quantity of these cells will then be seen to burst quite suddenly in the water, precisely like soap-bubbles in the air. In consequence of their paleness, the fact of the bursting is rendered manifest, in the first instance, only by the sudden motion of the nucleus, which, together with some minutely granulous substance, remains behind. If these cells were solid, although ever so soft, this sudden bursting would not be possible. They are therefore true cells. I cannot say whether the globule enclosed in them is to be regarded as the nucleus. Although it resembles an oil-globule, it does not appear to be fat; for if acetic acid be applied to a drop of the contents of the egg, it does not appear to act materially upon the cells, and the contained corpuscle becomes paler and somewhat swollen, which could not well take place if it were fat. These cells, then, are the earlier stage of development of the subsequent globules of the yelk-cavity. The larger ones already resemble them perfectly. These globules of the yelk-cavity are therefore likewise cells. Their nucleus-globule (Kernkugel) is acted on by acetic acid precisely in the same way as it was in the earlier condition. It does not lie centrally in the cell, but on the internal surface of the wall, as is seen when the cells are caused to roll under the microscope. When at rest, however, they are generally so placed that the nucleus-globule occupies the most depending point (because probably it is the heaviest portion of the cell), and, on that account, it then appears to lie in the centre of the cell. The yelk in the first instance contains only the yelk-cavity, with its cells; the proper yelk-substance with its globules not being as yet formed. The colour of these young eggs is therefore also white, like the contents of the yelk-cavity.

The membrane-like layer which surrounds the above-described contents of the egg, may be completely separated from the parts which surround it externally with facility, after the egg has been divided through the centre. It is not connected with them, and appears, to the unaided eye at least, to be pretty smooth on its external surface; it is not possible to trace it towards the interior. Its structure is peculiar. Purkinje, who discovered it, describes it as consisting of globules, which resemble in form and size, but are more transparent than the blood-corpuscles. When spread out upon a plate of glass, and examined with the microscope, it is seen to consist of two parts, an internal minutely granulous stratum, and an external layer of cells. Numerous little granules are observed in the internal stratum, which resemble the nuclei of the above-described cells of the yelk-cavity in their earliest stage, and I conjecture that the cells of the yelk-cavity are formed from this stratum, so that in fact it still pertains to the yelk-cavity. The external layer consists of small round granulous cells, each of which contains a nucleus, which again in many instances encloses one or two nucleoli. Two or three such layers of cells lie one above another. These layers of cells are surrounded externally by a very transparent, perfectly structureless membrane, which represents a closed cell-membrane, having as little connexion with the ovary as with the layers of cells, and which is denominated vitelline membrane. It is as readily separated from the ovary as from the layer of cells, the latter, therefore, cannot be merely its epithelium.

If we now proceed to examine larger eggs from the ovary, such, for instance, as have attained a diameter of half an inch or more, and are already yellow-coloured, on their being divided across the centre under water, a white substance, the yelk-cavity, will be found in their interior. This cavity contains those cells, now in a higher stage of development, which in the first instance alone formed the contents of the egg. Around these a stratum of yellow substance, the proper yelk-substance, appears, and round this again lies the layer of cells. Globules may be recognised in the proper yelk-substance with the aid of the microscope, as in the same substance of the mature yelk. These globules, then, have been formed between the yelk-cavity and the layer of cells. The question, however, arises how this has been effected? The following may be supposed to be the mode of their production:—the innermost portion of the yelk, the yelk-cavity, is the part which is first formed, the innermost yelk-globules are therefore also the oldest, and the formation of the new yelk-globules takes place externally upon the internal surface of the layer of cells. If a small portion of the layer of cells be so placed under the microscope that the inner surface becomes turned towards the eye, and a spot be sought for at which a thin layer of yelk-substance is attached to it, it will be seen that the yelk-globules do actually become smaller in the proximity of the layer of cells, whilst in other respects they retain their general appearance. The smallest of them, which lie immediately upon the inner surface of the layer of cells, are even smaller than the cells of the layer itself. It is therefore extremely probable, that the formation of new yelk-globules takes place on the inner surface of the layer of cells, and that the globules then expand to their normal size somewhat quickly, for the stratum of small ones is but thin. Meanwhile new ones continue to form externally, until the yelk has reached its normal size. The formation of the canal leading from the yelk-cavity to the germinal vesicle may also be explained in the same manner; for instance, no formation of yelk-globules can go on at that point at which the germ-vesicle and the stratum for the germinal membrane are in connexion with the layer of cells, but at that spot there must be a gap in each stratum of yelk-globules, which by the increasing thickness of the yelk-substance becomes a canal, necessarily conducting from the yelk-cavity towards the germinal membrane, and into which cells from the yelk-cavity become crowded. Now are these globules of the proper yelk-substance cells? I cannot prove decisively that they are so; the following arguments, however, render it probable: 1st, because Baer believes that he observed an external membrane in some of them; 2dly, because, when ruptured at a particular spot by the compressorium, they at once pour out a large portion of their contents without the pressure being increased; 3dly, because, notwithstanding that they lie close together in the yelk and flatten against one another, they do not run together; 4thly, because they so closely resemble some of the cells of the yelk-cavity which are furnished with granulous contents; 5thly, because they, like cells, appear to have an independent growth. These reasons are sufficiently strong to render it probable that the yelk-globules have a cellular structure, though they cannot be received as decisive of the point. However, inasmuch as they all form the contents of a larger cell, it is not absolutely necessary for our purpose that they should be distinctly proved to be cells. Both the indubitable cells of the yelk-cavity, and those problematical ones of the proper yelk-substance, have an independent growth in a fluid, and within another cell. They are cells within cells. For although the formation of new cells takes place only at the outside, yet they are still separated from the organized substance, not only by the cell-membrane of the entire ovum, but also by the layer of cells which is situated immediately beneath it. We here, then, meet with an instance of just such a formation and independent growth of cells within a fluid as was expressed by the fundamental phenomenon previously laid down. It is a point open to investigation, whether the cleaving of the yelk described by Baer, Rusconi, and others, in the development of the lower animals, the ova of frogs for example, may not also depend upon a process of cell-formation, two cells being developed within the yelk in the first instance, and in each of these again two new ones, and so on.

We next proceed to consider the changes undergone by the external layer of cells furnished with nuclei. In eggs which have a diameter of a line, this entire membrane, if it may be so called, appears to be made up merely of cells. In such as have reached a higher stage of development, such as have a diameter of upwards of half an inch, for instance, it consists of two strata, the external of which is granulous, and no longer exhibits cells; the internal, however, is composed of cells, which are flat, hexagonal, but also granulous, and bear the relation of a covering of epithelium to the outer one. The external stratum passes away over the germinal vesicle and the foundation of the germinal membrane, so that these structures may easily be removed from its inner surface without injury to it. The internal cellular stratum, on the contrary, is interrupted at the spot where the germinal vesicle lies. I have not traced the mode of formation of this external granulous stratum through all its details; I suppose it to be produced by a blending of the outer cells, which composed the original membrane when it was made up entirely of cells. As the period approaches at which the egg leaves the ovary, the epithelium-like stratum of cells gradually disappears, and the granulous membrane alone remains. It does not exhibit any disposition to unite with the structureless external membrane of the egg, even in eggs which are almost sufficiently mature for extrusion. If such an egg be cut open under water, and the investment derived from the ovary be drawn off, this granulous membrane frequently remains lying upon the yelk, whilst the structureless membrane follows the above-mentioned investment, and may readily be proved to be connected with it, when they are folded so that the inner surface forms a sharp edge. By the aid of the compressorium this structureless membrane may then be seen, projecting out from the border of the preparation. It often separates in large pieces during this manipulation, so that it has likewise no connexion with the parts pertaining to the ovary. If the signification of vitelline membrane is to be assigned to this structure, a blending between it and the granulous stratum must take place in the oviduct, in order to form the subsequent vitelline membrane of the extruded egg.

We now pass on to that portion of the egg from which the embryo is first formed, the germinal membrane. It represents, as is known, a round, white, little disc, somewhat above a line in breadth, which lies between the vitelline membrane and the yelk-substance. This little disc, in a fresh-laid hen's egg, consists of globules, which are of unequal size in different parts of the germinal membrane. When examined with the microscope, they appear much darker than the yelk-globules, (see plate II, fig. 4.) They lie in close contact, so that they flatten against one another to an hexagonal form. The boundaries of the distinct globules may be clearly distinguished, even when in connexion. They may also be readily isolated from one another, and are then round. They contain many smaller round granules of various size, with very dark outlines, which float about singly when the globules are burst by pressure. Although these granules, in most instances, completely fill the globules, yet some globules may be observed where that is not the case, and where a portion of the globule is transparent, and free from granules, (*a b*, of the above figure.) I thought that I distinctly saw a double external outline on one of these globules (*a*), which would be evidence of the presence of a cell-membrane. In most instances, however, this is not distinct, and my principal reason for concluding that they are cells, is, that it is so extremely probable that they are developed to form the indubitable cells of the incubated germinal membrane. I have not, however, fully investigated this process, and only communicate my observations on the point, incomplete as they are. If the unincubated germinal membrane be folded in such a manner that its external surface form a sharp margin, that surface is found to be tolerably even, dark, and composed immediately of the globules of the germinal membrane already described; the surface of the germinal membrane of an egg which has been exposed to brooding heat for four hours, presents a precisely similar appearance. The same membrane, when examined also upon its general surface, differs but very slightly in appearance from one which has not undergone incubation. The globules of which it consists merely appear to have more minutely granulous contents. But if a germinal membrane after eight[1]

[1] It is quite as impossible to define with any certainty a fixed time for a precise stage of development of the elementary cells of the germinal membrane, as it is to connect the formation of the area pellucida, the embryo, and its separate parts, with

hours' incubation be folded in the same manner, its margin at many points is found to be no longer dark and even, but to be composed of extremely pale transparent cells. These cells present every variety of size, some being as large and even larger than the primitive globules of the germinal membrane. They either project forward in the form of half-spheres, or the greater portion of their spherical surface juts out in some instances, and they may be completely separated by pressure. They contain a pellucid fluid, but no nucleus. The following fact shows them to be cells; some of them contain very minute, isolated, black granules, which resemble the molecules described by Brown, and exhibit molecular motion within the cell. This fact proves that the contents of the cell must be fluid. A fluid which is miscible with water cannot, however, preserve any definite form, unless it be encompassed by a membrane. Such a structure must, therefore, exist in this instance. It is not altogether easy to convince one's self that these granules, exhibiting molecular motion, do actually lie within the cells; but it may be concluded from the fact, that they do not flow away when the surrounding fluid is allowed to escape, and that they are not moved beyond the limits of the cell, but only to its wall and back again. Beneath this stratum of cells lie the globules of the unincubated germinal membrane, which, however, appear to have become still more clear and minutely granulous than those of the membrane examined after four hours' incubation. In addition to these, separate cell-nuclei may be observed, such as occur in the cells of the serous layer at a subsequent period, and may be seen in plate II, fig. 6. Still more internally than this layer, we meet with perfectly dark globules. The serous and mucous layers of the germinal membrane are perfectly formed in the egg after sixteen hours' incubation. If the membrane at that period be folded so that its external surface may be seen, it will be found

any degree of certainty to any precise hour of incubation. The periods cited should therefore only be taken as being near about the true determinations of the time. The cells in the germinal membrane, before incubation even, do not appear to be always at the same stage of development; thus, plate II, fig. 4, *c*, and fig. 4, *a*, *b*, represents cells from two different membranes. A great portion of the germinal membrane from which *c* was taken consisted of such cells as that delineated, and I thought I perceived molecular motion in the granules contained in some of them, which, if correct, would clearly prove them to be cells.

to be composed of cells, which project forwards in the form of half-spheres, (plate II, fig. 5). A nucleus of the characteristic form may be recognised in some of them. It lies upon the internal surface of the cell-wall, is round, and contains one or two nucleoli. In most instances, however, no nucleus can be seen, either because none is present, or because it lies upon the posterior side of the cell, in which position it cannot be perceived, in consequence of the dark substance lying beneath it. The cells also contain a transparent fluid, and some minute granules with molecular motion, which is evidence sufficient for the existence of a peculiar cell-membrane. If, after the germinal membrane has lain for a time in water, the mucous layer be washed off, the general surface of these cells may be observed. They are then seen to lie close together, and to flatten against one another to hexagonal forms, (see plate II, fig. 6). They contain a beautiful nucleus, which encloses one or two nucleoli. They also present many minute granules, which exhibit molecular motion. The cells may also be observed in the recent germinal membrane, especially on its margin, at which part it is more transparent, and there they project forward in the form of large segments of a sphere. These cells then represent the serous layer of the germinal membrane,—which, therefore, consists of round cells (their polyedrical form being referrible solely to their lying so closely together), furnished on the inner surface of their wall with the characteristic nucleus, and containing a clear fluid, and some isolated smaller granules. They might be conceived to be a mere covering of epithelium to the serous layer. But if the serous layer be separated after the blood has formed, for example, in an egg which has undergone forty-eight hours' incubation, the vascular layer remains lying immediately upon this stratum of cells. Valentin has already recognised these cell-nuclei, for he says, that each of these layers of the germinal membrane consists of a transparent vitreous jelly, but that they are to be distinguished by the corpuscles which they contain. (Entwicklungsgeschichte, page 287.) These corpuscles are the cell-nuclei, the transparent substance in which they lie is composed of the cells, and is gelatinous only in appearance. The cells have only a minimum of intercellular substance between them.

When, in the next place, we proceed to examine the mucous layer of the germinal membrane of an egg after sixteen hours' incubation, we find it to be composed of globules, which vary greatly both in size and appearance, (see plate II, fig. 7.) The large globules, which form the greater proportion, may be proved to be cells, and Baer has already named them vesicles. The molecular motion, which is frequently visible in isolated globules within them, although much slighter in these instances than in the cells of the serous layer, affords sufficient evidence of their cellular character. They contain a transparent fluid and granules of various kinds. One particular globule, having very dark outlines, resembling those remarked in the cells of the yelk-cavity, may be observed in almost every cell. Several of the globules, and of all gradations of size, are frequently seen in a cell. In addition to the above, a minutely granulated substance is present in many of them. These cells lie somewhat loosely together in a structureless, tenacious, intercellular substance, which is their cytoblastema, so that at this stage they are but slightly flattened against one another. This intercellular substance contains, in addition, perfectly dark globules and smaller granules, but I do not know what relation they bear to the cells. A portion of them may, perhaps, be nuclei of new cells. Yet I could not decide whether the *one* dark globule, which is generally so very prominent in the cells of the mucous layer, had actually the signification of a cell-nucleus. It differs in form from the usual cell-nucleus very materially. During the progressive development of the germinal membrane, the quantity of intercellular substance, and of those globules the cellular nature of which is not demonstrable, diminishes very much, so that at a subsequent period the cells lie close together, and present the appearance of vegetable cellular tissue. The description here given applies only to the mucous layer on the outside of the area pellucida. Within that the cells have quite a different appearance. They are very much smaller, of pretty equal size, very transparent, and contain no coarse granules, but only very small globules. They do not appear to have any nucleus, and this fact distinguishes them from the cells of the serous layer, which possess a nucleus even within the area pellucida.

The first rudiments of the embryo appear to be formed from the cells of the serous and mucous layers of the germinal membrane, that is, from such cells as are met with in the area pellucida, so that the embryo is composed, partly of small cells without nuclei, and partly of cells furnished with the characteristic nucleus. It presents, however, besides them, an extraordinary quantity of simple cell-nuclei with nucleoli, around which no cells have as yet formed.

I have made but few researches with respect to the structure of the vascular layer, and from them, I could not (with the exception of the vessels themselves and the blood) detect any such essential difference between it and the mucous layer, as was exhibited between the latter and the serous layer. As, however, the formation of the vessels themselves, although it appears to depend upon a production of cells, is not a process peculiar to the germinal membrane, we shall defer it, to be resumed at a subsequent stage of our investigation.

I have not ascertained the relation which these cells of the layers of the germinal membrane have to the primitive globules of the membrane before incubation, or within eight hours after that process has commenced; but inasmuch as it is probable that at least *one* of those kinds of cells owes its origin to the development of the primitive globules, we may be permitted to suppose that those globules are likewise cells.

For the purpose of giving, in outline, a connected view of the changes which the egg undergoes, from its first formation up to the period at which the actual development of the embryo commences,—in so far as the foregoing, more or less complete, observations enable us to form a provisional conception of the process of development,—we will proceed on the understanding, that the germ-vesicle is the nucleus of the yelk-cell; at the same time, however, we expressly refer the reader to the more detailed statement above furnished for the certainty both of this and of every other separate point which occurs in the following exposition. It is probable that the germ-vesicle is the first structure, and that the yelk-cell forms around it as its cell-nucleus. Both advance in growth, the latter, however, much more rapidly than the former. A precipitate, the commencement of the germinal membrane, next forms around the germ-vesicle. Young cells are simultaneously formed in the remaining space of the yelk-cell, these are the cells of the subsequent yelk-cavity. Then cells of another kind originate beneath the vitelline membrane, which are the subsequent cells of the proper yelk-substance. They are formed round about the neighbourhood of the vitelline membrane, with the exception of that spot where the germ-vesicle and the rudiments of the germinal membrane lie. These cells expand very rapidly, while at the same time a new layer is formed on the outside of them, and so on successively. In this manner they surround the white cells of the yelk-cavity with a layer of yellow cells, which is constantly increasing in thickness; as, however, a vacant space remains at the spot where the germinal vesicle and germinal membrane are situated, by the increasing thickness of the yelk-substance, the space becomes converted into a canal. The development of the vitelline membrane proceeds continuously with these changes, in proportion as the increasing contents require. When the yelk-cell has attained its due size and the egg leaves the ovary, the germ-vesicle, like most other cell-nuclei, disappears, and the now more fully developed germinal membrane remains. It is made up of globules, probably cells, having coarsely-granulated contents. It grows during the process of incubation by the continual development of new cells. After sixteen hours' incubation, a distinction may be observed in the cells composing the membrane. The more external ones form a layer, in which the cells exhibit a nucleus of the characteristic form, and contain a quantity of transparent fluid and minute isolated granules. These cells are therefore clear, and firmly united together, and have only a minimum of intercellular substance between them; they represent the serous layer of the germinal membrane. The under stratum of the germinal membrane or mucous layer contains cells of another kind; they have no nucleus of the characteristic form, but contain one or more dark globules, and frequently also some minutely granulous substance. These cells lie loosely together in a larger quantity of intercellular substance, which contains smaller granules of different kinds, in addition. When this division of the membrane into the two layers is completed, and its superficies has become considerably extended, and after a transparent spot, the area pellucida, has formed in its centre—(the cells of the mucous layer in this area being much smaller, but of pretty equal size, as compared with one another, and having transparent contents with very minute isolated granules),—the embryo is developed, as a portion of the germinal membrane separating from the whole by a constriction. Both layers contribute to its formation, and it therefore consists of small transparent cells, some of which (probably those pertaining to the mucous layer) contain no nucleus, whilst others (those derived from the serous layer) exhibit the characteristic cell-nucleus with its nucleoli. In addition to these cells it contains a great many nuclei, around which no cells have as yet formed. Between the two layers of the germinal membrane other cells arise, which may be regarded as representing a third layer, the vascular, although they do not really form a connected independent layer; of these we shall treat hereafter. These three layers then, and pre-eminently the first two, form the mediate basis of all the subsequent tissues.

The yelk is not a lifeless aliment for the embryo,—as it is when taken as food by the adult, to whose organism it is dead and must be chemically dissolved,—but the cells of the yelk take part in the vitality called forth by incubation. They effect an alteration in their contents, whereby the albumen which they contain loses its property of coagulating, and the granules become dissolved, in the same manner in which the granules of starch dissolve in the cells of the vegetable embryo. In short, the yelk bears the same relation to the embryo as regards its nutritive property, that the albumen bears to the vegetable embryo.

In accordance with the analogy between the cells we are treating of and those of vegetables, all the changes in the egg, the growth of the germinal membrane, and even the first formation of the embryo, proceed entirely without vessels.

SECOND DIVISION.

Permanent Tissues of the Animal Body.

The foregoing investigation having taught us that the entire ovum, from its first origin up to that period at which, by the formation of the serous and mucous layers of the germinal membrane, the foundation of all the subsequent tissues is laid, exhibits simply a continual formation and more extended development of cells, and having found the primordial substance of the tissues itself to be composed of cells, we are now required to prove, that the tissues do not only originate from cells in this general manner, but that the special basis of each individual tissue is a matter composed of cells, and that all tissues either consist entirely of or are formed from cells which pass through a variety of transformations. These modifications, which some of the cells undergo in the progress of their development to the subsequent tissues, are very important, since thereby the cells not infrequently cease to exist as separate independent structures. We have already (in the Introduction) seen such changes in plants, for example, in the coalescence of the cell-walls observed by Schleiden in the bark of the Cacti, and the blending of several cells to form a tube in the spiral and lactiferous vessels. This takes place to a much greater extent in animals, and, in general, the higher the importance of a tissue is, the more do the cells lose their individuality. We shall not, however, enumerate these modifications here; we shall become acquainted with them as the result of investigation of the separate tissues, and, at the conclusion of the work, we shall combine them into a connected representation of Cell-life. It is necessary, however, to mention the most important of them at least preliminarily in this place, in order to make a classification of the tissues.

Since all organic structure is primarily formed from cells, the most scientific classification of general anatomy would manifestly be one founded upon the more or less high degree of development at which the cells must arrive, in order to form a tissue. The complete retention, or relinquishment, to a greater or less extent, of their individuality by the cells, should serve as the scale for their degree of development. We give the name of *independent* cells to those in which the wall remains distinguishable from the neighbouring structures throughout the whole progress of its expansion. We apply the term *coalesced* cells to those in which the wall blends, either partially or entirely, with the neighbouring cells, or intercellular substance, so as to form an homogeneous substance. The cell-cavities, in such instances, are separated from one another only by a single wall, as we have already observed in cartilage. This is the first degree of coalescence; the cacti present an example of it in vegetables. The second is that in which the walls of several cells lying lengthwise together, coalesce with one another at their points of contact, and the partition walls of the cell-cavities become absorbed. In this way not only the walls but the cavities of the cells also become united, as in the spiral and lactiferous vessels in plants.

Upon these more or less important modifications of the Cell-life the following classification of the tissues is based: 1st. Isolated, independent cells, which either exist in fluids, or merely lie unconnected and moveable, beside each other. 2d. Independent cells applied firmly together, so as to form a coherent tissue. 3d. Tissues, in which the cell-walls (but not the cell-cavities) have coalesced together, or with the intercellular substance. Lastly, tissues in which both the walls and cavities of many cells blend together. In addition to these, however, there is yet another very natural section of the tissues, namely, the fibre-cells, in which independent cells are extended out on one or more sides into bundles of fibres. The naturalness of this group will form my excuse for sacrificing logical classification to it, and inserting it as the fourth class (4th), consequently, that last mentioned, consisting of tissues, in which the cell-walls and cell-cavities coalesce, becomes the fifth (5th).

All tissues of the animal body may be comprised under these five classes; the classification, however, gives rise to some difficulties. For instance, the fibres of cellular tissue and fat must be placed in very different classes, so also the enamel of the teeth and the proper dental substance. A second difficulty arises from the fact, that transitions take place, the isolated cells, for example, passing over into those with blended walls; and again, a tissue which usually consists of isolated cells, occasionally exhibits in different situations coalesced cells. Such difficulties, however, present themselves in all classifications of natural objects. Nature is very unwilling to accommodate herself to our schemes. The object of her aim is quite opposed to that of our intellect. She accords and accommodates all contrarieties by gentle transitions: the intellect disjoins, and seeks everywhere for strongly-marked contrasts. If, however, regard be had to the most important structure only in each individual tissue,—for example, in the nervous system, to the nervous fibres and not to the ganglion-globules, in cellular tissue, to its fibres and not to the fat, and so forth,—and further, if we regard only that which is the general rule as to these structures, all tissues may then be readily brought under these five classes. With the desire of making this work as complete as possible, I have applied this arrangement to all the tissues in the way which has appeared to be most probably correct, according to the investigations I have hitherto made. Those researches are, however, far from complete, and continued observations may perhaps render it necessary, at some future time, to assign a different position to some of the tissues. This may serve as a preliminary sketch:

Class I. Isolated, independent cells. To this class the cells in fluids pre-eminently belong; Lymph-globules, Blood-corpuscles, Mucus- and Pus-corpuscles, &c.

Class II. Independent cells united into continuous tissues. Such as the Horny tissues and the Crystalline lens.

Class III. Cells, in which only the cell-walls have coalesced: Cartilage, Bone, and the *substantia propria* (ivory) of the Teeth.

Class IV. Fibre-cells: Cellular (areolar), Fibrous, and Elastic tissue.

Class V. Cells, in which both the cell-walls and cell-cavities have coalesced: Muscle, Nerve, Capillary vessels.

CLASS I.

Isolated, independent Cells.

By the above term we understand cells which either float free in fluids, or, at least, are moveable, though lying in close contact. Such cells, therefore, possess the highest degree of individuality. This class includes the cells of lymph, blood, and the various secretions. The ovum might be placed at the head of this class in a system of general anatomy; but the plan of the present work required that it should be discussed previously.

1. *Lymph-corpuscles.* According to Vogel's description (Physiologisch-pathologische Untersuchungen über Eiter, &c. Erlangen, 1838), the lymph-corpuscles appear to be cells, although he does not express the fact in words. For example, after the corpuscles have been exposed to the action of acetic acid, a nucleus is brought into view, the production of which I do not suppose to be referrible to a separation into envelope and nucleus, but believe it to have been previously formed, and rendered visible solely in consequence of the greater degree of transparency acquired by the envelope, i. e. the cell-membrane, and its contents, from the action of the acid upon them. One of the nuclei, amongst the lymph-corpuscles, delineated in the above-mentioned work (fig. 4 *b*) appears to contain a nucleolus in its centre. I have not made any researches myself upon this subject. The mode of production of the lymph-corpuscles has not as yet undergone investigation. They are probably formed in the lymph-plasma, which serves as their cytoblastema, in accordance with the general law before laid down. We cannot as yet decide the question whether the nuclei are present before the cells, and whether the latter are first formed around them; perhaps the small granules which Vogel delineates from lymph are young nuclei.

2. *Blood-corpuscles.* C. H. Schultz was the first who proved

the blood-corpuscles to be vesicles.[1] He relied especially upon the manner in which they were acted on by water, whereby they lose their colouring matter, swell, and become round, and under which circumstances he frequently saw the nucleus roll about within the round and very transparent vesicle. The last fact would of itself be sufficiently conclusive. I have not as yet observed this fact; on the contrary, in most instances the nucleus decidedly adheres to the internal surface of the wall of the vesicle, eccentrical as in all cells, though it may probably also sometimes become detached. The fact, however, of the blood-corpuscles becoming swollen and round, renders their cellular nature highly probable. If the envelope (hülle) of the blood-corpuscle were not a flattened vesicle, it might indeed lose its colour and swell in water, but it would retain its flat form, like a sponge when filling with fluid. The circumstance of the nucleus remaining on the wall during the swelling of the blood-corpuscle in water is no accidental appearance; for even in the round blood-corpuscles of a chick, forty-eight hours after the commencement of incubation, when they were not as yet flattened, I found that the nuclei, which were also circular, were not placed in the centre, but lay eccentrical upon the internal surface of the wall. The cellular nature of the blood-corpuscle, and the signification of its separate parts scarcely appear to admit of doubt when regarded in connexion with the whole of this investigation. It is a flattened cell furnished with a cell-nucleus, which is fixed to a spot on the internal surface of the cell-membrane. The size of the cell as compared with the nucleus is not the same in all corpuscles; that of the nucleus is much more constant. The nucleus of some blood-corpuscles of frogs which had swollen in water, also appeared to me in some instances to be hollow. It also loses its flatness in water, but retains its oval figure. I have

[1] [This is clearly an oversight as Hewson not only demonstrated their vesicular nature, and *called them vesicles*, but accurately described their becoming "changed from a flat to a spherical shape," on the addition of water to the blood, and the falling of the nucleus "from side to side in the hollow vesicle, like a pea in a bladder." See 'Philosophical Transactions,' 1773, vol. lxiii, Part II; or, 'Experimental Inquiries,' Part III, being 'a Description of the Red Particles of the Blood,' &c., &c. (published after his death), edited by Magnus Falconar, London, 1777; also the very valuable republication of Hewson's Works by the Sydenham Society, edited by George Gulliver, Esq., where the reader is particularly referred to pp. 220, 221.—TRANS.]

never distinctly observed nucleoli in it; occasionally only I thought I perceived something of the kind, for instance, in the blood-corpuscles of a salamander; it was not, however, sufficiently evident to permit of my asserting their presence. Cell-contents must certainly exist; for if the cell-walls lay immediately upon one another, the corpuscle must be as much thinner on the margins beside the nucleus as the thickness of the nucleus amounts to. If it be assumed that the cell-membrane alongside the nucleus may be so much thicker as thereby to produce the almost level side surfaces, the cell-membrane must in such case have a thickness equal to the half of that of the corpuscle; but it would then be sufficiently thick to allow of a double outline being distinguished when it was swollen by water; observation, however, does not detect any such appearance. The red colouring matter forms the cell-contents. It is difficult to decide whether the cell-membrane and nucleus are also coloured, but it is in some degree probable that they are so, since otherwise the centre of the corpuscle where the nucleus lies must appear white, whilst it in fact exhibits a paler red colour. The colouring matter of the blood-cells is not contained in granules, as it is in most kinds of pigment, but in a state of solution. If the lymph-corpuscles be cells, their transformation into the blood-corpuscles may at least be conjectured as taking place by their becoming flattened and absorbing colouring matter. Those blood-corpuscles in which the envelope (hülle) is smaller in proportion to the nucleus, a fact often observed in the frog, are probably younger cells. I have made no observations upon the formation of the blood-corpuscles in the germinal membrane. According to C. H. Schultz (System der Cirkulation, p. 33), the blood-corpuscles in the chick are formed round the yelk-globules. (?) The latter are first present, and form the nucleus of the blood-corpuscles; they become surrounded with a delicate membrane. The vesicle then dilates, and at length becomes flattened. This description accords excellently with the fundamental laws previously developed, and shows that as early as 1836 Schultz had discovered the pre-existence of the nucleus of the blood-corpuscle, the formation of the blood-vesicle around it, and the gradual expansion of that vesicle.

3. *Mucus-corpuscles.* The mucus corpuscles have already been described as cells, in consequence of their resemblance to the cells of epithelium. They are round globules, enclosing a nucleus, which is eccentrical. We already know this to be the elementary form of most animal and vegetable cells, and the presence and characteristic position of the nucleus, therefore, warrant us in concluding that in this instance also the globule is a cell, although an especial cell-membrane cannot be distinguished. Güterbock discovered that the nucleus of the mucus-corpuscle has the peculiar property of splitting into two or three smaller corpuscles when acted upon by acetic acid, and that the enclosing or cell-membrane is gradually dissolved in the same acid. Vogel, indeed, attributes this property to such mucus-corpuscles alone as have been secreted by a morbid action, and to pus-corpuscles. But I have been informed by Henle that the true mucus-corpuscles (of which, according to him, only a very small quantity exist in healthy mucus,) exhibit the same peculiarity, and that those which are not affected by the acid are true epithelial cells. As I have never observed any other cell-nuclei to be similarly acted on by acetic acid, the fact marks the distinction between mucus and pus-corpuscles and all other cells, and, according to Henle, even the youngest epithelial cells do not possess this property, so that the mucus-corpuscles differ distinctly from them. It appears to be a characteristic of all cell-nuclei that they not only are insoluble, but do not even become transparent in dilute acetic acid. These, therefore, are peculiar cells, which are formed in the fluid of mucus as their cytoblastema, in the same manner as the yelk-cells in the fluid of the yelk-ball. They become more abundant, when the cytoblastema obtains a greater degree of "plasticity," as the result of irritation of the mucous membrane; and as on the other hand the secretions in the normal condition possess but a very small amount of plastic force, and some—the urine and bile, for instance—have not any; we accordingly find in them but a very few cells, or indeed none at all, save some cast-off epithelium. I have not investigated the question whether the nucleus exist before the cell in the mucus-corpuscles, or upon what the division of these nuclei by means of acetic acid depends.

4. *Pus-corpuscles.* We are entitled to consider the pus-corpuscles as cells, by the same arguments which we applied to those of mucus. Vogel, indeed, regards them as identical with those mucus-corpuscles which, according to his view, are morbidly secreted, but which Henle believes to be normal. They are similarly affected by acetic acid, and cannot therefore be young epithelial cells, in which, according to Henle, the splitting of the nucleus does not take place under similar circumstances; indeed, that property appears to be confined entirely to the nuclei of the mucus and pus-corpuscles. Vogel states that the nuclei of pus-corpuscles are concave. The pus-corpuscles are thus peculiar cells which are formed in the serum of pus,—i. e. in cytoblastema, exuded during inflammation, in increased quantity, and of anomalous composition,—precisely in the same manner that mucus-corpuscles originate in mucus, and, indeed, as all cells form in their cytoblastema, in accordance with the fundamental law already laid down. According to the observations of H. Wood, they appear to be earliest formed upon the surface of the granulations, and for the reason that their cytoblastema, the pus-serum, is constantly exuding freshest at that part, and therefore possesses in that situation the greatest amount of plastic force, as we have already observed in reference to the formation of new yelk-cells on the outside and in the neighbourhood of the vitelline membrane. It is, however, probable that the pus-cells pursue an independent growth for a period, as we have seen to be the case with respect to those yelk-cells which were far removed from the vitelline membrane. It is also most likely that the nuclei of the pus-cells are their first formed part, but I have no investigations on the subject. The more healthy the pus, the greater is its plastic force, and the greater the number of cells which are formed in it, so that in healthy pus the quantity of serum is very small in comparison with the number of cells.

I cannot state whether the oil-globules which are present in certain secretions, such as milk and chyle, are contained in cells or not. I have not been able to detect anything indicating that they are so in milk; and, according to the theory of the secretions, which will be communicated at a subsequent stage of the work, there does not appear to be any necessity why they should be so.

The low grade of development held by the class of cells now under consideration, in which those elementary formations retain their greatest degree of individuality, is indicated by the fact that it presents so very few modifications. The mucus-, pus-, and lymph-corpuscles are small round cells with a nucleus attached to their walls. According to Henle, mucus- and pus-corpuscles cannot be distinguished in any way from one another, and those of lymph differ from them only inasmuch as their nucleus is more round and granulous, and does not crumble under the action of acetic acid. No difference exists between them in the form of the entire cell. The blood-corpuscles present a higher degree of development in this class. In them we not only find very characteristic cell-contents, the red colouring matter, but the form of the cell also undergoes an important alteration, inasmuch as it becomes flattened. As this flattening takes place in cells which float free in a fluid, it cannot be explained as the result of mechanical causes, but must manifestly be regarded as a peculiar stage of development of these cells. The nucleus is persistent in all these cells, whilst in those more highly developed it usually disappears at some subsequent period. Throughout this class the cytoblastema is a fluid; and it is present in greater quantity than we shall find to be the case in the next class. If the egg be included in this class, we have yet another peculiarity in the cells to be added to the above; viz. that not only have the separate yelk-cells cell-contents consisting of distinct granules, but that the development of the yelk-cells within the yelk considered as *one* cell, is a formation of cells within cells, and in some of these cells even a second enclosure takes place. This peculiarity, however, is one which may almost be said to stand in inverse ratio to the importance of the tissue. It is most frequent, perhaps indeed universal, in vegetables, occurs more rarely in animals, as in the egg, crystalline lens, cartilage, and so on, and appears to be altogether absent in the higher structures, as areolar tissue, muscle, &c. We have already discussed the other peculiarities of the cells of the egg. In the following class we shall not only find a greater change in the form of the cells from flattening, but we shall also become acquainted with many other different modifications of them.

CLASS II.

Independent Cells united into continuous Tissues.

This class presents us with the greatest similarity between animal and vegetable structure, and, indeed, in so high a degree, that even an experienced botanist cannot distinguish some of the objects which belong to it from vegetable tissue. Most animal cells may be distinguished from the mature vegetable cells by their greater softness and delicacy; but those characteristics are in some measure wanting in this class, and it would be very difficult to distinguish microscopically between a thin layer cut off from the interior of the shaft of a feather and a portion of vegetable tissue. We shall, therefore, take the feather as our example, and endeavour to trace these cells, which correspond in so striking a manner with vegetable tissue, backwards to their primitive condition, explaining this transition by delineations, and in this way convince ourselves that, in their early stage, they also accord with the primitive cells of all other tissues. The tissues comprised under the term *horny* belong to this class, and the crystalline lens may also be included in it. The cells of these tissues generally remain independent, but more or less intimate blendings of the cell-walls with one another also occur in this class. Horny tissue may be reduced to two unessential subdivisions, viz.—1. Its membranous expansions, to which belong the Epithelium, in the extended sense of the term (including the Epidermis), and the Pigmentum nigrum, which must be enumerated here, in consequence of its intimate alliance with the epithelium. 2. The compact horny formations, including the Nails, Claws, Hair, Feathers, &c.

1. *Epithelium.*—It is very difficult to determine what this term ought to comprise. The cortical substance of the chorda dorsalis, which is composed of flattened hexagonal cells (in the larva of Rana esculenta, for example), cannot be regarded as epithelium, since it is made up of the same cells as those of the interior of the chorda dorsalis: the sole difference consisting in

their being flattened. The serous layer of the germinal membrane also cannot well be considered to be epithelium, although it has the same structure, and yet it is difficult to give a definition of it which shall not comprise these structures. We shall not, however, enter upon this contention about mere terms, but proceed to the consideration of the structure of the epithelium.

The simplest form of epithelium is that of the round cells furnished with a nucleus which lies upon the inner surface of their wall, and encloses one or two nucleoli. When in connexion they assume a polyhedral form, but their free surface usually projects in the form of a segment of a sphere. Such is the appearance presented by the epithelium in many situations; I instance only that of the branchial rays of the fish by way of illustration. The cells are usually smaller and more granulous in mammalia; but in the lower animals and in the fœtal stage of mammalia they are, in general, larger, smoother, and sometimes so transparent as to be visible by a subdued light only. I once had an excellent opportunity of observing the epithelium upon the mucous membrane of the stomach of a fœtal sheep, and its perfect resemblance to the parenchymatous cellular tissue of plants. A minutely granulous deposit may often be observed in the interior of the transparent epithelial cells; in those of the branchial rays of the fish, for instance, it appears to be formed in the neighbourhood of the nucleus. According to Henle, two nuclei never occur in an epithelial cell in mammalia; but I have several times observed that number in the external covering of the tadpole, and on one occasion I remarked that a perfectly developed epithelial cell furnished with a nucleus was enclosed within a larger cell. Changes in form from this rudimentary globular shape occur in the epithelial cells in two different manners; they either become flattened into tables, or prolonged into cylinders. The flattening out into tables takes place in such a manner that the nucleus forms the centre of one surface, as in the blood-corpuscle. I have observed the stages of transition from the globular to the tabular form in the epithelium of the external covering of the tadpole, which occasionally presented hexagonal flat columns or tables, the thickness of which was about equal to one third of their breadth. The thickness is so very slight in proportion to the breadth in the completely flattened epithelial cells, that it is no longer possible to distinguish the two lamellæ of the cell-membrane. It often occurs that the tabular epithelial cells are not regularly hexagonal, but represent flat elongated stripes, a fact which has been observed by Henle in the epithelium of the vessels.[1] The cells which are prolonged into cylinders con-

[1] During several years past I have occasionally observed an innermost apparently structureless layer in different parts of the vessels, and as the elastic fibres of the middle coat of arteries become gradually more and more minute towards the interior of the vessel, and at length are scarcely perceptible, I regarded the layer above described as analogous to the middle arterial coat, in every respect but the possibility of discovering fibres in it. I explained certain scattered spots which occurred in it, by analogy with the middle and external coats of vessels. Lamellæ, for instance, were occasionally present, in which the elastic fibres had coalesced more or less intimately, and only a trace of a fibrous arrangement remained. In such instances there is seen a table composed of elastic tissue, perforated at different spots; I regarded those spots as openings which might perhaps be filled with some foreign substance. Purkinje and Räuschel (de Arter. et Venar. Structurâ) acknowledged the accordance of this membrane with the middle arterial coat, but distinguished it as a separate layer. Valentin denied that accordance, and described it as a peculiar structureless membrane. Henle was the first to explain its true relations. By his mode of scraping the internal surface of the vessels he obtained scales, which, from our present more accurate knowledge, we now recognise as epithelium. They were sometimes converted into lamellæ. There cannot in fact be a doubt about the correctness of this explanation, when the vessels of the fœtus are examined. I obtained by scraping, both from the larger veins and heart of a fœtal pig, large lamellæ of the most beautiful epithelium, consisting of flat stripes, which were nearly as long again as broad, and contained a very distinct and, in proportion to the size of the scales, large nucleus, with one or two nucleoli. I could not succeed so well in the few attempts which I made on arteries; probably the scales separate more readily from one another in them, and can then no longer be distinguished from the primitive cells of the elastic coat. The cells probably coalesce more or less intimately at a subsequent period, so as to form what is then a partially structureless layer, and the nuclei also disappear in part. I now conjecture that the above-described spots upon the inner coat may probably be persistent nuclei; I have not, however, made any new investigation upon the subject. With respect to the situation in which the one or other form of epithelium occurs, I refer to Henle's very complete treatise (Müller's Archiv, 1838, Heft 1). In addition to the parts mentioned by Henle, I have found epithelium upon the internal surface of the amnion in the fœtus of mammalia and man, where the hexagonal scales were very large and beautiful, enclosing a very distinct nucleus and nucleolus. Amongst those in the fœtal pig were some larger round cells, furnished with a larger nucleus without a nucleolus. The inner surface of the portion of the allantois projecting from the chorion in the same fœtus was also lined with tesselated (tabular, scaly) epithelium consisting of small scales. The external surface of the chorion was formed of cylindrical cells closely packed together, and provided with a nucleus, being similar to the epithelial cylinders of the intestinal mucous membrane discovered by Henle.

stitute the other modification in the form of the epithelial cells. They were discovered by Henle in the intestinal mucus-membrane. They likewise enclose the characteristic nucleus, and are arranged with their longest sides in apposition. Their blunt ends are turned outwards and free. The opposite end either terminates abruptly also, as in the chorion, or proceeds to a point. This tapering figure frequently commences at the upper part, so that the cells then have the form of a pointed cone, the base of which is turned towards the outside. Henle found that the cilia stand upon the free surfaces of the epithelial cylinders in those membranes which present the phenomenon of ciliary motion, a fact of itself sufficient to show that the epithelium ought not to be regarded as a mere inanimate covering to the organized structures.

With regard to the formation of the epithelial cells, Henle has already proved the rete Malpighii to consist of round nucleated cells, probably the young epidermal cells, and also that the diameter of the cells increases towards the outside, so that in the fœtal pig he was enabled to trace the gradual transition of the cells of the rete Malpighii into those of the epidermis. (Symbolæ ad anatomiam villor. intest., p. 5.) An actual growth of the epithelial cells thus became very probable; I have likewise followed this process in the fœtal pig. The uppermost layer of the epidermis is there formed of large, tabular, hexagonal cells, furnished with a nucleus. Immediately beneath these lie nucleated cells, which are already much smaller, and almost round, so that the flattening must take place very rapidly. The farther you proceed from the surface the smaller the cells become, and the closer they encompass the nucleus. The size of the nucleus also diminishes in some degree, but by no means in the same proportion. In the lowest strata, the cells cannot any longer be distinguished, but the nuclei lie close together, with a small quantity of minutely granulous intermediate substance. It is, however, very difficult to obtain positive conviction of this fact, for the stratum of nuclei is too firmly connected with the cutis. We shall have an opportunity of observing this relation of the nuclei more distinctly hereafter in the feather. The mode of formation is probably this: cell-nuclei are formed, in the first place, immediately upon the surface of the cutis; and then around, and closely encompassing them, the cells.

The cells and the nuclei (the latter, however, in a much less proportion) increase in size, and at length those in the uppermost layers become flattened in such a manner that the nucleus forms the centre of the table. This, then, is but a repetition of the same course of development observed in most other cells. Before I had proved the universal accordance between animal and vegetable cells, Henle thought that the original increase in volume of the epithelial cells might possibly be explained as taking place by imbibition. (l. c., p. 9.) As, however, we have observed this growth to be a phenomenon which occurs in all animal cells—as we have seen the formation of cells around the nuclei—as a chemical change in the cell-membrane may be proved to take place during the expansion of many of the cells, and as it frequently happens that not only does no thinning of the cell-membrane occur during expansion, but that an actual thickening takes place, all which are processes similar to those of plants—we must ascribe a peculiar vitality to the animal as well as to the vegetable cells, and explain this expansion of the epithelial cells, like as we did that of plants, as a growth by intussusception. The new epithelial cells, it is true, are formed immediately upon the cutis only, where the greatest vital energy prevails; but the cells expand independently, and grow by intussusception. I have brought forward an instance in which a young epithelial cell was formed within another in the tadpole. But this is certainly a very rare circumstance, and the majority of epithelial cells, in all the vertebrate animals, are certainly not formed as cells within cells, but on the outside of the cells in a minimum of cytoblastema, which is exuded from the cutis. It might be objected that this process of formation of the epithelium could not be possible, for the reason that, if the cells of the second stratum were twice as large as those of the first, then the whole layer of epidermis must be also twice as large as the first. But this objection may be easily set aside by the fact that the cells slide upon one another, and a double or triple layer of cells may thus originate from one stratum of nuclei.

2. *The Pigmentum nigrum.* The pigment is familiarly known as being usually contained in round or (in consequence of their close apposition) hexagonal cells, in the form of innumerable

very minute granules, which exhibit a lively molecular motion. This motion may sometimes be observed even within the cells, so that the rest of their contents must be fluid. As it is also known, that the pigment-granules may sometimes be pressed out from the cells, no doubt can exist respecting the cellular nature of these bodies, formerly called pigment-globules. The wall of the pigment-cells exhibits a nucleus, which is already familiar to some observers. It may be seen in the fœtal condition of the pigment cells of the choroid coat in mammalia, at different points in that of the very young fœtal pig for instance, quite distinctly; and it occasions the well-known white spot in the centre of the cells. It commonly contains one or two nucleoli. It sometimes happens that no pigment-granules are deposited around the nucleus, but that it is surrounded by a clear, transparent areola.

Some pigment-cells undergo a most remarkable transformation, and one which acquires an especial importance, from the fact that it serves as a type of formation for other more important classes of cells. This transformation consists in the cells being elongated on three or more sides into hollow fibres. These we shall name stellated cells. It has, indeed, been necessary to allude to them already when treating of bone. The characteristic contents of the pigment-cells render them best adapted for an accurate examination of this type of formation. The stellated pigment-cells, known under the name pigment-ramifications, are best observed in the skin of the tadpole. They exhibit varieties in form; we select for our description such of them as present the longest fibres. (See plate II, fig. 9.) Their appearance is that of separate black spots, from which slender black fibres issue on different sides. The black spots represent the bodies of the cells filled with pigment; the fibres are the prolongations of the cells filled with the same material. The separate pigment-granules may be distinguished in many situations. The body of the cell, which is sharply defined on its exterior, sometimes presents a clearer spot of a round or oval form, through which the cell-nucleus glimmers, and in some few instances can be distinctly perceived with its nucleolus. The diminution of the cell in various directions, in order to pass over into a fibre, is so gradual that there is no defined limit between them. The fibres pass between the cells of the epithelium, and are therefore frequently curved: they are in general thickest in the neighbourhood of the cell, and diminish as they proceed from it; but they sometimes also swell out slightly at some distance from the cell. These fibres give off others at different points. The presence of the cell-nucleus, and the fact that all the stages of transition from indubitable pigment-cells to these bodies may be demonstrated, are sufficient evidence that these black spots, with the fibres proceeding from them, are actually cells, and that the fibres are hollow prolongations of them filled with pigment. These transitions are delineated in plate II, fig. 8, just as they existed close together in another part of the tail of a tadpole: *a* is an indubitable pigment-cell, scarcely differing from an ordinary one; it has also its nucleus. The only circumstance which distinguishes the majority of the primitive cells of these stellated pigment-cells from common pigment-cells is that they are generally smaller, and more closely filled with pigment. *b* is a smaller cell, which has commenced to taper; and *c* is distinctly elongated into a fibre. A slightly clearer spot is the only indication of the nucleus in both instances. *d* and *e* elongate at both ends into fibres, one of which (the upper end of *d*) terminates in a knob with a defined outline. At the spot where this knob unites with the body of the cell, a shading, indicating a cavity, may be clearly perceived, the pigment being more closely deposited in the neighbourhood of the cell-wall than in the centre; and lastly, *f* is a cell which elongates into fibres on three sides. When a small piece of the skin of the tadpole is torn in water, separate portions of these pigment-fibres, or prolongations of the cells filled with pigment, may be observed to float about isolated. Instances sometimes occur in which one of these pigment-fibres passes uninterruptedly from the body of one cell to that of another; for example, fig. 9, *a*. We may imagine this to be effected by the prolongations of two cells meeting at one point. As the pigment does not move from one cell to another, we cannot accurately determine whether the partition-walls become absorbed at such a point or not. Such, however, may be supposed to be the case, otherwise an interruption of the pigment corresponding to the double thickness of the cell-wall must be seen at the spot where the prolongations are in contact. The fibres issuing from the cells often become very minute in the last part of their course, from which we learn that the delicacy of fibres does not preclude their being hollow.

3. *Nails.*—In order to investigate the structure of the nail we should make use of that of a child immediately after birth, or, what is better, that of a mature, unborn, human fœtus; such an one, when divided into delicate longitudinal sections, will be found to consist of laminæ deposited one upon another, surface to surface. This laminated arrangement, however, becomes more and more indistinct upon the under surface of the nail which lies upon the skin, the nearer we approach to that portion contained in the fold of skin at the root, and the posterior half of the part which is embedded in that fold exhibits no laminated structure whatever, but consists of small polyhedral cells, many of which present perfectly distinct cell-nuclei. When a small portion is cut or torn off from the surface of such a nail, the form of the margins, which present smooth angular projections, leads at once to the supposition that the laminæ of the nail are not structureless, but produced by the junction of little scales resembling those of epithelium. When treated with acetic or concentrated sulphuric acid, the scales separate more readily, and in some rare instances an indistinct nucleus may be recognized in them. No such scales can be seen in the root of the nail after the adherent lamella of epidermis has been scraped off, but polyhedral cells, which are much smaller than the scales, are found in that situation. Now it is a well known fact that the nail increases from its root, and is constantly pushed forwards. The polyhedral cells of the root must thus, therefore, become transformed into those scales by flattening and extension of their superficies, a process which the independent vitality of the cells renders easily conceivable. The cells of the nail already formed increase in size from the same cause, and the growth of the nail by no means depends upon a mere apposition at its root, although it is probable that the formation of new cells takes place in that situation only where the nail is in connexion with the organized skin. The nail would certainly be pushed forwards by the extension of the superficies of those cells,

and by their flattening in reference to its thickness, but the more the cells become flattened, the thinner must the anterior part of the nail become. This probably is compensated for, by a formation of epithelium-scales upon the under surface of the nail, and especially at its posterior part. If, for example, an epithelium-scale become attached to the most posterior part of its under surface, it will be advanced somewhat forwards by the flattening of the cells above, and the formation of new cells at the end of the nail. At that part, however, a new scale is next formed, and laid upon the former one, and as the advance forwards goes on, a third and fourth are formed, and so on, so that, by this means, a thickening of the nail must take place proportionate to its advance from behind forwards. I consider, therefore, that this thickening of the nail, in consequence of growth from the under surface, and the thinning consequent upon the flattening of the cells, compensate each other, and that the almost uniform thickness of the nail is produced by this means. The superficial laminæ of that part of the nail which lies external to the fold of skin at all events do not continue to grow. I marked several nails with two points, by boring them with a needle and colouring the spot with nitrate of silver; the marks were made at the root of the nail, some in the longitudinal, others in the transverse direction. In the course of two or three months they had advanced to the point of the nail, but their distance from each other had not altered in the least.

4. *Hoofs.* The horny tissue of hoofs, in the fœtus at least, consists entirely of the most beautiful vegetable-like cells. If a thin transverse lamella be cut off from the hoof of a large fœtal pig, the preparation will present the exact appearance of vegetable cellular tissue. The following facts prove that the cells are not flat: in the first place, when the side walls do not stand quite perpendicular, they may be traced down below the level of the section, and the depth to which they go may be estimated; and secondly, longitudinal sections of the horny tissue of hoofs present a similar appearance to those made in the transverse direction. They are, therefore, polyhedral cells, and some of them, at least, contain a distinct nucleus.

When the tissue is quite fresh, it is not possible to distinguish the particular wall of every cell. But when the fœtus has lain for a time in strong spirit, the horny substance of the hoof may be easily separated from the foot, in consequence of the connexion between the cells having become looser. The undermost layers of cells, however, remain attached to the foot. The interior of the layer of horny substance so separated, consists of a crumbling mass, somewhat resembling a boiled yelk. The particles cannot, however, be separated quite so readily from one another as those of the yelk are. With the aid of the microscope, this mass is found to be composed of irregularly angular bodies, resembling the yelk-substance when boiled. These bodies are the isolated cells, whose peculiar walls are distinctly perceptible, and some few of them have a nucleus, which lies upon the inner surface of their wall. A continuous firm layer of flat epithelium-scales, the immediate continuation of the outer lamellæ of the epidermis, consisting of flat cells, surrounds these polyhedral cells as an external covering to the entire hoof. This lamella exists in the fœtal pig at a very early age, the layer of polyhedral cells being at that time very slight; in a more advanced stage of development, however, the latter forms the chief mass of the horny substance of the hoof. In the recent condition these cells must also have somewhat firm contents, otherwise, with so delicate a cell-membrane, the substance could not be so firm. But its elasticity was such as to prevent my crushing one of the cells with the compressorium, my object being to observe whether the cell-contents would flow out, or be torn like a firm substance. As the cell-contents form a large portion of this horny substance, whilst the nails consist for the most part of flat cells without any discernible contents, almost entirely therefore of cell-walls, a chemical distinction may be presumed to exist between the two structures.

5. *Feathers.* The feather is composed of the quill, the shaft, and the vane, or beard. The elementary structure of these parts is, however, what most interests us at present; and in order to investigate it, at least in order to become acquainted with the relation which the different elementary formations in the feather bear to cells, we must take one in which a part of the shaft is in progress of formation. The feathers at that

time are surrounded by a dense capsule, which is composed, throughout its entire thickness, of gigantic tabular epithelium. The feather is so placed in this capsule, that the shaft and vane are folded together to form a hollow cylinder, which is occupied by the so-called organized matrix of the feather (see an article on this subject by Fr. Cuvier, in Froriep's 'Notizen,' No. 317). According to Cuvier, a membrane lines the inner surface of the vane, and gives off septa, which penetrate between its separate barbs. This membrane, however, as well as the septa, is composed of epithelium.

The shaft of the feather consists of a loose medullary substance (the pith), surrounded by a firm cortex. On making thin transverse or longitudinal sections of the pith, it is seen to be composed of beautiful polyhedral cells, which perfectly resemble the parenchymatous cellular tissue of plants,—as the substance of cork for example. (See plate II, fig. 10.) The cell-cavities which have moderately thick, dark partition-walls, are at first filled with a transparent fluid, but subsequently become dry, and in that state contain air. Notwithstanding, however, that this pith so precisely resembles vegetable tissue in its general appearance, it may be questioned whether these cells be actually cells in that sense of the word in which we receive it here, viz. elementary cells of organic structure, and whether they correspond to vegetable cells. It therefore becomes necessary to investigate whether each cell has its peculiar wall, and whether the course of development of each individual cell be the same as in plants. There is no structure, however, in which it is easier to follow the process of development than in the one before us, chiefly because the cells, even from the first, have no connexion with the organized so-called matrix, but remain attached to the fully-developed cells of the shaft, when the matrix, which terminates externally with a smooth surface, is taken away. The following description is taken from the large wing-feather of a raven: it applies however equally well to the feathers of the young chicken.

The pith, when in progress of formation, is soft and friable. When a small portion of it is examined, after the component particles have been separated asunder, it is found to consist of cells, in various stages of development. Those which are most completely developed resemble the cells which we have seen in the mature feather (see plate II, fig. 11, *a*) in every other respect, but that they lie less firmly connected together, so that they may readily be isolated, and the peculiar wall of each cell be distinctly seen. The walls are of sufficient thickness to prevent their losing their angular shape, even when in the isolated state. There are intercellular spaces between some of them, and such also occur between the fully-developed cells of the perfect feather. The cell-membrane is dark and smooth, and the cell-contents consist of a transparent fluid. A very distinct nucleus is also seen lying upon the wall of each cell. It is oval, and contains one or two nucleoli, which are large in proportion to its size (see the figure). There is no nucleus to be seen in the fully-developed cells, and it is only in very rare instances that its remains can be detected; it must therefore undergo absorption at some subsequent period. The process may, indeed, be followed; for example, the cells which form the stages of transition between those delineated in fig. 11 *a*, and fig. 10, are more closely connected together, the nucleus in them becomes smaller, and its outline more irregular, the nucleolus meanwhile remains; at length both disappear. The degree of development attained by the cells is generally proportionate to their distance from the matrix; and as that is situated on the inner side of the feather, at the part where the shaft exhibits a furrow, those cells which lie immediately under the cortex, at the back of the shaft, are the most perfectly developed. Now the cells when traced from that part inwards towards the matrix, are found to become gradually smaller; the cell-membranes lose their dark outlines, and present a granulous aspect. The nucleus of the larger granulous cells has still the same form as in those previously described with a smooth cell-membrane; its size, however, diminishes with that of the cell. The cells in this granulous condition resemble most of the elementary cells of other tissues. Plate II, fig. 11, *b*, *c*, represents the stages of transition. Advancing still nearer towards the matrix, the cells are no longer recognizable; all that we can see being numerous nuclei, which lie close together in a minutely-granulous substance (plate II, fig. 12).

The process of formation of the cells of the pith is, therefore, as follows: a minutely-granulous mass is present in the first instance, in which numerous cell-nuclei lie, some of them exhibiting a nucleolus. Around them the cells are formed, being at first not much larger than the nuclei, and having a granulous aspect. The cells gradually expand; the nucleus also grows, and soon reaches its full maturity. It remains eccentrical, lying upon the cell-wall. The cell-membrane retains its granulous aspect for a time; gradually losing it, however, as the expansion of the cells advances; at the same time the contents of the cell-membrane become darker, but the cell-walls are not at all diminished in thickness. The walls of the cells, in the next place, become more firmly united together, so that they cannot be separated from one another so readily, and at the same time the nucleus gradually disappears. The contents of the cells at last dry up, and they become filled with air. The development of these cells accords, therefore, entirely with the vegetable cells, the nucleus being their true cytoblast; it is present before the cell, and, as is generally the case in the cells of plants, afterwards becomes absorbed. The cell expands, growing by intussusception, and the membrane of the fully-developed cell might, without much danger of error, be assumed to be more than ten times heavier than that of the youngest one. The physical, and probably also the chemical, condition of the cell-membrane undergoes a change. The cytoblastema, in which the cell-nuclei are in the first place formed, consists of granules, analogous to the mucus-granules, in which, according to Schleiden (Müller's Archiv, 1838, plate III, fig. 2), the cytoblasts of vegetable cells originate. According to Schleiden, those mucus-granules are deposited from a solution of gum within a parent-cell. The cells of feathers are not formed in parent-cells, but in the neighbourhood of the organized matrix. There can be no doubt, however, but that the matrix only exudes a fluid, which afterwards becomes transformed into a granulous substance. I have not investigated the mode in which the nuclei originate in the cytoblastema, whether by a junction of smaller globules, whether the nucleoli first exist, and so forth. The growth of the nucleus proceeds for a time with that of the cell; for the latter is formed around the nucleus before it has reached its full size. The cytoblastema of the cells of the pith of the feather is supplied by the nearest contiguous substance provided with vessels, that is, by the so-called matrix. In the young feathers of the hen, however, I found a layer of very small, extremely pale, round cells without nuclei,—a sort of imperfect epithelium,—between the matrix and the granulous cytoblastema, so that not even so much as an immediate contact exists between the latter and the organized substance.

The cortical substance of the shaft of the feather is a fibrous structure. Here the Cell-theory seems, at first sight, to fail; but we are soon taught otherwise, when we examine the generation of the fibres as exhibited in the incompletely formed portion of the cortical substance of a feather, which is in progress of formation within the capsule. The cortex is then seen to consist of large flat epithelium-cells, each having a beautiful nucleus, with one or sometimes two nucleoli. Some of these epithelial tables are long flat stripes, others are of an irregular rhomboidal form. They are very firmly connected together. Each cell generates several fibres, and the transitions may be readily observed at different parts of the same preparation. Plate II, fig. 13, represents them. The cells at first are flat tables, having a smooth margin, a slightly granulous aspect, and containing a very distinct nucleus (fig. 13, *a*). Upon their margins and surfaces indistinct fibres gradually become visible, which project out insulated from the edges, but are connected together upon the surface by the substance of the tables (fig. 13, *b*). At this stage the fibres are pale, and the nucleus of the cell still quite visible. The fibres afterwards become more sharply and darkly defined; the insulated portions projecting from the edges are larger, the part of the table connecting them together becomes more indistinct, and the nucleus begins to wane, although it is still distinctly perceptible, and the nucleolus especially so (fig. 13, *c*). At length all traces of the original cell and the nucleus disappear, and we see only dark, stiff, thin fibres, which are closely connected together but may still be recognized as being insulated for a space, the length of the original table (fig. 13, *d*). These fibres, therefore, also originate from cells, and that not so much by an elongation of the cells, as by their division into several fibres. As the fibres which lie close together in the first instance, do not, as it seems, continue connected with one another, a portion of the original table must be absorbed, and the following may therefore be conceived to be the mode in which the fibres originate. After the two laminæ of the table are in part or entirely blended together, an absorption takes place at certain parts, in such a manner, that the portions not absorbed lie in longitudinal lines, and thus remain as fibres. The reality of an absorption is, moreover, distinctly shown by the disappearance of the cell-nucleus. We have no evidence as to whether the fibres are hollow or not; it is sufficient for our purpose to know that they originate by a transformation of cells.

The quill of the feather has a similar structure to that of the cortical substance of the shaft.

The vane is composed of separate barbs, and each barb is again a miniature feather. The following description is taken from the undeveloped wing-feather of a sparrow. Each barb contains a secondary shaft, on the side of which is placed a secondary vane. The secondary shaft has the same structure as the principal one, and consists of a cellular medullary substance (pith), and a firm cortex. The secondary vane is composed of a great many triangles, which lie with their surfaces close together, having very narrow bases by which they are fixed upon the secondary shaft. Each triangle is formed of flat epithelium-cells arranged with their angles overlapping each other, each having its nucleus. The separate epithelium-cells are broadest below, diminish more and more towards the point, and extend proportionately in length. The nuclei lie in a row, near about the middle line of the triangle. The last cell, at the apex of the triangle, is contracted into a long fibre. The last cell but one, and all the others in succession, become elongated, at the point at which the next following cell is attached to them, into pointed processes, which vary in length, and are extended on both sides of the cells in the plane of the triangle.

6. *The Crystalline lens.* The mode in which the lens is nourished has always been an enigma. Having no vessels, it has either been regarded as a secretion of its capsule, or its

mode of life has been considered as generally resembling that of vegetables. We shall find the latter to be the correct view, and the singularity of the mode of its nutrition disappears altogether, when we become acquainted with the fact, that the growth of the organized tissues resembles that of vegetables. The general statement, that the lens has the vitality of a vegetable, does not, however, express much, unless the relation of its elementary structure to the cells of plants be proved. The lens is known to be composed of concentric layers, made up of characteristic fibres, which, not to go into details, may be said to pursue a general course from the anterior to the posterior surface.

In order to become acquainted with the relation which these fibres bear to the elementary cells of organic tissues, we must trace their development in the fœtus. When the lens of a chick is examined after eight days' incubation of the egg, no fibres are to be found; but it is composed of round, extremely pale, and transparent smooth cells. Some contain the characteristic cell-nucleus, in others it cannot be detected; and there are also many nuclei without surrounding cells. Some larger cells may be observed in the chick at a more advanced period, which contain in their interior one or two smaller ones (see pl. I, fig. 10, *d*, from a fœtal pig), and from the manner in which these cells become flattened against the wall of the parent-cell, as well as from the presence of the nucleus in other cells, we may conclude, that these pale globules are actually cells, although a cell-membrane be not distinctly recognizable. Werneck, who first observed them, likewise calls them cells.

The following conditions of the crystalline lens may be observed in Mammalia. In a fœtal pig, three and a half inches in length, the greater part of the fibres of the lens is already formed; a portion, however, is still incomplete; and there are many round cells awaiting their transformation. The perfected fibres form a sphere in the centre of the lens; but there is no laminated structure as yet perceptible in it. The fibres may readily be separated from each other, and proceed in an arched form from the anterior towards the posterior side of the lens. This sphere, composed of the perfected fibres, becomes surrounded, in the circumference of the lens, with a thick and broad zone of fibres, which are as yet imperfectly developed.

They have much the same course as the others, that is, they form arches from the anterior towards the posterior surface. They do not, however, reach the axis either in front or behind, but the fibrous zone is thickest in the middle, gradually diminishes towards the anterior and posterior surfaces of the lens, and terminates altogether without the fibres meeting anywhere in front, or reaching the axis. No laminated structure can be perceived in the zone; but the fibres may be readily insulated throughout its entire breadth. When the ends of these fibres are examined, they are found to be either simply rounded off, or to terminate in a small round dilatation, or to pass over into larger globules (cells); or, on the contrary, it may be more correctly expressed by saying, that the larger globules or cells become elongated to these fibres (see pl. I, fig. 12). The transition from cells to fibres may either be very gradual or somewhat sudden; but even in the latter case, the contour of the cell passes immediately over into that of the fibre, so that the latter is not merely affixed to the globule, but is a true continuation of it. Now, these cells which become elongated into fibres, perfectly accord with other neighbouring cells which are as yet quite round; and these again accord with the cells forming the greater portion of the lens in the embryo chick. They are round, extremely pale, smooth, transparent cells of very various size (see pl. I, fig. 10). Some have a very beautiful, sharply-defined, oval nucleus, which, in most instances, is not flattened, and which lies upon their wall, and encloses one or two nucleoli. Some cells are scarcely larger than the nucleus which they contain, fig. 10, *b*, for example. Some of these enclose young cells (fig. 10, *d*), and as they may be observed to flatten against the wall of the parent-cell, there would seem to be no question about the existence of a special cell-membrane for the latter, and thus the true cellular nature of these globules appears indubitable. The presence of the nucleus, and the fact of the outlines of the cells being too sharply defined for mere shadows, would, however, have been sufficient to render their cellular character probable. The very distinct nucleoli contained in the nuclei, which are not flattened, lie upon the inner surface of the wall and not in the centre, as represented in fig. 11.

Since, then, the round cells, as we have seen in the chick, form the primary structure of the crystalline lens, and no fibres can be detected in the early stage, and since the more fully-developed lens of the fœtal pig exhibited many fibres and fewer round cells, and at the same time cells which became elongated into fibres, we cannot but regard the fibres generally as elongated cells. It is true that a cell-membrane cannot be distinguished on the fibres, nor can it be distinctly recognized on the round cells. If, however, the arguments above cited rendered its existence in the round cells certain, they must avail equally in the case of the fibres. Nuclei are also frequently found upon the fibres of the fœtal pig. Some of the fibres are flat. I have, also, several times observed an arrangement of the nuclei in rows; but I do not know what signification to attach to the fact. A blending of several cells to form a fibre may also possibly occur; but I have no observations decisive of the point. In fishes also, in a young pike for instance, the elongation of the cells into fibres may often be very distinctly seen.

Brewster found that many fibres of the crystalline lens, especially in fishes, exhibit the remarkable peculiarity of having their margins serrated. Pl. I, fig. 13, represents such a fibre taken from the innermost lamina of the lens of a pike. The fibres are flat, and their sharp margins furnished with long teeth, which are so disposed, that two neighbouring fibres lock into each other by them. We have here an instance of perfect analogy to a form of vegetable cells, which is delineated in fig. 14: it is an epidermal cell of a species of grass. It is very much elongated, quite flat, and furnished on the sides with teeth precisely similar to those of the fibres of the lens, which, in like manner, fit in between the denticulations of the contiguous cells. The fibre-cells of the crystalline lens which are delineated, have somewhat longer teeth in comparison with the breadth of the cell; they represent, however, some of the most strongly denticulated fibres. On pursuing the examination from the external towards the internal laminæ, the same lens will be found to present all possible stages of transition in this serration, from the smooth or only minutely-notched cells, to such as are strongly denticulated like those in the figure. This striking accordance of so remarkable a form of animal structure with a similar modification of vegetable cells, is a brilliant confirmation of the correctness of the view, that the fibres of the crystalline lens are really cells, however much they may deviate from the fundamental type of the cellular form.

There is no longer, therefore, any more difficulty in explaining the process of nutrition in the lens, than there is that of plants. The cells grow by their own independent force, and blood-vessels are unnecessary, as the nutrient fluid can be conducted from one cell into another. A morbid change of the cell-vitality, rendering the cell-contents opaque, is also possible.

The structures included in this class, notwithstanding the strong general resemblance which they bear to each other, have furnished us with far more varied modifications of the cellular form than the previous class exhibited; indeed, these so-called unorganized tissues have already prefigured the type of all the changes by which the organized tissues are developed from simple cells. Here, also, the fundamental form of the cells is that of a sphere, which, in consequence of their close contact, passes over, from mechanical causes, into a polyhedral figure. Two different modifications of this fundamental form occur, which cannot be explained mechanically; they are the flattening of the cells on two opposite sides to form tables, and their elongation in two directions into cylinders or fibres. We have already seen an instance of flattening of the cells in the blood-corpuscles of the previous class. It is not only more strongly marked here in the tabular epithelium, where the cell-cavity is quite obliterated, but a modification even of this form is presented to us in the elongation of these tables on two sides into flat stripes, as seen in the epithelium of the internal coat of veins for example, and still more distinctly in the cortical substance of the shaft of the raven's feather. The epithelium of many of the mucous membranes, that of the intestine for instance, which Henle describes as consisting of little palisade-like cylinders placed close to one another, furnishes us with a rudimentary form of the elongation of cells into cylinders and fibres. Sometimes these little cylinders become acuminated at their lower extremity, or they may diminish throughout their entire length from above downwards, and thus become small cones.

This prolongation of cells into long cylinders (called fibres) is much more remarkable in the crystalline lens. The fibres or cylindrical cells of the lens, however, themselves undergo very important modifications, inasmuch as they often become flattened on two sides into bands, and then the margins of these bands become denticulated. This serration is probably produced by a more forcible expansion, and therefore bulging-out of the walls of these bands at different points, which follow each other at pretty regular distances, whilst the intervening points, situated close to them, remain stationary. All the different stages of this serration, may be observed in the lens of the fish, if the fibres are examined from the exterior towards the centre of the structure. Now, in this flat and serrated condition, the cells of the crystalline lens perfectly resemble those of the epidermis of some grasses, and this accordance with indubitable vegetable cells is a proof that, despite the modifications which they undergo, they do not lose their cellular character. If the explanation I have given of the mode in which the serration is produced be correct, it will not materially differ in principle from the elongation of the cells into cylinders and fibres. For, in the latter case, a more forcible expansion of the cells is likewise presumed to take place in certain situations : the sole difference being, that in the latter case it takes place only at one or two opposite points of a cell, whereas with the serration it occurs at many separate ones. At this stage of our inquiry, we are reminded of the form of many pigment-cells, in which this expansion of the cell, at certain spots, takes place on several sides, and in a far higher degree, causing the cell to assume an irregular stellated form. The prolongations of these cells, however, retain their character as hollow processes, even when almost as minute as the fibres of cellular (areolar) tissue.

The distinction between cell-membrane and cell-contents is nowhere more distinctly defined than in the fully-developed cells of this class. In the perfected cells of the pith of feathers, for example, it is as marked as we ever find it to be in plants. When traced backwards to their earliest stages of development, their true cellular formation scarcely admits of a doubt, although the cell-membrane, for reasons given at page 36, cannot be so clearly distinguished. The elementary cells of the tissues of the following classes, in most instances, do not advance beyond this early stage in the development of the feather-cells, but the changes necessary to the formation of the subsequent tissues occur at this period; their cellular nature is, however, quite as certain as is that of the young feather-cells, although it be not possible to recognize their cell-wall so clearly as in their perfectly-developed condition.

The matter contained in the cells is either a transparent fluid, as in the cells of the pith of feathers previously to their becoming dry, or in the crystalline lens, when it contains albumen; or, a minutely-granulous mass, as in many epithelium-cells, or pigment-granules; or, it is altogether absent, and the cell-walls, in consequence of their flattening, are in immediate contact. The air in the cells of the pith of mature feathers simply penetrates from without, during the process of their desiccation. With the exception of some of the cells of the lens, all the cells of this class are invariably furnished with a nucleus of the characteristic form. It is not, however, a persistent structure, as in the previous class, but in very many instances becomes absorbed when the cells have reached maturity; such is the case in the pith of the feather, the superior laminæ of the epidermis, the nails, crystalline lens, &c. &c.

As a general rule the cells remain independent during all these changes, that is to say, each cell retains its especial wall, and its own peculiar closed cavity. More or less complete blendings of the cell-walls, and even of their cavities also, occur, however, as exceptions even in this class. The epithelial scales of the nail are so intimately connected together, that it is rarely possible to trace the contour of one of them in its entire circumference; and the same appears to be the case with the epithelium in the vessels of the adult. The coalescence, however, does not appear to be perfect, for, by the employment of concentrated acids, the scales of the nail may be separated somewhat more readily from each other. A union of the cavities of several cells seems to occur in the pigment-cells. A prolongation of a cell filled with pigment may be seen to pass uninterruptedly to the cavity of another cell (plate II, fig. 9, *a*). In such an instance, probably, the prolongations of two cell-cavities join at a certain point, the cell-walls unite together there, and the partition-wall becomes absorbed, and thus an uninterrupted passage from one cell-cavity into the other is produced. I am not certain as to whether a similar process does not take place in some fibres of the crystalline lens.

The transformations which the cells undergo are not, however, restricted to those already mentioned. A completely opposite process occurs in the cortical substance of the shaft of feathers, viz. a division of the cells into fibres. By this process, out of a single cell several fibres are generated, which, in the first instance, are united together by the rest of the substance of the cell, but at a later period of development may be insulated to a considerable extent. An elongation of the cells into these fibres takes place, indeed, at the same time, but the major portion of each fibre is formed by the division of the bodies of the cells.

With respect to the formation of the cells of this class, we find it to be a constant rule, that their size increases in proportion with their age, a fact which Henle has already pointed out with regard to the epithelium. We have seen in the different tissues, that the nucleus is first present, that the cell is then formed around it, the nucleus, therefore, being the true cytoblast, and that it holds the same position in these cells that it does in those of plants, being fixed eccentrically upon the internal surface of the wall. Cell and nucleus advance in growth for a time, the former, however, much more vigorously than the latter. The nucleus is generally absorbed after the formation of the cell is completed. The generation and growth of the cells and all the phenomena connected with the nucleus resemble those of the vegetable cells, and we may unhesitatingly draw a parallel between them. In no class is the quantity of the cytoblastema smaller than in this. In the immature state the walls of the cells lie close together, with at the most, but a minimum of intercellular, substance between them at points where three cells are in contact, and it is only between those nuclei, around which no cells have as yet formed, that a somewhat larger quantity of cytoblastema is present.

The class of cells now treated of, and the teeth which will be examined in the following class, have been comprised under the term unorganized tissues, and their growth represented as dependent upon a secretion of the so-called matrix. If by this it is meant that the substance of horn is secreted by the matrix and hardened in the air, the view is manifestly an erroneous one; what we call horny substance being either merely the cell-walls, when, for example, the cells are flat, and there are no cell-contents, or the cell-walls and cell-contents together, when the cells are polyhedral, as in hoofs. All these cells are independent structures, which grow organically. But if, by the above description, it is meant that the organized matrix only furnishes (or secretes) the cytoblastema, no important objection can be raised. The cells of the horny tissue require a nutritive fluid for their growth. This is supplied to them by the blood, as it is in all tissues. As, however, the blood-vessels themselves do not pass between the cells of the horny tissue, the nutritive fluid must be furnished by the nearest substance in which blood-vessels exist, and in this sense the nearest organized substance may be called, matrix. But whether this cytoblastema which exudes from the matrix have a specific character, and on that account horn-cells are formed in it—or whether their formation take place in it for the same reason that the muscle-cells, those of areolar tissue, and so on, originate in other parts of the body, that is to say, whether it is determined by the plan of the entire organism, —is a question which does not as yet admit of a decision. It is, however, a characteristic of all the cells of this class (with the exception of the crystalline lens, which I have not examined in reference to the point), that the new cells are not generated between those already formed, but only in the cytoblastema nearest to the organized substance, if not, indeed, always in immediate contact with it. The teeth were necessarily separated from this class, because, as we shall see hereafter they present quite a different relation of the cells. The new cells of cartilage, so long as it does not contain any vessels, are not only formed upon the surface of the tissue, but also between the most recently-formed cells.

The chorda dorsalis forms the transition from this class to the following one. The cell-walls remain separate in the highest stage of their development, and it is only in their rudimentary forms, in the osseous fishes for example, that they coalesce and exhibit fibres between the cell-cavities. It does not appear to possess any vessels. The formation of new cells goes on at the extremities, for instance, at the point of the tail of the tadpole; it is not, however, limited to the surface, but appears to take place between the most recently-formed cells, for cytoblasts may be observed in the intercellular substance between the cells which have reached maturity. In this respect the chorda dorsalis resembles cartilage, but differs again from it, in that, as Müller discovered, it undergoes no change in boiling water, and also, in that, the nuclei are flat, while those of cartilage-cells are round or elliptical.

If the chorda dorsalis be reckoned in this class, it affords, as we have seen, an example of the generation of cells within cells. A different signification might, however, be ascribed to these young cells within the true cells of the chorda dorsalis, for they do not seem to be formed like their parent-cells, from cytoblasts. A generation of cells within cells takes place also in the lens. In all the other tissues of this class, with few exceptions, the formation of new cells takes place only on the outside of those already existing.

CLASS III.

Tissues, in which the cell-walls have coalesced with each other, or with the intercellular substance.

This class comprises the firmest structures of the animal body, namely, cartilage, bone, and the ivory and osseous substance of the teeth. The following is the type of these tissues in their mature state: they present either a multitude of small roundish cavities in a firm transparent substance, or cavities, from which canaliculi issue out in a stellate form; or again, merely canaliculi dispersed through the tissue with tolerable regularity. The cavities do not communicate immediately with each other; the canaliculi, however, often unite together. A special cell-membrane cannot be distinguished in any of them in the mature condition, but in an earlier stage the cavities may be proved to be cells, that is, hollow spaces enclosed by a peculiar membrane, and the canaliculi are then also seen to be hollow prolongations of cells. The intermediate substance between the cavities is produced in one of the following ways: either the walls of the cells become thickened, and then coalesce to form an homogeneous substance, or, which is much the more frequent mode, the intercellular substance is developed in greater quantity, and a coalescence takes place between it and the unthickened or only slightly thickened cell-walls. I cannot positively assert that a blending of the unthickened cell-walls with the intercellular substance takes place universally: I cannot do so, for instance, with respect to the cartilages of the higher animals, and so far the mere coalescence of the cell-walls is not a certain characteristic of this class of tissues. Should it be found not to prevail universally we must look for a distinctive character in the abundant development of a firm intercellular substance—a peculiarity which is presented by no other class.

1. *Cartilage and Bone.* As these tissues have been already treated of (pp. 15-33), the reader is referred to that part of the work.

2. *The Teeth.* The teeth were formerly classed with the bones, but have of late been treated of as non-vascular structures under the head of horny tissues. Since Miescher's discovery, however, that the vessels of bone also traverse only the medullary canaliculi, since Müller observed that the teeth, like the bones, afford gelatine by boiling, and Retzius discovered osseous corpuscles in the ivory, it seems more correct to class the teeth with the bones again, and the more so, as we now know that the presence or absence of vessels proves no *essential* difference in the growth. The coalescence of the cell-walls which appears to take place in the ivory of the teeth forms an additional reason for our classing them with bone. The teeth, as is well known, consist of ivory, osseous substance, and enamel.

a. The enamel.

The enamel consists, according to Purkinje, of square, or, according to Retzius, of hexagonal closely-aggregated prisms, which stand nearly perpendicular upon the surface of the ivory, and pass outwards in a slightly curved direction. It is at first soft, and if some of it be scratched off in that state, we obtain, what Müller has described as needle-shaped bodies pointed at both extremities. According to Purkinje, Raschkow, and Retzius, some organic substance remains after the young enamel has been treated with hydrochloric acid, whilst Berzelius asserts that the enamel of mature teeth does not contain two per cent. of organic matter. For further details I refer the reader to the excellent works of Purkinje, Raschkow and Fränkel, and those of Retzius, J. Müller, and v. Linderer

If an immature tooth of a child or mammal (the pig, for instance) be removed from its capsule and placed in dilute hydrochloric acid, the organic substance of the enamel which remains after the solution of the earthy matter, may be separated from the ivory entire. It has exactly the form and size of the enamel previous to the action of the acid. It is very soft, and breaks readily in the direction of the fibres of the enamel. Examined with a high magnifying power and subdued light, it is found to be composed, like the enamel itself, of closely-aggregated prisms, which may be insulated from one another, so that each one forms an independent structure. (See pl. III, fig. 3.) This organic substance, therefore, cannot be, as Raschkow and Retzius considered, a mere deposit from the moisture with which the enamel-fibres are at first surrounded, and thus a sort of cast of the enamel-fibres, but either the fibres must result from an ossification of these prisms, or the prisms must be hollow, and the inorganic substance deposited within them. When the enamel of the pig's tooth is examined with a subdued light, the contour of these organic prisms is found to be so dark in comparison with their interior, that it can scarcely be regarded as the mere shaded outline of a solid prism, but suggests the idea of a cavity surrounded by a thin membrane. This distinction is, however, much less striking in human teeth, so that the question as to which of the two views is correct must remain undecided.

What, then, is the process of formation of these enamel-prisms? According to Purkinje and Raschkow, the crown of the growing tooth is surrounded externally by a peculiar membrane, the enamel-membrane, the inner surface of which is composed of short hexagonal fibres, which stand perpendicularly upon the membrane, and are directed towards the enamel, so that each fibre of the enamel-membrane corresponds to an enamel-fibre. On examining a portion of this membrane, particularly that part which lies nearest to the root of the tooth, we readily recognize in it the characteristic nuclei, some of them being furnished with nucleoli. They lie in a minutely granulous substance. This granulous aspect, however, is seen to be produced, in many situations, by granulated cells which contain the nuclei. Each nucleus is surrounded by a circular areola of small granules, and seems to lie in a minutely granulated globule, which we know to be the rudimentary form of most elementary cells. Some of these cells are prolonged into very delicate fibres; they appear to be young cells of areolar tissue; most of them, however, are round. The fibres or prisms of the membrane, which have a direction from its inner surface towards the enamel-fibres, have assumed an hexagonal form, which Raschkow attributes to their close contact. They very closely resemble the columnar epithelium upon mucous membranes, only that they are prismatic in their entire length, that is, so far as they project out from the membrane to which they are attached. I am inclined therefore, to regard them as merely elongated cells. In the recent state they also contain a very distinct nucleus, which encloses its nucleolus. (See pl. III, fig. 4.) In the upper part of the enamel-membrane they lie quite close together; but in the portion nearest to the root of the tooth, they diminish in number and stand insulated, so that at this part the structure of the membrane beneath them may also be recognized, and I suppose the round cells before mentioned to be the earlier condition of these prismatic cells. What, then, is the relation which these prismatic cells of the enamel-membrane bear to the prisms of the enamel?

Purkinje and Raschkow regarded each fibre of the enamel-membrane as an excretory organ, a little gland which secreted the enamel-fibre corresponding to it. With our altered views of the growth of unorganized[1] tissues, however, this explanation, previously so plausible, loses much of its probability. Various other explanations might be offered in place of it, but I have not made sufficient observations to enable me to decide upon the correct one. Firstly, one might suppose the organic basis of the enamel-prisms to be cells, which are formed, and continue to grow independently upon the dental substance, having no other connexion with the prisms of the enamel-membrane than that the latter furnishes their cytoblastema. This explanation, however, would compel us to regard the remarkable accordance which exists between the prisms of the enamel-membrane and those of the enamel as an accidental circumstance. But we should be obliged to adopt such a view, if it could be proved that another peculiar substance intervened between the enamel-membrane and the enamel, and I have several times observed such an one on the molar teeth of swine. It is very soft and full of vesicles, having the appearance of a slag. I think Purkinje mentions it also, but I cannot find the precise passage at this moment. It lay between the enamel-membrane and the tooth, but I am not certain whether it was also present at those points where the formation of the enamel had already commenced, and whether, therefore, it actually interrupted the continuity of the enamel-membrane with the formed enamel. We might suppose, as a second explanation, that the enamel-prisms are uninterrupted continuations of the prisms of the enamel-membrane, which become filled towards one end with calcareous salts. This is a very improbable explanation, and the connexion between the two structures is of too loose a nature to warrant its adoption. A third, and as I am at present disposed to think the most probable, explanation is, that the prismatic cells of the enamel-membrane separate from it, and coalesce with the enamel already formed, while at the same time their cavities either become filled with calcareous salts, or they become ossified throughout their entire thickness, their cavity being previously filled with an organic substance. This explanation makes the formation of the enamel accord with

[1] [The author appears to use this word as synonymous for "non-vascular."—TRANS.]

the growth of the other unorganized tissues treated of in the previous class. If we suppose, for example, that the little cylinders (columnar epithelium) of the mucous membranes (which, according to Henle, are constantly being thrown off) could become ossified at the moment when they separated from the surface of the mucous membrane, we should obtain a covering to the membrane, consisting of little calcareous cylinders, each of which, however, would still have its organic basis like the enamel-fibres. Beneath this covering would be other cylinders not as yet ossified, which, when they in like manner became calcified would add to its thickness, whilst new cylinders grew forth from the mucous membrane. The quantity of the organic basis is extremely small in the teeth of adults which have been exposed for a considerable time to the action of the saliva, a circumstance which I suppose to be referrible to its undergoing a chemical solution in that fluid.

b. The ivory.

This is known to consist of a structureless[1] substance, traversed by a great many minute canals. These canals (tubes) have for the most part a radiate course from the cavity of the tooth towards its external surface, and, according to Retzius, often give off branches as they proceed. Their peripheral terminations are extremely minute; they are thicker towards the dental cavity, and, when the pulp is removed, open freely into it. Müller observed that the tubes projected beyond the intermediate substance from the fractured surface of thinly-ground laminæ, and of lamellæ which had been macerated in hydrochloric acid, and were surrounded therefore by a special membrane; Retzius also remarked the same upon a transverse section. Purkinje and Müller noticed that when teeth are placed in ink, the fluid penetrates into the tubes; they must therefore be hollow. If any of them contain calcareous matter, it must be only the most minute ones. According to Retzius, many teeth present corpuscles which resemble those of bone, and like them send forth minute radiating canaliculi.

[1] See note to page 39.

What relation then does the ivory bear to the cells? I must at once avow that I cannot give a positive reply to this question, and that I only communicate the following imperfect investigation for the sake of presenting a connected view of my subject. The formation of the dental substance is described by Purkinje and Raschkow as follows: "Primordio substantia dentalis e fibris multifariam curvatis convexis lateribus sese contingentibus ibique inter se concrescentibus composita apparet. . . . . In ipso apice istæ fibræ æqualiter quamcunque regionem versus se diffundunt, attamen parietes laterales versus directio longitudinalis prævalet, dum fibræ sinuosis flexibus æqualique modo se invicem contingentes ibique ubi concavæ apparent lacunas inter se relinquentes, ab apice coronali radicem versus ubicunque procedunt. Non nisi extremi earum fines tunc molles sunt ceteræ autem partes brevissimo tempore indurescunt. . . . . Substantiæ dentalis formationis secundum crassitudinem processus pari modo ac primo ejus ortu cogitandus est. Postquam . . . . . fibrarum dentalium stratum depositum est, idem processus continuo ab externa regione internam versus progreditur, germinis dentalis parenchymate materiam suppeditante. . . . . Convexæ fibrarum dentalium flexuræ, quæ juxta latitudinis dimensionem crescunt, dum ab externa regione internam versus procedunt, sibi invicem appositæ continuos canaliculos effingunt, qui ad substantiæ dentalis peripheriam exorsi multis parvis anfractibus ad pulpam dentalem cavumque ipsius tendunt, ibique aperti finiuntur, novis ibi, quamdiu substantiæ dentalis formatio durat, fibris dentalibus aggregandis inservientes." (Raschkow, *Meletemata circa Mammalium dentium evolutionem.* Vratislav. 1835, p. 6.)

I must admit that I do not clearly understand some of this description, but if I rightly comprehend it, the dental substance originates from fibres which are formed in strata around the pulp (the latter supplying the material for the purpose); that these fibres then coalesce, leaving, however, spaces between them which are the dental tubes. Since, according to Müller, the tubes are furnished with special walls, we can no longer regard them as mere spaces between the fibres. His observation, however, does not affect the explanation of the formation of the firm substance.

If a tooth be removed from its capsule, and macerated for some days in slightly diluted hydrochloric acid, the dental substance, which on the first withdrawal of the calcareous salts possessed a cartilaginous consistence, becomes so very soft that it can only be removed from the acid in very small portions with the forceps. This pappy mass is found on examination to consist of fibres, which may here and there be insulated. (See pl. III, fig. 5.) These fibres are too thick to be the walls of the tubes; they form the entire substance. Nor can they well be an artificial product, the result of the acid penetrating into the tubes, and dissolving, in the first instance, the substance in immediate contact with them, so that the intercellular substance remained undissolved in the form of a fibre; they are too regular and smooth for that. It appears rather that the dental substance is composed of these fibres, which have become blended together, that they are therefore identical with those fibres, by the coalescence of which, according to Purkinje and Raschkow, the dental cartilage is formed, and that this coalescence is not so complete, but that it may be artificially dissolved. The fibres have the same course as the tubes in human teeth, but I could no longer perceive the tubes between them in this preparation; I could, however, recognize the fibres everywhere, save in the most external layers which lay immediately under the enamel, in which situation the mass was more completely broken down by the acid, and traversed by more minute fibres of a different kind, having the most confused and varied directions, and which I suppose to have been the remains of the dental tubes.

We must therefore regard the dental substance as composed of fibres blended together, between which run tubes provided with special walls. The fibres and tubes are nearly perpendicular to the dental cavity in human teeth. What connexion now is there between the fibres, or the tubes, and cells? I should incline to the old opinion, that the dental substance is the ossified pulp. According to Purkinje and Raschkow, the pulp in the first instance consists of globules, of nearly uniform appearance, but has neither vessels nor nerves. At a subsequent period vessels appear in it, and afterwards nerves. Upon the surface of the pulp, the globules are more regularly arranged, and more extended in the longitudinal direction, and are directed towards the outside perpendicularly, or at a slightly acute angle. These elongated globules are clearly cylindrical cells. In recent teeth, the characteristic nucleus with its nucleoli may be distinctly seen in them, and they very closely resemble the prisms of the enamel-membrane. (Pl. III, fig. 4.) The interior of the pulp also consists of round nucleated cells, between which the vessels and nerves pass. When the pulp of a young tooth is detached from its cavity, and the dental substance is examined (without further preparation, or after the earthy matter has been withdrawn), a stratum of the cylindrical cells of the pulp will be found to remain attached to its internal surface, at least to the lower part of it, where the newly-formed dental substance is yet thin and soft. These cells are of about the same size, and have the same course as the solid fibres of the dental substance; and since, on the one hand, they clearly belong to the pulp, which follows from their accordance with the cylindrical cells that remain attached to the rest of its surface, and as, on the other hand, they are still more firmly connected with the dental substance than with the pulp, and remain affixed to the former, I suppose a transition to take place at that part, and the cylindrical cells of the pulp to be merely the earlier stage of the dental fibres, i. e. that the cells become filled with organic substance, solid and ossified. In some instances, these little cylinders are not found upon the dental substance, but a quantity of cell-nuclei seen in their place; these are very pale, and so intimately united with the dental substance, that they readily escape notice; when, however, attention is once attracted to them, it is impossible to mistake them, and they lie side by side with extremely small interspaces. The facility with which the two structures may be separated, has been adduced as an argument against the opinion that the dental substance is the ossified pulp, and I fully acknowledge the weight of the objection. But the following circumstances deprive it of at least some of its importance. Firstly, some portion of the pulp actually remains attached to the dental substance; again, in ribs which are half ossified, the cartilage may easily be separated from the ossified portion; and lastly, the separation must be effected with more facility in the tooth, in consequence of the greater difference in consistence between the dental substance and the pulp. There are therefore, at least, reasons enough to warrant our entering more particularly into the details of this opinion. The pulp accords with all the other tissues of the fœtus, therefore with cartilage, in being composed of cells: the difference between its consistence and that of the cartilage of mammalia, depends on this, that the quantity of cytoblastema (to which the latter owes its hardness) is very small, for the cylindrical cells of the pulp lie quite close together, at least such is the case on its surface. In this respect, the pulp bears a closer analogy to certain cartilages of animals lower in the scale, in which there is also only a small quantity of cytoblastema present, and the consistence of the cartilage is principally occasioned by thickening of the cell-walls. As I have not actually observed the transition, I do not know whether the filling up of the cavities also takes place by thickening of the cell-walls, in this supposed conversion of the cells of the pulp into the dental fibres. If such be really the case, the cavities of the cells are in general so completely obliterated by it, that no cartilage-corpuscles remain. From the observations of Retzius, however, it might be supposed that some of the cells retain their cavities, and even become transformed into stellated cells; for he saw true osseous corpuscles in the dental substance. When the uppermost stratum of the pulp consisting of cylindrical cells has become converted into dental substance by ossification, the round cells lying immediately next beneath it in the parenchyma of the pulp, must first commence their transformation into cylindrical cells, the vessels of the stratum must become obliterated, and then this stratum ossified, and so on.

What, then, are the dental tubes? Retzius compares them to the calcigerous canaliculi of bone which issue from the osseous corpuscles, and I was myself at first of that opinion; for I regarded them as prolongations of cells, the bodies of which lay in the pulp. For, when the pulp is drawn out from the cavity of a pig's tooth, and its margins examined, it will be seen that each of the cylindrical cells of the surface of the pulp becomes elongated into a short minute fibre towards the dental substance, and that these fibres are about as numerous as the tubes projecting upon the surface of the pulp. I thought formerly, that they became elongated to form the dental tubes, and that the intertubular substance was merely intercellular substance between these prolongations. But I was compelled to relinquish that idea in consequence of there being no such appearance in the human tooth, and because the explanation led to difficulties with respect to the teeth of the pike, in which, according to Retzius, an immediate transition of the dental into the osseous substance takes place. If one of the largest teeth in the lower jaw of the pike be sawn off, deprived of its earthy matter by means of hydrochloric acid, and then divided into thin longitudinal sections, the dental substance will be seen to form a hollow cone, which is filled with osseous substance. The dental substance is transparent, and consists of fibres which have a direction from the point towards the base of the cone. Canals traverse the osseous substance, resembling the Haversian medullary canals of ordinary bone, only they are not so regular. The dental tubes then are connected with these canals of the proper osseous substance, and may be distinctly seen issuing from them in a funnel-shaped form. The canaliculi soon ramify in the dental substance, and, as they run across the thickness of the dental cone, interlace with the dental fibres. According to this view, the dental tubes would correspond to the medullary or Haversian canaliculi of bone, and not to the calcigerous canaliculi proceeding from the osseous corpuscles. It appears impossible, however, to be assured of the right explanation of all the structural relations of the dental substance, until its development is examined in teeth differing widely from each other in construction.

c. *Osseous substance of the teeth.*

This requires no particular explanation, as it entirely accords with the ordinary osseous substance.

Having examined in detail the tissues comprehended in this class, and compared them one with another, we have yet to consider the entire class in relation to those which have been previously discussed, and to observe how much our knowledge of the transformations which the cells are capable of undergoing, has been advanced by the study of it.

It is easy to see which elements of the tissues of this and the preceding class correspond. There the whole tissue consisted of cells, closely crowded together, and the intercellular substance was almost *nil*. Here we find the like arrangement only in the lowest stage of development of the most simple cartilages. In such as are more highly developed, those of all the mammalia for example, the cells lie surrounded by a larger quantity of intercellular substance, which forms the proper cartilaginous substance; but the cell-walls contribute only very slightly, or not at all, to its formation. The proper firm substance of these higher cartilages, therefore, has its analogy in the former class, only in the minimum of cytoblastema by which the cells are connected, while, on the other hand, it corresponds with that which, in the first class, was the fluid, wherein the isolated cells were formed. The cartilage-cells in this class, however, correspond precisely to the epithelium-cells, the feather-cells, &c. &c., in the preceding one, and the blood-corpuscles, mucus-corpuscles, &c. in the first class.

We have not found any new changes in the form of the cells in this class. Most of them were angular, somewhat approaching the circular form; and stellated cells, so far at least as we may be permitted to regard the osseous corpuscles as such, were also frequently met with. (See pp. 29, 30.) Some cells, which were remarkably elongated, were observed near to the surface of several cartilages, in which situation they are known as greatly elongated cartilage-corpuscles; still, however, this appearance is never presented by the cells of this class in so remarkable a degree as it is by those of the crystalline lens in the previous one. The fibro-cartilages, on the other hand, form the immediate transition from this to the following class, for in them a bundle of fibres seems to be formed out of each cartilage-corpuscle, a process which we shall consider more minutely when treating of cellular (areolar) tissue in the next class.

We have observed the formation of cells around the previously-existing nucleus, and their progressive growth, going on in this class in a similar manner to that exhibited in the preceding, and the true cartilage-cells were also seen to form around a cytoblast which lay external to the cells already developed. On the other hand, a formation of cells also takes place within the true cartilage-cells, but it is probable that they have a different signification from those within which they are generated. A deviation from the previous class seemed to occur with respect to the spot at which the young cells are formed, in relation to the entire tissue. In the former class, so far as we could perceive, they were formed at that part only where the tissue was in immediate contact with the organized substance. The formation of the new cells in cartilage, it is true, did not take place throughout the entire thickness of the tissue, but (so long at least as the cartilage itself is not furnished with vessels) only near the surface, and therefore, at the spot where it was in contact with the organized substance; still, however, it not only took place at that point of contact, but went on also between the cells most recently formed, as if cartilage had a greater capacity of imbibition, so that the cytoblastema penetrating from the blood-vessels into the parenchyma arrived at the deeper seated portions of the tissue more speedily; and, therefore, retained its fresh plastic force even in that situation; or, as if the cartilage itself possessed a higher vitality, and, therefore, the cytoblastema retained its productive power for a longer period, although penetrating quite as slowly as in the previous class.

Although the modifications in the form of the cells of this class vary but slightly from those of the preceding one, yet we see two striking changes in the cells and their cytoblastema, namely, the coalescence of the cell-walls and ossification. The thickening and transformation of the cell-walls were very distinct in the last class, for example, in feathers. Here a still more strongly-marked thickening of the cell-walls takes place in several cartilage-cells. The external contours of the walls, however, gradually disappear in such instances, and a coalescence takes place to such an extent as to leave merely the cell-cavities perceptible, lying in an homogeneous substance. The blending of the cell-walls takes place either between the walls of neighbouring cells, in instances where they are in immediate contact, or, with the intercellular substance, when the cells are surrounded by it. Further investigations are required in order to decide the question as to whether this blending be so complete that it cannot in any way be dissolved, the simple fact being, that the cell-walls are no longer discernible with the microscope. I shall not bring forward the splitting of the dental fibres as examples here, nor indeed make any reference to the teeth in this retrospect, their explanation being as yet too problematical. It has, however, been already mentioned as a doubtful point, whether a coalescence of the walls actually takes place in all cartilage-cells, for instance, in those of the higher animals.

Ossification appears to occur especially, perhaps exclusively, in those cartilages which have a greater quantity of intercellular substance. It consists probably in a chemical union between the calcareous salts and the firm portion of the cartilage substance. In the first commencement of the process the cartilage frequently acquires a granulous appearance, which subsequently disappears, the entire substance meanwhile becoming gradually dark. At the same time the cartilage-cells undergo a transformation into the osseous corpuscles, a process which must probably be explained as analogous to the formation of the stellated pigment-cells. There is reason to suppose that the osseous corpuscles and the canaliculi which issue from them, also become filled with earthy salts by the calcifying process.

The class of cells now under consideration has yet another point of especial interest for us, since it is the first in which organized structures, that is, structures provided with vessels, occur. The accordance between the elementary cells of unorganized animal tissues and vegetable cells might be conceded, without granting a connexion between the organized tissues (which are especially characteristic of animals) and the structure of vegetables. A distinction had always been drawn between the growth of the organized and that of the unorganized structures; and much had already been said in a general way about a vegetative growth of the non-vascular structures, the crystalline lens for instance, though the analogy which existed between their elementary particles was not proved. Cartilage, then, is the first structure which teaches us that a tissue, which, at a later period at least, contains vessels, is composed of cells, perfectly according, in their development, with those of plants; and, therefore, that a similar formative principle is the basis both of the organized and unorganized tissues. We shall have further evidence of this presented to us in the following classes, which comprise the rest of the tissues,—those, indeed, which are most perfectly organized, and the most important to the animal organism. In them we shall also find that the formation of cells is the general principle of development, and that their elementary particles are derived from cells, although at the first glance one would scarcely imagine that any connexion could exist between them and cells.

CLASS IV.

Fibre-cells, or tissues, which originate from cells that become elongated into bundles of fibres.

Mere fibres are all that can be detected as the elementary components of the tissues of this class when they are examined in the mature animal. But when we investigate the mode in which they are generated, we see that the fibres are formed only as prolongations of cells, which, in most instances, are elongated in two opposite directions, sometimes terminating at once in a fasciculus of fibres, at other times in a single fibre, which afterwards splits into several finer ones. This constitutes the characteristic feature of the class. We are already acquainted with the type of the prolongation of cells into fibres in the pigment-ramifications, osseous corpuscles, &c. The cells next to be considered differ from them in the following particulars: the fibres originating from any one cell generally lie together in a fasciculus, and in these prolongations of the cells, it is principally the wall which is most strongly developed, whilst, in the former instances, the cells though extended into fibres, were chiefly rendered conspicuous by their cavities. This class comprises the Cellular (areolar), Fibrous, and Elastic tissues.

1. *Cellular (areolar) Tissue.* This tissue is known to be composed of extremely minute, tough, smooth fibres, having a pale outline, and usually a serpentine course; they may be seen in their natural state in the mesentery with-

out any dissection. Most areolar tissue may be distended by forcing air into it, and then innumerable cellular spaces are seen communicating with each other in it; it is not known whether these are produced artificially, or whether they existed previously. Areolar tissue also frequently contains fat-vesicles, which, according to Gurlt, are surrounded by a thin and transparent, but not fibrous, pellicle, often have an hexagonal form, and in that respect resemble vegetable tissue. (Gurlt's Physiologie der Haussäugethiere, p. 19.) In order to become acquainted with the relation which these constituent parts of areolar tissue bear to the elementary cells, we must refer to the formation of the tissue in the fœtus.

If we examine some areolar tissue from the neck, or from the bottom of the orbit of a fœtal pig measuring three inches and a half in length, we shall find it to be a gelatinous substance, somewhat more consistent than the vitreous humour of the eye, and, in its earliest state, quite as transparent; as development proceeds, however, it becomes more of a whitish colour, and loses its gelatinous quality. When examined with the microscope, small corpuscles of various kinds are seen in greater or less numbers; they are not, however, sufficiently numerous in a fœtus of the size specified to form the entire gelatinous substance, but must necessarily be situated in a transparent, structureless,[1] primordial substance of a gelatinous nature, which we will for the present call cytoblastema. The whiter this substance appears to the unaided eye, the greater is the number of corpuscles contained in it; their quantity, therefore, is continually increasing during development, while that of the cytoblastema constantly diminishes. As in consequence of its transparency, the cytoblastema cannot be seen, but is only inferred to exist from the circumstance that the corpuscles, which are visible under the microscope, could not, at the period when they are but few, form the entire jelly, and that when moved, it is plainly seen that they are held together by some invisible medium, so it is no longer possible to convince ourselves of its existence, when the corpuscles are very numerous. It is probable, however, that it remains between the fibres of the areolar tissue throughout life.

[1] Vide note at page 39.

This cytoblastema is present in the greatest quantity, and therefore most distinctly demonstrable in the jelly which lies between the chorion and amnion in the fœtus of the pig at a somewhat more advanced period, and where it may be rendered very clearly perceptible on the margin of the preparation by colouring it with iodine. It is quite as evident in the cellular tissue of the young tadpole. An indistinct fibrous appearance is sometimes given to it by drawing it asunder; but a fibrous structure must not be inferred from that fact simply, since all tenacious matter assumes that appearance under similar circumstances. Since the number of the corpuscles in the cytoblastema continually increases as development proceeds, it would appear that the cytoblastema must be regarded as the primary formation, so that we may suppose some of it to be first present, and then the corpuscles originate in it; at the same time, however, new cytoblastema is formed, in which new corpuscles are in like manner generated, whilst the formation of those in the previously-existing cytoblastema proceeds simultaneously.

Three kinds of these corpuscles may be distinguished in the mammalian embryo; one, which is developed at an earlier period than the rest, and is found in all the areolar tissue throughout the fœtus, and two others, which are formed subsequently, and, as it would seem, do not occur in the areolar tissue of some parts. We shall, therefore, designate the first (which is the only essential kind) proper corpuscles of areolar tissue, or—in accordance with the signification which will shortly be determined for them—fibre-cells of areolar tissue; the second kind are fat-cells; the third form round cells of areolar tissue, the precise signification of which I have not yet been able to make out.

a. Proper corpuscles of areolar tissue, or fibre-cells of areolar tissue. The areolar tissue is not found in the same stage of development in every part of the same fœtus. When some of the tissue that has reached about its middle stage of development is removed from the neck of a pig's fœtus, measuring from four to seven inches in length, and examined with the microscope, a quantity of corpuscles of various forms are observed in it. The majority of them, however, appear as they are represented in pl. III, fig. 6, *a*, being spindle-shaped or longish corpuscles, which are thickest in the middle and gradually elongated at both extremities into minute fibres. They may therefore be described as consisting of a thicker portion, or body, and fibres, which proceed from it.

The body is either round or slightly compressed upon the sides. The surface is covered with very minute granules. Within the thickest portion of it lies another small corpuscle of a circular or generally oval form, and which again encloses one or two small dark points, and accords entirely with the common cell-nucleus. It is therefore probable, that the entire corpuscle is a cell containing a nucleus. The nuclei have not a similar size in all the cells; there is a much more striking variation, however, in the relative size of the cells and the nuclei. In the largest cells, such as *a*, fig. 6, the body is almost as thick again as the nucleus, and it may be observed that the nucleus does not lie in the centre, but upon the wall of the cell. In most instances, however, the cells are relatively smaller, scarcely larger indeed than the nucleus; insomuch, that the fibres often appear to proceed immediately from the nucleus, as at *b* in the figure: the cell in that instance encompasses the nucleus quite closely. Cells frequently become separated during the process of preparation for the microscope, and float about singly in the water, with a portion of the fibres issuing from them. By causing them to roll, when so detached, it may be satisfactorily seen that many of them are somewhat flattened laterally, and that the nucleus is attached to the inside of the cell-wall. The larger cells, under such circumstances, appear as though the granulous aspect were produced by the external wall only, therefore by the cell-membrane, the interior being filled with a clear fluid.

The cells pass by a gradual process of acumination into the fibres, it being quite impossible to discern any defined boundary between them. The fibres are pale, minutely granulous like the cells, and frequently give off branches. Their course is usually straight. It is difficult to find out how they terminate; but they are generally lost in a bundle of extremely minute fibres.

The above-described corpuscles, then, are the fibre-cells of areolar tissue in the middle stage of their development, a condition in which they immediately attract attention in the investigation of that tissue in the fœtus. We shall in the next place consider the earlier, and then the subsequent stages of their development. In addition to the corpuscles before mentioned, others may be seen in very young areolar tissue, which are not elongated into fibres, but are more or less round. They are granulous and contain a nucleus with nucleoli, and as they present all the stages of transition up to those cells which are prolonged into fibres, we must regard them as being the undeveloped fibre-cells. Various forms of them are delineated in pl. III, fig. 6. I will not assert that all round cells in fœtal areolar tissue are young fibre-cells; for we shall presently become acquainted with some which are not. It is only after the commencement of the process of acumination that the young fibre-cells can be distinguished from these; in the earliest state, when they are as yet quite round, almost all cells are alike. It is difficult to determine positively whether or not these cells are formed around a previously existing nucleus; probably, however, such is the case, as there are no cells to be seen without nuclei, although there are many nuclei observed without investing cells.

The following, then, are the results of our investigation into the progress of development of areolar tissue, in so far as we have as yet pursued it. In the first place, small round cells are formed (probably around a previously existing nucleus), in the structureless jelly-like cytoblastema of the tissue. The cells, furnished with the characteristic nucleus, become acuminated in two opposite directions, and these acuminations elongate into fibres, that sometimes give off branches, and at length split into fasciculi of extremely minute fibres, which, in the early stage, cannot be distinctly perceived to be insulated. As development proceeds, the splitting of the two principal fibres, issuing from the body of the cell into a bundle of more minute fibres, continually advances nearer towards the cell, so that, at a later period, a fasciculus of fibres issues immediately from the body of the cell (see pl. III, fig. 7.) At a subsequent period, this process of splitting reaches as far as the nucleus, and at length goes quite through the body of the cell, and the nucleus then lies merely upon a fasciculus of fibres. At the same time the fibres in the progress of development are rendered smooth, become distinctly and individually discernible, and assume their waving course; in short, they acquire the appearance of the ordinary fibres of areolar tissue. (See the figure.) As the process of splitting advances from both sides towards the nucleus, the fibres in its neighbourhood are those which are longest united together, and that part of the cell is the last to undergo division. The nucleus remains for a time lying upon the fasciculus of fibres; and when it is at last absorbed, we have a bundle of fibres in the place of the original cell. The figure represents a nucleated cell, which is elongated at the upper end into the characteristic fibres of areolar tissue, each one being individually perceptible; the upper part of the body of this cell has also begun to split into fibres. With regard to the elongation downwards, it is not possible to distinguish whether there are separate fibres yet formed, and collected into a cord, or whether it is still merely a simple prolongation of the cell.

It now becomes a question how the elongation of the cells into fibres, and their division, and at a later period the splitting of the body of the cell also into more minute fibres, can be conceived to take place. We have already observed a prolongation of the cells into fibres in several instances, and have traced it minutely in the stellated pigment-cells. The only difference between them and the fibre-cells of areolar tissue is, that in the latter, the elongation generally takes place in two opposite directions only, a circumstance which also frequently occurs with pigment-cells; whilst, on the other hand, the cells of areolar tissue also frequently become elongated into fibres on several sides; see, for example, pl. III, fig. 8. There is often a striking resemblance in form between some of the cells of areolar tissue and those of pigment; compare, for instance, pl. III, fig. 6 *a*, with pl. II, fig. 8 *e*. Analogy would lead us to regard those fibres as hollow; but since the cell-contents are not so characteristic in them as they are in the pigment-cells, a cavity might really exist, but not fall under observation, in consequence of the minuteness of the fibre; the appearance of the fibres, therefore, proves nothing, either in favour of or against their hollowness. Since, however, we are already acquainted with many extremely minute hollow prolongations of cells, and as the transformation of the cells into fibres in the areolar tissue, takes place by a gradual acumination, it seems to me, for the present, more probable that they are hollow rather than solid. If we imagine the formation of the fibres from a cell to take place by the cell-wall growing more vigorously at two opposite limited spots than it does at any other part, we can then conceive that the division of these main fibres into branches, and their prolongation into fibrils, may be effected by the same process. The question as to the hollowness or solidity of these fibrils, is still less capable of being settled by observation than that with respect to the larger fibres. Analogy is in favour of their being hollow, and the minuteness of an object forms no limit to nature's operations.

The splitting into fibres, which, as we have seen, pursues a retrograde course from the branches towards the main fibres, and thence towards the body of the cell, might be illustrated in the following manner :—suppose that part of a glove which corresponds to the hand to be the body of a cell, and the fingers to be a fasciculus of fibrils. If the membrane situate in the angle between two fingers grow in the direction of the hand, the glove will at length be split into five portions. But a difficulty arises with respect to the fibre-cells of areolar tissue, which is, that the division into fibres advances from two opposite sides towards the body of the cell, and, therefore, the fibres of one side must ultimately correspond with those of the other. This, however, admits of no further explanation than the healing of the corresponding primitive fibres in the reproduction of nerves does. Meanwhile the above are only attempts to convey a clear idea of the results of my investigations, modes of representation which are susceptible of various modifications, provided they be not made to contradict the observations; the latter may be briefly summed up as follows :—cells, furnished with the characteristic nucleus, are present in the first instance, which become elongated on two opposite sides, more rarely on several sides, into fibres, and these are prolonged into more minute fibres. At a later period the principal fibres, and then also the bodies of the cells are split into fibres, so that a small fasciculus of fibrils, with a nucleus fixed upon it, remains in the place of the original single cell. Last of all, the nucleus also disappears, and fibrils alone remain. All these transformations proceed in a homogeneous cytoblastema, which probably also continues to exist between the fibres of areolar tissue in the adult.

b. Adipose cells. In the later periods of fœtal existence, adipose cells occur in many situations in addition to the fibre-cells before described. They are usually first seen in small groups between the fibre-cells. They are round cells of very various sizes, which are generally completely filled by a single fat-globule. The cell-membrane which closely encompasses the contents, is most minutely granulous, or, according to Gurlt, homogeneous. It is in most instances very thin, being about half the thickness of a blood-corpuscle, but sometimes it is much thicker, and in the subcutaneous areolar tissue of the thigh of a rickety child, at the age of twelve months (probably in connexion with the disease), was almost as thick as the breadth of a human blood-corpuscle. In the early stage, this cell-membrane encloses a very distinct nucleus of a round or oval form, which is sometimes flattened. When the former is thin, the nucleus presents itself externally as a little prominence upon the round fat-globule, which is closely encompassed by the cell-membrane; but when thick, the nucleus lies embedded in it. It contains one or two nucleoli. It is not uncommon for adipose cells to contain a number of small globules instead of *one* fat-globule, in such instances, one of them is generally remarkable for its larger size. The adipose cells are best seen in the fat found in the cranial cavity of a young carp, before it has attained the length of six inches. (See pl. III. fig. 10.) They there lie in so soft a substance, that they may be insulated without any difficulty, and float singly in the water in which they are examined. Some are so large as to be visible even with the unaided eye. When examined under the microscope with a magnifying power of 450, the cell-membrane is readily recognized, it is very thin, and closely encompasses the contents. It rises into a little prominence on one side, within lies a proportionately large, and very beautiful cell-nucleus, which is oval, but not flattened, and contains one or two very distinct nucleoli. Some of these fat-cells have two such nuclei, which have precisely similar relations to the cell, and both elevate the cell-membrane into a prominence at the points where they are attached. When one of these cells is pressed under the compressorium, the cell-membrane is at first remarkably expanded, and then tears to a very limited extent, allowing the fat to flow out. When the pressure is discontinued, it contracts again strongly. It has a minutely granulous aspect, is soft and very elastic, but not fibrous.

In close apposition, the cells become flattened against one another into polyhedral shapes, and, as Gurlt remarks, they then resemble vegetable cells in their appearance. We, however, may go further, and regard them as corresponding in signification also. In them the fat forms the cell-contents, as the pigment does in its cells, and the ethereal oil, &c. in those of plants. In its physiological signification of nutritive deposit it has more analogy with starch than with any other substance. I know not whether the nucleus is the part first formed in these cells, or not. Nuclei without any investing cells are found in the cranial cavity of the carp, lying with the adipose cells in the surrounding cytoblastema; these, however, may be nuclei of fibre-cells of areolar tissue. Sooner or later the nuclei become absorbed. They were still quite distinct in the adipose cells of the subcutaneous areolar tissue in the thigh of the before-mentioned rickety child twelve months old, whilst I could not detect any in the neck of a fœtus at the seventh month. The absorption of the nucleus proceeds in one of two ways; either its external contour becomes gradually indistinct, some granulous substance merely being left in its place, which substance also disappears at a later period, or small fat-globules are formed both within the nucleus itself, and in its immediate proximity, which go on increasing in size, whilst the nucleus gradually disappears. The cell-membrane probably remains, even in the mature condition of the tissue, and Gurlt has made the very interesting observation, that in emaciated persons, the ordinary adipose cells are filled with serum.

c. The third kind of cells which occur in the areolar tissue of the fœtus are round, for the most part extremely pale and transparent (pl. III, fig. 9.) They vary very much in size, most of them being much larger than the fibre-cells, and some as large as the largest adipose cells. They can very rarely be seen without the aid of the most favorable light, but when, under such circumstances, the observer has once detected one of them, and become familiar with the degree of its transparency, they may be recognized in great numbers. They have a distinct nucleus attached to the internal surface of their wall, containing one or two nucleoli. The nucleus always attracts attention first; the cell surrounding it is either quite transparent, and void of granules, or has granulous contents, and this granulous deposit is first formed in the neighbourhood of the nucleus, the remaining portion of the contents being still transparent. (See the figure.) Gradually, the entire contents appear to become granulous. These cells are distinguished from the fibre-cells of areolar tissue by the circumstance of their becoming much larger than the latter, and their not being elongated into fibres, and from the adipose cells, in that they do not contain fat. I have found them in areolar tissue taken from the bottom of the orbit, and from the neck of a fœtal pig, but do not know whether they occur in the areolar tissue of all parts of the body; nor can I determine their signification. They might be regarded as cellular spaces which had been produced by the distension of the areolar tissue with air. In such case, they must communicate with one another in the course of their further development. But this appears to me to be somewhat improbable; and those spaces may be merely artificial productions. I should rather regard the cells in question as a modification of the adipose cells. For since, according to Gurlt, the ordinary adipose cells in the adult may contain mere watery fluid, one may also conceive the cells destined to the formation of fat becoming completely developed, without that formation actually taking place within them. There are, indeed, adipose cells which contain fat even in the earliest stage of their development, but that is no reason why the formation should not take place at a much later period in other cells. The granulous deposit in many of them might be regarded as the transitional step to the formation of fat.

The cellular tissue of the fœtus differs in its chemical constitution from that of the adult, since we cannot obtain any gelatine from it by boiling, none at least which has the property of gelatinizing. The integument was removed from a pig's fœtus measuring four inches in length, cut up into pieces, and steeped in distilled water for a day. It was then boiled for twenty-four hours. The last process caused it to crumble into small particles that clouded the fluid, in which also some large lamellæ of epidermis floated. When examined with the microscope the epidermis exhibited the same structure as it did previous to being boiled; the nuclei in the separate cells were also distinct. A quantity of fibre-cells floated in the fluid in the same state as when they, in their recent condition, composed the entire cutis, that is to say, longish corpuscles extended at both extremities into somewhat long fibres. The cell-nucleus could still be distinctly recognized in some of them. Thus the process of boiling, which had not produced any effect upon the fibre-cells or the fibres issuing from them, had dissolved the connecting cytoblastema, by which they had been held together in the recent state. The fluid was then filtered. Acetic acid caused a precipitate which was not dispersed by an excess of acid. A solution of alum produced a much more copious precipitate, which, in like manner, was not redissolved by an excess of alum, or at least not completely. Tincture of gall-nuts caused a thick clouding, spirits of wine only a slight one. Hydrochloric acid clouded the fluid, and an excess of acid did not render it clear again. These reactions accord with what Güterbock has called pyine, save that the clouding produced in the latter by hydrochloric acid, was redissolved by an excess of the acid. A portion of the filtered fluid was evaporated almost to dryness, but even after twenty-four hours, there was no trace of the formation of a jelly observable. In order to separate the component particles of this, in all probability, still very heterogeneous fluid, in some degree from one another, some pure alcohol was added to that portion of it which had been so long evaporated, whereby a very copious precipitate was produced. This was separated by filtration and washing, first with pure alcohol, and afterwards with spirits of wine of 80 per cent. strength, then dried, and again dissolved in boiling water. Acetic acid and alum caused precipitates in this solution, which were not again dissolved by the addition of either of those substances in excess. With respect to hydrochloric acid, the result was the same as before described.

It cannot appear at all surprising that the areolar tissue of the fœtus differs from that of the adult, when it is known that many cell-membranes undergo a change in their chemical constitution at different stages of their development, and that the growth of the cells is not a mere mechanical expansion.

Previous to quitting the subject of areolar tissue, we must consider some other processes, by means of which a new formation of it takes place in the adult. If (as I have already laid down as an axiom in my first essays, Froriep's Notizen, 1838, Nos. 91, 103, and 112) the formation of cells be really the principle of development of all organic structures, it must apply no less to pathological than to physiological processes; and that it really does so, is proved by the investigations of Henle with reference to the new products resulting from inflammation, namely, exudation, suppuration, and granulation; the results of his observations are communicated in Hufeland's Journal, vol. lxxxvi, No. 5.

Vogel pronounced the pus-corpuscles to be epithelium, in consequence of their resemblance to epithelial cells, and there was much of probability in the statement, so long as it appeared that every diversity in the physiological signification of an elementary structure was based upon a recognizable diversity of formation. But this conclusion lost its importance, when I brought forward the formation of cells as the common principle of development of elementary structures, which were perfectly distinct in a physiological sense, and at the same time showed the most opposite tissues to be developed from cells, which, in the first instance, perfectly resemble each other, and present no distinction either in appearance or in the signification of their individual parts. Henle, however, proved a positive difference between the epithelial cells and pus-corpuscles, for he found that the nuclei of the youngest epithelial cells were not broken down by the action of acetic acid like those of the pus-corpuscles. The latter must, therefore, be regarded as peculiar cells, which are developed in the serum of pus in the same manner that all other cells originate in their cytoblastema; the only difference being that in this case the cytoblastema is fluid. Beneath the pus, in healing wounds, lie the granulations, composed of a firm cytoblastema, in which lie a quantity of cells. Henle thus describes the microscopical structure of granulations: "The most superficial part presents cells, which resemble the pus-granules, except that their nuclei are not broken down by acetic acid. In the deeper strata, the nuclei are very distinct, and the envelopes are polygonal, in consequence of mutual pressure. Wood has already drawn attention to their resemblance to epithelial cells. Deeper still the envelopes of the cells are found passing through all the gradual transitions of the fibres of areolar tissue, just as in the immature areolar tissue of the embryo. The first rudiments of these fibres are the longish nucleated corpuscles, which Güterbock observed, and compared to the cylindrical epithelium. Hence it follows, that the formation of new cells proceeds upon the surface of the granulations, and that the transformation of the latter into cellular tissue (cicatrix-material, narbensubstanz) proceeds successively from the bottom of the wound towards the surface." As no gelatine can be obtained from the granulations by boiling, Güterbock thought that those fibres in the granulations and exudations which resemble the areolar tissue ought not to be regarded as the actual fibres of that tissue, but as merely those of fibrin. But, as we have seen above, the entire areolar tissue of the fœtus also does not afford any gelatinizing gelatine; and since Henle observed a similar course of development in these fibres to that which I had pointed out in the areolar tissue of the fœtus, we must regard them as the young fibres of that tissue (although they may differ from the mature tissue in their chemical qualities), and the granulations as nothing more than a primitive formation of areolar tissue.

A formation of areolar tissue similar to that in the fœtus takes place also in exudations resulting from inflammation. R. Froriep (Klin. Kupfertafeln, 11te Lief. Weimar, 1837, Th. lxi) had already observed that irregular granules, some of which seemed to be extended on one or both sides into thin fibres, existed in the exudation of pericarditis, in addition to the fibres resembling areolar tissue. "These elongated granules of fibrin," he continues, "seem to be the commencements of the formation of the new mass of tissue, that is, the rudiments of the newly-forming cylindrical fibres of the areolar tissue composing the proper false membranes, or substance of the cicatrix." Thus Froriep had already observed the generation of fibres, resembling those of areolar tissue, by the elongation of corpuscles; what he here calls fibrine globules, are, no doubt, the nucleated fibre-cells becoming elongated into fibres. Henle examined the exudation by which wounds that heal by the first intention are closed, and found, that, in this also, cells are formed which undergo transformation into fibres of areolar tissue by an elongation of their envelope, just as in the fœtus. He thence concludes, that the formation of exudations and granulations are essentially similar processes. The exudation-globules (exsudatkugeln) discovered by Valentin, and described also by Gluge, which, according to the former, occur in every form of exudation, are, he says, allied to pus-corpuscles; and Henle also found that their nuclei are likewise broken down by the action of acetic acid.

Suppuration, therefore, differs from exudation and granulation only in this circumstance, that a more fluid cytoblastema is formed, in which fewer perfect cells are developed. It represents an intermediate stage between the formation of the firm tissues and the true function of secretion; between which two processes again no essential difference exists.

2. *Fibrous Tissue.* The fibres of tendons and those of areolar tissue, differing but little from each other, and it being impossible to define precisely the respective limits of the two structures in the perfectly developed condition, we accordingly find that they agree in their mode of origin. Cells, resembling the fibre-cells of areolar tissue, are found in the tendons of the fœtus at a very early age. They are arranged with their long axis corresponding to that of the tendon, and are prolonged in two opposite directions into fibres, which again subdivide into more minute ones. (See plate III, fig. 11.) These cells split into fibres precisely in the same way as those of areolar tissue; they have a nucleus similar to theirs in shape, which remains for a period, but is at last absorbed, leaving nothing but the fasciculus of fibres persistent. All these processes, however, take place much earlier in fibrous tissue than in the areolar, so that,

unless the tissue is investigated in a very young fœtus, we can only detect cell-nuclei intermixed with fibres, or nuclei, in whose immediate proximity a small fasciculus of fibres arises on both sides. At an early stage of development the tendons have a gray appearance, not having assumed the white colour of the adult tissue. This fact is probably connected with a chemical difference existing between the young and perfectly developed fibrous tissue, as in areolar tissue. The quantity of the cytoblastema in which these cells are formed, and by which the fibres and tendons, when perfected, are probably connected together, must be extremely small, and cannot in any way be demonstrated by observation. Its existence can only be inferred by analogy with areolar tissue: it will be remembered that it was proved to be present in the fœtal condition of that tissue. The quantity of cytoblastema, in comparison to the fibres present, seems to me to be the principal distinction between areolar and fibrous tissue in the adult. The fibrous tissue contains a great many more fibres within a given space than the areolar does, and they are not more minute than those of the latter tissue. There is just as great a difference, however, between fibres of areolar tissue taken from different parts of the body, as there is between the ordinary fibres of tendons and the most common form of areolar tissue, so that a very gradual transition takes place.

3. *Elastic Tissue.* The distinction between elastic and fibrous tissue is exhibited at a very early period. But my investigations into the history of the development of this tissue are very incomplete, and extended only so far as to render it probable that it presented no exception to the principle of development from cells. I made use of the aorta of a fœtal pig and the ligamentum nuchæ of a fœtal sheep for the purpose. The tissue taken from these two parts was very different in its general character. In a pig's embryo, of six inches in length, the aorta had already acquired its yellowish colour and perfect elasticity. The external coat could be easily drawn off in long pieces, almost, indeed, as a distinct tube. Having drawn off a small portion of the middle coat (which, in order to avoid any suspicion of epithelium being mixed with it, was so carefully done, that the internal surface of the vessel remained

uninjured), and torn it asunder a little, it was examined with the microscope; the first appearance presented was that of a great quantity of isolated cells, floating about in the surrounding fluid, each of which had its peculiar nucleus. (See plate III, fig. 12.) This easy separation of the cells is never seen in the same degree in the areolar and fibrous tissues, as they are there connected together by the cytoblastema, and by the tough fibres issuing from the cells. These cells of the coat of the aorta vary very much in shape. (See the figure.) Some are round, but most of them oblong, some terminate with a blunt extremity, others are acuminated on two or more sides, others again are prolonged into small processes, which again subdivide, but never extend to any great length. Many of them are somewhat compressed laterally. They all have a granulous aspect, but that appearance, so far as one can judge by rolling the cells about, seems to be referrible to the cell-membrane, and the contents appear to be transparent. The nucleus, enclosing one or two nucleoli, is attached to the interior of their walls. It is sometimes round, at others more or less elongated. These cells have become disengaged from the small portion of the coat of the artery before described. When the preparation itself is examined, many more cells are observed in it, and in addition to them, distinct elastic tissue, consisting of a network of minute, elastic, rough (?) (rauher) fibres, such as are found nearest to the internal coat of the aorta in the adult. (See Eulenburg, de Tela elastica, fig. 9.) It does not, however, present any fibres so thick as those which are found in the external layers of the same part. A blighted nucleus may be recognized here and there in the network. What relation, then, do these cells bear to this still delicate, but so far as regards its characteristic features, perfectly-formed elastic tissue? Analogy would lead us to suppose them to be the primitive formation; I sometimes also thought, that in rare instances I could observe an immediate transition; that I could see, for instance, one of these cells, furnished with a nucleus, pass continuously on one side into a small portion of reticular tissue, resembling in appearance the undoubted elastic tissue, whilst on its other side it retained its perfect cellular figure. But this occurred so rarely, that I am not enabled to state that a transition of these cells into elastic tissue was proved by observation. If, however, such be really the process of formation, as, from analogy, we are entitled to suppose, the bodies of these cells must then take a much more important share in the formation of the fibres than those of areolar tissue do, and the formation of the elastic fibres of the aorta holds a middle position between the generation of the horny fibres in the cortical substance of feathers (see p. 86, and pl. II, fig. 13) and the production of fibres in areolar and fibrous tissues. The reticular appearance of elastic tissue loses its singularity, when it is conceived to be generated in the same manner as those horny fibres in the feather, that is, partly by an elongation of the cells, and partly by a splitting of their bodies. The splitting of the elastic fibres is not to be regarded as an isolated phenomenon, since such division undoubtedly occurs in transitional stages in the development of all forms of areolar and fibrous tissue in the fœtus. In this respect the elastic tissue seems to remain at a lower stage of development. Purkinje and Raüschel observed a darkish point in the centre of a transverse section of the elastic fibres of the aorta, and a dotted line in the course of the fibres, and thence inferred the existence of a rudimentary canal in their interior. This supposition, which I must confess formerly struck me as being a very bold one, has much more weight now, inasmuch as it is not improbable that all fibres which are formed by the prolongations of cells (even those of areolar tissue) are hollow, at least, that they are not composed throughout of one uniformly solid mass. If, as an observation of Valentin's seems to indicate, still more minute fibres may be rendered visible by the aid of caustic potash in those of ordinary elastic tissue, I should be inclined to regard them as analogous to the primitive muscular fibres, whose signification, as we shall subsequently see, differs entirely, in a morphological view, from the primitive fibres of areolar tissue.

Whilst the elastic tissue of the aorta taken from a very young fœtal pig exhibited in the manner before described the main characteristics of the tissue, namely, its yellowish colour and elasticity, the ligamentum nuchæ of a sheep's fœtus, at a much later period of gestation, was but very slightly developed.

It had a gray and translucent appearance, exhibited no elasticity, and when examined with the microscope, presented no trace of its future structure. A gray cord, indistinctly marked with longitudinal fibres, was seen, in which a great many cell-nuclei might be recognized. I did not prosecute any further researches, as the presence of the nuclei was sufficient proof that there was nothing essentially different in the type of its formation.

On casting a retrospective glance over the class of fibre-cells which we have just been considering, we find that it forms a very natural and somewhat strictly defined group amongst the tissues. The tissues comprised in it are generated from nucleated cells, which are transformed into fasciculi of fibres by elongation, in the first place, and by the splitting of the bodies of the cells themselves into separate fibres at a subsequent period. The fundamental phenomenon previously described at page 39 is distinctly presented in the formation of these cells; a structureless, gelatiniform mass, the cytoblastema, is first present, and lies outside the cells already formed. The cells are developed in this, the nucleus being, in all probability, the earliest formation. The growth of the cells proceeds, and they become transformed into fibres in the manner described. The quantity of the cytoblastema continually diminishes in proportion to the cells or fibres which are forming, but probably part of it remains persistent between the fibres throughout the whole of life; in the mature condition, however, it exists in greater quantity in areolar than in fibrous or elastic tissue.

The mode of generation teaches us which parts of these tissues correspond to the constituents of those hitherto treated of. The elementary cells of areolar tissue, before undergoing change, correspond morphologically with the cartilage and epithelium-cells, the mucus-corpuscles, &c.; and as a fasciculus of fibres is generated from each cell of areolar tissue, a whole fasciculus of fibres of areolar tissue accordingly corresponds to what was an individual cartilage- or epithelium-cell, in the previous classes. The structureless cytoblastema between the fibres of areolar tissue corresponds, however, to the firm intercellular substance, forming the principal mass of most cartilages, or to the minimum of cytoblastema between the epithelium-cells; or, lastly, to the fluid, in which the cells of the first class are formed. In this way one can also readily understand how fibro-cartilage forms a gradual transition between true cartilage and fibrous tissue; it only requires that the cartilage-cells pass through the same transformations as the elementary cells of areolar tissue.

As the present class was based upon the alteration in form which the cells comprised in it undergo, it necessarily could not present many modifications in the shape of the cells, and accordingly exhibits throughout merely an elongation of nucleated cells into fasciculi of fibres, and a subsequent splitting of the bodies into fibres. We have already seen the types of these changes in the second class, where the pigment-cells and those of the crystalline lens, &c., became elongated by a more vigorous growth of the cell-membrane at different spots; and the class now before us merely affords us an instance of the same process in a higher degree, since here, one side of one of these more highly developed fibre-cells gives origin to a great number, or even a whole fasciculus, of fibres. The cells of the cortex of the feather also furnished us with an example in the same class of the division of the body of the cells into fibres. Inasmuch as the prolongations of the pigment-cells remain hollow, however minutely they may ramify, one may suppose the same to be the case with regard to the fibres of the tissues now under consideration. The decision of this point would, as we shall subsequently see, be of great importance for the theory of nutrition; but it is quite impossible to determine it by observation, in consequence of the cells of this class not possessing any characteristic contents like those of pigment. An observation by Purkinje and Raüschel was quoted, however, in favour of these cells being hollow. If the hollowness of the fibres of areolar tissue, &c., could be proved, there would then be a division of a single cell into *many cells* at each transformation of a fibre-cell, and thus the fibrous tissues would not lose their *cellular* character.

The fibre-cells undergo chemical changes during their growth and gradual transformation into the fibres of areolar tissue, since that tissue, when boiled, even long after the formation of fibres has commenced, yields no *gelatinizing* gelatine.

The formation of the fibres of areolar tissue from cells, having been typified already in the second class, it follows that organization, or the presence of blood-vessels, does not establish any essential difference in the growth of the elementary particles; for this class belongs to the perfectly organized tissues, and areolar tissue is highly vascular. The unorganized tissues were formerly said to grow by apposition, and the organized by intussusception. We have already discussed this distinction at page 95. It is so far correct, that the young cells of unorganized tissues are not formed throughout the entire thickness of the tissue, but only in the neighbourhood of that surface, on which they are in contact with vascular substance, and where they therefore obtain the freshest cytoblastema. But if this distinction between the surface and parenchyma of the tissue be not present, in consequence of the blood-vessels being distributed throughout its whole thickness, the young cells are then also generated in every part of the tissue; and such is the case with areolar tissue. The primary distinction, therefore, merely consists in the absence or presence of vessels, the difference in the place of formation of the new cells being but a secondary distinction. The elementary particles grow in both instances and by the same powers. We shall see hereafter how far the presence of vessels facilitates certain processes which occur during growth. The essential phenomena of growth, and, therefore, also the fundamental powers called into activity by it, are similar in both. But why a formation of vessels should take place in areolar tissue and not in epithelium, is a question for future discussion.

CLASS V.

Tissues, generated from cells, the walls and cavities of which coalesce together.

The following is the type of formation in this class: independent cells, by which we mean such as have a special wall and cavity, are present in the first instance; these we shall call *primary* cells. They are either round or cylindrical, or of a stellate figure. When round or cylindrical, the primary cells are applied together in rows, the contiguous portions of the cell-walls then become blended, in such manner that merely simple septa remain, dividing each succeeding cell-cavity from its neighbour. These septa, however, become absorbed, so that the cavities of the different cells communicate. Instead of a number of primary cells, we then have one single long one, which we shall call a *secondary* cell. The cavity of such a one, therefore, consists of the united cavities of the original cells, and its cell-membrane of all their blended cell-membranes, except that the parts with which they were in contact are absorbed. The growth of the secondary cell proceeds like that of any simple independent cell. This appears to be the process of formation in muscle and nerve, so far, at least, as the observations, which will presently be communicated, extend. When the primary cells have a stellate figure, their bodies are not applied in rows, as in nerve and muscle, but are generated in larger interspaces filled with cytoblastema or with cells of another kind. Their prolongations, however, come in contact, the walls coalesce at the points of junction, and the blended septa then become absorbed, so that the cell-cavities, which were at first separated, now communicate. In this manner, when several prolongations of one cell come into contact with those of another, or of several others, we obtain, in the place of isolated, hollow, stellate cells, a network of canals, which are, in the first instance, somewhat thicker at the parts corresponding to the bodies of the cells, but become of pretty equal dimensions, in consequence of more vigorous expansion of the communicating prolongations. This appears to be the mode in which the capillary vessels are formed. The following detailed statement of observations upon the relation which muscles, nerves, and capillary vessels bear to elementary cells, will show how far the description just given, as the probable mode of formation, is to be regarded as proved by these, as yet, very incomplete researches, and will also indicate what deficiencies have yet to be supplied.

1. *Muscle.* To ascertain the relation which this tissue bears to the elementary cells, we must have recourse to the history of its development. I was, unfortunately, prevented from investigating the earliest formation of muscular fibre, in consequence of not being able to obtain any very young

embryos; but the deficiency in my researches may be supplied from the description given by Valentin (Entwicklungs-Geschichte, p. 268), from which the following passage is extracted: "Long before separate muscular fibres can be discerned, the globules of the primitive mass are seen, arranged in parallel lines, particularly when they are lightly pressed between two pieces of glass. The granules then appear to be drawn somewhat nearer together, to become completely coalesced, in some situations, while at others the blending takes place only on the one or the other side, and to be combined into one transparent mass. In this way filaments are formed, which, in some situations, have an appearance like strings of pearls, at others, on the contrary, are less sharply indented; they often also continue slightly puckered on one side, whilst the margin of the other has already become more straight. At a subsequent period, all trace of granules or division in the filament vanishes, and its outline becomes symmetrically transparent and cylindrical. The muscular fibre usually undergoes no other change until the sixth month, except that its substance becomes somewhat darker and its cohesion closer. The first traces of transverse striæ are exhibited in the sixth month. These fibres are the primitive fasciculi of muscle and not the primitive fibrils, which latter are formed by a splitting of the fasciculus into smaller fibres. From the period at which the muscular filaments become transparent and uniform, masses of globules, of a more or less spherical form and somewhat larger than the blood-corpuscles, begin to accumulate between them. They diminish again afterwards, and, blending with the gelatiniform mass which connects them, become converted into the connecting areolar tissue."

The youngest embryos in which I have investigated the generation of muscle were those of the pig, measuring three and a half inches in length. If a portion of one of the superficial dorsal muscles be removed from an embryo pig of that size, and examined under the microscope upon a black ground, a transparent gelatiniform mass is observed, in which parallel fibres (primitive fasciculi of muscle) run in close contact, having a whiter appearance than the surrounding gelatinous substance. As development proceeds, the transparent substance diminishes in quantity, the muscular fibres lie closer together, and have a more intensely white appearance upon the black ground. When some of this transparent substance, taken from a fœtus of the size before mentioned (and in order to exclude as completely as possible the embryonal cellular tissue which surrounds the entire muscle, a portion should be cut out from the centre of the muscle), is examined with a magnifying power of 450, it exhibits various kinds of granules differing in size, and lying in a finely granulous mass. On examining these granules more accurately, they are found to vary, both in size and appearance, being round or oval, more or less opaque or transparent. A great many of them may be recognized as cell-nuclei by their form. In many instances, even when they are still connected together, the granulous substance around them is more or less distinctly seen to have a defined globular figure, within which the nucleus lies. This is, however, observed most distinctly when any of the granules become separated from the transparent substance, and float about in the fluid upon the object-glass. A quantity of globules are then seen floating about isolated, each one containing the characteristic cell-nucleus, which is placed eccentrical, varies much as to its size, and is often furnished with nucleoli. (See pl. III, fig. 13.) We are already familiar with this as the rudimentary form of most cells. The finely granulous portion of the transparent mass is formed, in part, of the bodies of the cells, which, when in close contact, are difficult to distinguish, and in part, of the cytoblastema in which the cells have been generated. Some of these cells which float about are becoming elongated into fibres, which are manifestly those of areolar tissue. Such instances, however, are rare, and these cells seem to be something quite peculiar. They might be regarded as the primitive cells of new muscular fibres; but from the manner in which Valentin expresses himself, one should infer that they are formed at a later period, for he says, "masses of globules begin to accumulate between the muscular fasciculi from the period at which they become transparent;" it is clear that he here refers to the nuclei of these cells. This must, therefore, remain an undecided point.

We next examine the muscular fibres (primitive fasciculi) in the dorsal muscles of the same fœtus. They do not all resemble one another in general character; some are more irregular, more granulous, whilst others are relatively smooth. The smoother ones represent cylinders, which are generally more or less flattened (see pl. IV, fig. 3), in which they are delineated from the brachial muscles of a fœtal pig seven inches in length, *a* representing the flat surface, *b* the marginal. The cylinder *a* presents a dark margin, and an internal clear portion, a distinction which is yet more manifest in *c*, where the dark margin is broader and sharply defined on its inner edge, so that it has quite the appearance of a hollow cylinder. I must, however, remark, that but very few fibres present this appearance sufficiently distinct to satisfy the mind of the observer. But in many instances it was so manifest, that no other explanation seemed left than to suppose the fibre a hollow tube. In the clear portion of the cylinder, which corresponds to the cavity, (in addition to some small granules,) larger oval corpuscles are seen, which are often very much extended in the longitudinal direction. Their form at once shows them to be nuclei, and they frequently contain one or two nucleoli. The distance at which they lie from one another is more or less regular in different instances. They do not lie in the axis of the fibre, but eccentrically, upon and within the thickness of the wall, as is seen when the fibre rests upon its margin. (See the fibre *b*.) That delineation exhibits a regularity in their position, since a nucleus lies upon the one side of the wall, the second on the opposite, and the third again upon the first side, and so on; such, however, does not appear to be the case in every instance. The nuclei are flat, for when viewed edgeways they have the appearance of mere stripes. The thickness of the wall of the cylinder seems to vary, as is shown by a comparison of *a* with *c*. The latter, *c*, the wall of which is the thicker, already presents an appearance of transverse striæ. The nuclei, however, are also still visible in it, as well as small isolated globules which are contained in its cavity. Muscular fibre does not present any appearance of a cavity after the period of development before mentioned has passed, but the nuclei remain visible for a long time, lying in the thickness of the fibre, and often project upon the outside in the form of small prominences.

The other form of muscular fibre is delineated in pl. IV, fig. 1, from the dorsal muscles of a fœtal pig of three inches and a half in length. They are in general somewhat thicker than those last described, more irregular, not so smooth, but more granulated. The existence of a special wall to the fibre and of a cavity in its interior, may be quite as distinctly, or even more clearly, recognised in many of these. (See the fibre *c* in fig. 1.) The wall is not so smooth as in the other form of muscular fibre. The contents are always very granulous. Distinct cell-nuclei, and not unfrequently nucleoli also, even in the natural state, may often be perceived in them. Commonly, however, only the circular or oval outlines of the nuclei are distinctly perceptible, in consequence of the other granules which are contained in the cavity of the fibre lying above them, and the general granulous nature of the fibre renders an accurate discernment of the nucleus particularly difficult. But if a drop of acetic acid be added, the fibre becomes perfectly transparent, and swells; the nuclei, on the contrary, remain dark, shrivel up slightly, and may then be distinguished with perfect accuracy. This is exemplified by fig. 2, which represents the fibre *c* of fig. 1 after having been treated with acetic acid. The indubitable cell-nuclei, partially furnished with nucleoli, are there seen, with isolated small dark granules between them. The nuclei have indeed undergone a slight change from the acetic acid, but they do not all present a regular aspect even in the recent state. The majority of them are flat. In the recent state, some appear to be placed on their edges, presenting an appearance as though the cavity of the fibre were divided into compartments by small thick transverse striæ. The nuclei lie much nearer together in this than in the form of muscular fibre previously described, so that the distance of the central points of two nuclei from one another, is generally equal to, or even less than, the thickness of the fibre.

This second form of muscular fibre appears to be an earlier condition of the first. The younger the embryo the more abundant is this form of fibre, and it gradually becomes less so as development proceeds. The steps of this transition may readily be conceived. The fibre becomes extended in its entire length, is thereby rendered thinner, the cell-nuclei are removed farther from one another, and in some instances are also elongated in the direction of the fibre. Some of the nuclei, those for instance which appear to be placed on their edges, may possibly become absorbed at the same time, for they never present that position at a later period. The development of the whole cylinder proceeds simultaneously, its granulous aspect disappearing, and the small granules of the cavity also diminishing in quantity. All the stages of transition from the second form into that first described may be observed. The extension does not appear to take place quite regularly, but may be stronger at particular parts, so that, for a considerable extent, a fibre may be somewhat narrow, and present no nucleus, and then again an intumescence occurs in which a nucleus lies.

It now, however, becomes a question how the form of muscular fibre last described is generated, and what its elementary form may be. It presented a cylinder, which is most probably hollow, and may be presumed to be closed at both ends, since the muscular fibres terminate abruptly at the tendons, with a well-defined and bluntly-rounded extremity. Cell-nuclei lie within this cylinder at very small distances from one another. Is the cylinder an elongated cell, in which nuclei are formed as the rudiments of new cells, which, however, are not developed; or are the nuclei the remains of cells, which, by coalescence with one another and absorption of the septa, form the entire fibre or cylinder? Or, in other words, is the fibre generated by a coalescence of cells?

I have not observed the stages of transition in which original cells arranged themselves in a linear series to form a fibre, the recent embryos at my command not being sufficiently young for the purpose. I have, indeed, met with an appearance in the form of muscular fibre last described, which might be regarded as an indication that those fibres are composed of small portions joined together. Their margins were incurvated at different spots, and a line, indicative of a division, ran transversely across the entire thickness of the fibre. I have endeavoured to delineate this appearance in pl. IV, fig. 1, *b*, but I have not succeeded in representing its true character, and it was not, in itself, conclusive. There are some other arguments in favour of the fibre of muscle being composed of separate particles. Many of the muscles of fishes or tadpoles, for instance, when simply torn, separate into microscopic particles, which have an almost similar length. The same takes place, according to C. H. Schultz, during the digestion of muscle in the stomach, and, according to Purkinje, in muscle which is exposed to the action of an artificial digestive fluid. The observations of Valentin, already mentioned, admit, however, of no other explanation than that previously given; and the history of the period of formation deficient in my researches (from the cause before stated) may be completed from his. According to him, "globules of the primitive mass, arranged longitudinally, in a linear series, are present previous to the muscular fibres. The granules, then, seem to draw somewhat nearer together, and to coalesce, at some parts completely, at others, on the contrary, only on the one or other side. In this manner threads are formed, which present at some spots the appearance of strings of pearls, whilst at others they are less sharply indented; they are also often seen to be still wrinkled on one side, while on the other their margin is already nearly a straight line. The expression "granules of the primitive mass" (Urmasse), or other similar terms, have been hitherto used to denote either the elementary cells themselves or their nuclei, indiscriminately; in consequence of the distinction between them, and their relation to each other being unknown. In the passage quoted, Valentin cannot have meant the nuclei, for, as we have seen, they do not coalesce. What he calls globules of the primitive mass must, therefore, be the elementary cells furnished with their nuclei, and in their earliest stage of development; that is, before they have undergone any transformation. The following arguments may likewise be adduced in favour of the correctness of the explanation which assumes these "globules of the primitive mass" to be cells. In the first place, the structure formed by their coalescence, namely, the primitive fasciculus of muscle, is hollow; and, secondly, in the early stage of development of the fasciculi, the cell-nuclei lie just so closely together, as they would if each nucleus had pertained to a previously round cell. If these nuclei were subsequent formations, generated in the primitive fasciculus of muscle, as in a cell, they ought to be more numerous in old than in young muscles.

It, therefore, seems scarcely to admit of a doubt, that each primitive muscular fasciculus is a secondary cell, formed by the coalescence of primary round cells, each furnished with a nucleus, and which were arranged together in a row. After the coalescence of the contiguous portions of the cell-walls has taken place, an absorption of the septa remaining between the cavities of the two neighbouring primary cells must commence, since no such septa can be perceived within the secondary cell at a later period. If the little transverse striæ, by which the cavity of the fibres is sometimes divided, be actually nuclei placed transversely upon their edges, they are probably such as lay upon that part of the wall of the cells which was absorbed. It seems that the coalescence of the cells, however, is not sufficiently complete to prevent a separation taking place more readily at the points of junction than elsewhere, and on this the phenomena of the artificial division of muscle before mentioned probably depend.[1]

When I made my first communication upon the formation of the primitive fasciculi of muscles by the coalescence of cells (Froriep's Notizen, No. 103), the only corresponding instances known to exist among vegetable cells were those of the spiral and lactiferous vessels. The interest attached to the subject has very much increased since Meyen's discovery of a much more striking analogy in the cells of the liber or inner bark —(bastzellen). (Wiegmann's Archiv, 1838, p. 297.) He found that these long-extended cells, when boiled in hydrochloric acid, fell into small particles of nearly equal length; and investigation into the development of the cells of the liber in buds showed, that in the early period a corresponding quantity of distinct, somewhat longitudinally extended, prismatic, parenchymal cells are present, which are placed with their extremities accurately arranged one upon another, that they unite together at those parts, and that their septa are afterwards absorbed.

The secondary muscle-cell passes subsequently through all the changes incident to a simple cell. Its wall is at first thin,

[1] It might be important to examine whether the zigzag plications of muscles, during contraction, have not perhaps some connexion with the length to which the portion of a muscular fibre generated from one single cell has become expanded, so that probably the angle of each flexion coincides with the point of junction of two cells.

and it contains many small granules in its cavity in addition to the nucleus. A transformation of the cell-contents then takes place, the granules gradually disappearing; the wall of the cell at the same time becoming thicker at the expense of the cavity, so that eventually the latter completely disappears, and the entire secondary cell is converted into a solid cord. The cell-nuclei at first remain whilst this thickening of the cell-wall is going on, and become enclosed by it, rather than pushed into the cavity of the cell. They are at length entirely absorbed. Is, then, the thickening of the wall of the secondary muscle-cell a thickening of the cell-membrane itself, as appeared to be the case in cartilage? or is it a secondary deposit upon its inner surface, so that the cell-membrane is chemically and microscopically distinct from the substance, by means of which the secondary cell becomes converted into a solid cord? The latter is the more usual case in vegetables. The position of the cell-nuclei affords important evidence for the solution of the above question; for as those bodies, generally at least, lie firmly attached to the inner surface of the cell-membrane, they would be pushed towards the interior by a thickening of the cell-membrane itself, whilst a secondary deposit upon its inner surface, must enclose and fix them there, unless they should become separated altogether from the cell-wall. Now, in muscle, they actually remain lying in the circumference of the fasciculus, as represented by pl. IV, fig. 3, *b*. This fact, then, renders it probable that the thickening of the wall of the secondary muscle-cells is due only to a secondary deposit. Such a supposition must, however, have been adopted, independent of the argument just raised, since the muscular fasciculi are, as it seems, enclosed by a structureless membrane. The fasciculi have been long described as invested by a sheath, but that investment has been considered to be composed of cellular tissue, and to correspond in the primitive fasciculi to the cellular tissue, by which the larger fasciculi are separated from one another. This membrane seems, however, to have quite a different signification, and to be the cell-membrane of the secondary muscle-cell. It is structureless, very transparent, and appears as a very narrow and sharply-defined border around each primitive fasciculus. I well know how readily such an appearance is produced by a mere optical deception, and that one can never be positive with respect to it unless it be observed that the margin in question does not accurately follow every bend of the fasciculus. It is, therefore, difficult to be convinced of this in mammalia; but in all those larvæ of insects which present the broad transverse striæ of the fasciculi, discovered by Müller, the membrane, when the continuity of the proper muscular substance of a primitive fasciculus has been broken at a certain point, may be distinctly observed passing over uninterruptedly from the one portion to the other. Pl. IV, fig. 4, represents such a fasciculus; the membrane encompasses it so loosely (this larva had been preserved in spirits of wine) that a portion of the muscular substance could even change its position within the cavity. The membrane, where entirely isolated from the other parts of the preparation, shows itself to be quite structureless, and, indeed, the sharply-defined external contour renders it very improbable that it should be composed of areolar tissue. I, therefore, consider it extremely probable that it represents the cell-membrane of the secondary muscle-cell. It thus not only serves to isolate the fasciculi, but forms an essential constituent part of them. Pl. IV, fig. 5, exhibits this structureless membrane upon a muscular fasciculus of the pike; this preparation, however, was not quite convincing, inasmuch as the inferior edge of the fasciculus was covered by muscles lying above it. By means of this membrane, the muscular fasciculus remains, throughout its entire existence, a cell with a closed membrane and a cell cavity, the latter being filled with a firm substance, the peculiar muscular substance. It, therefore, clearly follows from the above that nervous fibres cannot pass between the primitive fibres (fibrils) of muscle; and that the latter cannot separate from their fasciculi, so as to pursue a more extended and independent course, as is common with fibres of areolar tissue; since, in either case, the cell-membrane must be ruptured.

The true muscular substance, which is thus, in the first place, formed as a secondary deposition upon the inner surface of the secondary muscle-cell, and continues to be so deposited until the entire cavity is filled, is composed in its mature condition, of very minute longitudinal fibres, the so-called primitive fibres (fibrils) of muscle. These longitudinal fibres do not appear to represent the original condition of the secondary deposit, but the latter is structureless at first, and its transformation into fibres takes place subsequently. The change seems, however, to commence at a very early period, and indeed before the cavity is completely filled. The transverse striæ of the muscular fasciculi, which, according to my mode of explanation, are produced by the peculiar form of the primitive fibres, likewise make their appearance before the complete filling up of the cell-cavity, as pl. IV, fig. 3, *c*, exhibits.

According to the observations of Meyen on the formation of the cells of the liber, after the coalescence of the cells and absorption of the septa, a secondary deposit also takes place upon the common cell-membrane in the same way that we have observed to take place in muscle; but I know of nothing amongst vegetables analogous to a secondary deposit consisting of longitudinal fibres. On the contrary, according to Valentin, such deposits appear to take place in plants universally in spiral lines. The beaded appearance which the primitive muscular fibres here and there present, might perhaps be regarded as the result of this tendency to a spiral formation, the intumescences (beads) being so placed, as to produce the transverse striæ, and the latter may perhaps be spiral and not circular. This is, however, a mere conjecture, and requires further research.

The involuntary muscles, such as do not present the transverse striæ, appear to originate in a manner similar to that just described. They differ, however, from the voluntary or striated muscles, in their fibres being generally shorter than those of the latter; probably, therefore, fewer primary cells arrange themselves together to form a secondary cell, and their fibres are commonly thinner and flat. I found in a human uterus, which contained a mature fœtus, some long muscular fibres of the breadth of the common primitive fasciculi of voluntary muscles, which were so flat as scarcely to amount to 0·0010 to 0·0015 of a line in thickness. The involuntary muscles, likewise, have cell-nuclei, proving that the fibres composing them do not correspond to the primitive fibres (fibrils), but to the primitive fasciculi of the voluntary muscles. An opposite view of the matter might be taken from the circumstance of their frequently exhibiting no trace of longitudinal striæ, and that probably the greater portion of them do not contain other more minute primitive fibres, or at least only such as are imperfectly developed. In this respect they are not so highly developed as the voluntary muscles. Perhaps the peculiar secondary deposit upon the cell-membrane of the secondary cell is all that is essential to the contraction of muscle; and it may not be important that that substance should consist of minute longitudinal fibres.

In order briefly to recapitulate our researches into the generation of muscle, the process may be thus stated. Round cells, furnished with a flat nucleus, are first present, the primary cells of muscle. These arrange themselves close together in a linear series; the cells thus arranged in rows, coalesce with one another at their points of contact; the septa, by which the different cell-cavities are separated, then become absorbed, and thus a hollow cylinder, closed at its extremities, the secondary cell of muscle, is formed, within which the nuclei of the original cells, from which the secondary cell has been formed, are contained, generally lying near together on its wall. This secondary cell, then, passes through all the stages of a simple one. It expands throughout its entire length, whereby the nuclei are farther removed from one another, and sometimes even become elongated in the same direction. A deposit of a peculiar substance, the proper muscular substance, takes place at the same time upon the inner surface of the cylinder, by which the cavity is at first narrowed, and at length completely filled. The cell-nuclei lie external to this substance, between it and the cell-membrane of the secondary cell.

The transverse striæ in the voluntary muscles become more manifest, and the deposited substance is more distinctly seen to be composed of longitudinal fibres, as the fœtus advances in age. The nuclei are gradually absorbed. The cell-membrane of the secondary muscle-cell remains persistent throughout life, so that each primitive muscular fasciculus is always to be regarded as a cell.

2. *Nerves.* The nervous system presents two forms of elementary structure: 1st, fibres, nervous fibres in the ex-

tended sense of the term, including the fibres of the brain and spinal cord: 2d, globules, ganglion-globules, in addition to the ganglia occurring in the brain and spinal cord. Our task is to point out the relation which these two forms of elementary structure bear to the elementary cells.

Nervous Fibres.

Of these, there are two different forms: *a*, the common white nervous fibres; *b*, the gray, so-called organic fibres.

a. White nervous fibres. They have the appearance of fibres, which, when examined microscopically, exhibit very dark margins, and these margins are produced by a substance apparently identical with that which gives them their white colour when examined with the unaided eye. Since the cause of this colour does not appear to be situated in the whole fibre generally, but to be confined to its external portion, this latter may be termed the white substance of the nervous fibres. The margin of a fibre generally presents a double outline on both sides, so that it has the appearance of a hollow tube, and the distance between the two outlines, then, denotes the thickness of the white substance. According to the researches of Remak, the white substance of every nervous fibre may be removed by pressure, and an extremely pellucid, pale band, which was previously surrounded by the white substance, then remains, corresponding to that which, previous to the manipulation, seemed to be the contents of the tube. (See R. Remak, Obss. Anat. et Microsc. de Syst. Nerv. Struc., Berol. 1838.)

Two opinions with respect to the nervous fibres may be deduced from the above observations; either this pale band is the proper nervous fibre, and the white substance only a sheath (cortex) around it (this is the view taken by Remak), or the nervous fibre is actually a hollow fibre, the wall of which is formed by the white substance, the contents of which, however, are not fluid, but composed of a tolerably firm substance, namely, the above-mentioned band.

The history of the development of the nervous fibres must explain the relation which they bear to the cells. Remak[1] describes the early condition of the nerves in the following manner: "The substance of the cerebro-spinal nerves of the rabbit, in the third week of embryonal existence, consists of corpuscles, some of which are irregularly spherical, others slightly elongated, having a very delicate filament adhering to them; they are mostly transparent, and arranged in rows without, however, presenting any distinctly perceptible fibrous structure." And l. c. page 153, he says, "A structureless and general globular mass is the original form, from which the primitive fibres of the cerebro-spinal nerves are developed. These primitive fibres are at first varicose, and contain no medulla; most of them pass into the cylindrical form, through the intermediate stage of transitional fibres."

I have investigated the development of nerve in the fœtal pig. The nerves of the fœtus have not the shining white colour, presented by those of the adult animal, but are gray and transparent, and the younger the embryo the more striking are these appearances. We are, therefore, quite prepared to find that microscopic investigation shows the white substance of the fibres to be less perfectly or not at all developed. If a nerve, taken from a fœtal pig of about six inches in length, be spread out, in the usual mode of preparation by tearing it under water, some fibres are seen which very much resemble those of the adult animal, and which are furnished with outlines almost as dark. The greater part of the substance, however, does not form connected fibres, but consists of separate round globules, or more or less long, irregular little cylinders, arranged with their long axes in the direction of the course of the nerves, having outlines, however, quite as dark as those of the nervous fibres. These appear to be what Remak refers to in the description previously quoted. In addition to them, however, a substance of quite another appearance is seen, which has not the dark outline, does not appear pellucid but granulated, and in which the cell-nuclei are distinctly recognisable.

When the other constituent parts predominate, the nuclei

[1] Müller's Archiv, 1836, p. 148. Respecting the microscopic structure of the brain and spinal cord of the fœtus, see Valentin, Entwickelungsgeschichte, p. 183.

may very probably be overlooked, or possibly be regarded as extraneous substances. But they are in fact the primitive structure of nerve, for the younger the fœtus the greater is their relative quantity, and in a pig's fœtus of three inches in length, I found them the sole constituent of nerve, none of the fibres furnished with the dark margins, nor any of the cylinders or globules being visible at that period of development. The development of nerve, however, does not appear to proceed uniformly in all individuals; for the dark globules and cylinders were already present in some other pigs' embryos, which were scarcely any larger. Pl. IV, fig. 6, represents a portion of the ischiatic, and fig. 7, of the brachial nerve of such a fœtus. We observe a palish, and very minutely-granulated cord, which, in consequence of certain longitudinal shadings, such as the delineation exhibits, presents the appearance of a coarse fibrous structure. Round or for the most part oval corpuscles, which are immediately recognised as cell-nuclei, and which sometimes also contain one or two nucleoli, are generally seen in the course of these shaded parts, throughout the entire thickness of the cord. Sometimes a fibre separates from such a cord, and stands out isolated, as at *a* in both the figures, and the nuclei are then seen to lie in the course of the fibres. A single fibre presents several nuclei in its course, as was also observed in secondary muscle-cells (see fig. 8, *b*), but I have never remarked it in the cells of the fourth class, the fibre-cells. Although the (nervous) fibres cannot at this early period be distinctly perceived to be hollow, the wall not being distinguishable microscopically from the contents, yet we shall see that the progress of development renders it highly probable that they are so. If then these (nervous) fibres are so far analogous to the early condition of secondary muscle-cells, that they are hollow, and in various parts of their course contain nuclei, whose form shows them to be ordinary cell-nuclei, it is probable that they are generated in a similar manner to muscle; that is, that they are formed by the coalescence of primary cells, to which the nuclei, just noticed as present upon the fibres, have pertained; so that thus the nervous fibres would be secondary cells, corresponding to the secondary muscle-cells, or primitive muscular fasciculi. The actual observation of the primary cells of nerve in their independent state, is very difficult, from the circumstance of our being unable at that period to distinguish between them and the surrounding tissues; for a whole organ is then composed entirely of independent cells, which have not as yet undergone any transformation. It is true I saw an independent cell, furnished with a nucleus, which seemed to have separated from the nervous cord, in one of the preparations alluded to, fig. 6 *b;* but I cannot positively assert that it had actually separated from that particular part, nor that it was a primary nerve-cell, for the cells in that preparation had not as yet undergone any change. In this instance, therefore, we must content ourselves, for the present at least, with the analogy to muscle.

These fibres, or secondary nerve-cells, differ very much in their appearance from the subsequent nervous fibres, which are furnished with distinct but not dark outlines; they have a pale, granulated aspect. By progressive development, however, they become converted into the white fibres, and pl. IV, fig. 8, *d,* represents the transition. The part of the figure to the right hand exhibits the fibre yet in the early condition, pale, granulated, and furnished with a cell-nucleus; in the portion to the left, it has completely assumed its subsequent form: it has a dark outline, is not granulated, and the one portion passes immediately into the other. The identity between these pale fibres and the subsequent white nervous fibres is thus established.

In what then does this transformation of the pale granulated fibres into the white fibres consist? Clearly in the development of the white substance; we may, however, imagine three different modes in which this development may take place. It may take place, 1stly. By the white substance forming as a sheath (cortex), around each fibre, and in this manner enclosing it. By this mode of explanation the fibre would be identical with the pale band discovered by Remak, which would therefore be the cell-membrane itself. 2dly. The white substance might be regarded as a transformation and thickening of the cell-membrane of those fibres, or secondary nerve-cells. According to this view, the white substance would be the cell-membrane, and Remak's band the firm contents of the secondary cell. 3dly. The white substance may be formed as a secondary deposit upon the inner surface of the cell-membrane, being chemically distinct from the latter, and the remainder of the cell-cavity may then, and not until then, become filled up by Remak's band.

It will be seen that the above question is analogous to that raised when we were treating of muscle, viz., whether the proper muscular substance be a thickening of the original cell-membrane itself, or a secondary deposit upon it. The reply is not, in either instance, essential to the proof of the origination of nerves or muscle from cells, but it is of so much the more importance for the explanation of the structure of a perfectly-developed nerve. If any conclusion may be drawn from the few observations which I have made on this point, the latter view appears to me the most probable, viz., that the white substance is a secondary deposit upon the inner surface of the cell-membrane. The white substance of each nerve is surrounded externally with a structureless and peculiar membrane, which appears to be minutely granulated. This membrane presents itself as a narrow, clear border, which is readily distinguished from the dark contours of the white substance. This membrane seems hitherto to have been included with the neurilema or with the cellular tissue, which surrounds the nervous fibre, and although its external outline is generally very sharply defined in the nerves of the frog, it would be difficult, on examination of the entire nerve of a mammal, to arrive at any conviction of its distinct and separate existence, did not opportunities of observing it in an isolated state present themselves. Pl. IV, fig. 9 *a*, represents such a preparation, taken from the cranial portion of the nervus vagus of a calf. The continuity of the white substance has here been broken by the process of preparation; but where it still exists, the double contours, (and thus the thickness of the white matter), may be clearly distinguished. But the nerve still exists at the part where the white substance is separated, its sharply-defined external margins may be seen, although their contours are but pale, and it may be observed that this pale outline does not pass into the external dark one of the white substance, but is continued on the outside of it as a narrow border, parallel to the two outlines of the white substance. The white substance of nerve is, therefore, surrounded externally with a thin, pale membrane, which has a sharply-defined external margin. If the membrane be very thin, it cannot be recognised as the pale border round the nervous fibre; it is still, however, distinctly visible at situations where the white substance is destroyed. (See fig. 9 *b*.) The mere fact of the membrane possessing a defined external border, is evidence against its being composed of areolar tissue; and even the portion which does not contain any white substance, presents no appearance of a fibrous structure; it simply appears to be somewhat minutely granulated. If this be correct, the membrane can have no other signification than that of cell-membrane of the nervous fibre, or secondary nerve-cell. The white substance is then a secondary deposit upon its inner surface. The position of the cell-nuclei is also favorable to this view. Most of the cell-nuclei, presented by the nervous fibres in their earliest and as yet pale condition, disappear during the formation of the white substance, a circumstance which is common to most other cells. Some, however, appear to remain for a longer period; occasionally, although rarely, a cell-nucleus is here and there seen upon the side of a nerve, (the white substance of which is completely developed), lying in the pale border, which surrounds the white substance. Fig. 9, *c* and *d*, exhibits them from the nervus vagus of a calf. At *c* the white substance, corresponding to the nucleus, even forms a slight projection into the cavity of the fibre. This nucleus seems therefore actually to belong to the fibre, and to lie upon the inner surface of the cell-membrane, while the white substance is so deposited, that the nucleus remains situated external to it. The band discovered by Remak would then be the proper cell-contents. Meanwhile I beg that the above may be regarded simply as an attempt at an explanation, the accuracy of which must be decided by further researches, for much more extensive investigations and a separate and distinct consideration are absolutely necessary for accurate decision of so important a subject.

According to the foregoing explanation, therefore, each nervous fibre is, throughout its entire course, a secondary cell, developed by the coalescence of primary nucleated cells. With respect to these cells, we remark, 1stly. An external, pale, thin cell-membrane, having a granulated but not a fibrous aspect, the inner surface of which constantly exhibits cell-nuclei in the very early period of the development of nerve; but in the somewhat more advanced stage, when the white substance is developed, they are only occasionally found. 2dly. That the white, fat-like substance to which the peculiar appearance and distinct outline of the nerves are chiefly referable, is deposited upon the inner surface of this cell-membrane. When this deposit is thick, its double contour (to which the nerve is indebted for its tubular appearance), may be recognised; this, however, escapes observation when only a thin stratum of white substance is present. Morphologically considered, it therefore corresponds to the peculiar substance of muscle, for that is likewise developed as a secondary deposit upon the membrane of the secondary muscle-cell. 3dly. That the rest of the cell-cavity appears to be filled up by a firm substance, namely, the band discovered by Remak. There seems to be no structure analogous to this band in perfectly-developed muscles, for there, the secondary deposit, that is, the formation of the proper muscular substance, proceeds until the cavity of the secondary cell is completely filled.

We have thus traced the development of nerve to its perfect state, without those irregular globules and little cylinders with the dark outlines, (which were mentioned at page 143, as occurring at a middle stage of the development of nerve in addition to the pale fibres and the matured nervous fibres), having proved to be a transitional step in the process. I am inclined to regard them as an artificial product, caused by pressure and the action of water upon the as yet very delicate nerve. If, for example, water penetrate through the cell-membrane by imbibition, the oil-like white substance retracts into separate rounded bodies, and the facility with which this takes place is proportionate to its slight degree of consistence. This is often seen even in fully-developed nerves; an entire nerve frequently separates from this cause into separate globules or little cylinders, which have sharply-defined outlines, so that merely the cell-membrane proceeds uninterruptedly, in the form of a pale stripe, from the external wall of one of the dark portions to that of the other. Valentin has given a delineation of such a state of the nervous fibre, (Acta Acad. Leopold. Nat. Curios. vol. xviii, pl. III, fig. 7). As the white substance is less consistent in the fœtus, it separates the more readily, and the artificial generation of such globules is very easy of observation in fœtal nerves.

The growth of nerves neither proceeds from the circumference towards the central organs, nor *vice versâ*, but their primary cells are included amongst those from which every organ is formed, and which, so far at least as their appearance is concerned, present no marks by which they can be distinguished from other cells. They are first characterized as nerves, when they become arranged in rows and coalesce to form a secondary cell. After that coalescence each nervous fibre forms a separate cell, which pursues an uninterrupted course from the organ, in which its peripheral extremity is situated, to the central organ of the nervous system. The white substance of nerves does not appear to be formed at so early a period in their peripheral extremities, as it is in their trunks. The Medizinischen Zeitung for August 1837, contains a description which I gave of some nerves from the tail of frog's larvæ, which presented an appearance quite different from ordinary nerves, inasmuch as they had a pale contour and no perceptible cavity. They were nerves in an early stage, previous to the development of the white substance. They represent the only form of nervous matter which we find in the tail of very young larvæ. Some isolated nerves, having the ordinary appearance of the dark contours, gradually make their appearance, and afterwards increase in quantity; they were first observed in the neighbourhood of the muscular fasciculus which traverses the middle of the tail. The development of the white substance appears therefore to advance from the trunks towards the circumference. These white fibres become more minute and paler towards the periphery. Sometimes such a fibre seems to terminate suddenly with even an incomplete acumination. But, on a more accurate observation, some extremely delicate, very thin filaments are generally seen going off from it. The pale immature fibres in the tail of the frog's larvæ also subdivide. A question now arises are those more minute fibres (which at least present an appearance of subdivision) already prepared within an ordinary white primitive nervous fibre, or are they actual subdivisions? Since each nervous fibre is a secondary cell, and retains its character as a simple cell, and since the simple cell-membrane continues to exist distinct from its secondary deposits, and from the cell-contents, it is quite conceivable that fibres may be generated in the secondary deposits or in the cell-contents, as they are in muscle, although we have as yet no evidence of the fact; but these fibres could no more issue out free from the white nervous fibre, than the primitive fibres of muscle could from secondary muscle-cell, because, in order to do so, they must necessarily rupture the cell-membrane of the secondary cell. These subdivisions, therefore, so far as the structure from whence they issue corresponds to an ordinary nervous fibre, and is not merely a fasciculus of very minute secondary nerve-cells, cannot be a mere appearance, nor anything but actual divisions, a simple secondary nerve-cell becoming elongated into several minute fibres, in a manner analogous to that which we have witnessed in the fibre-cells, (see page 115.) The nerves in the tail of the tadpole may therefore be described as terminating by the nervous fibres, that is, the secondary cells becoming split in different directions after the manner of fibre-cells or stellate cells. In the memoir before alluded to, I have noticed some swellings upon the pale nervous fibres in the tail of the tadpole. They have a double signification; some which are marked off from the rest of the fibre by a sharply-defined outline are the nuclei of the cells, from which the fibres have been generated; the majority, however, which pass into the fibre without a well-defined contour, as generally occurs at situations where the fibres divide and diverge towards different sides, are the bodies of the original cells, which (especially when they become elongated at different parts into fibres) remain somewhat thicker than the prolongations themselves; the pigment-cells, pl. II, fig. 9 *a*, exhibit this appearance.

b. Gray or organic nervous fibres. The gray cords, which, according to the researches of Retzius and J. Müller, are derived from the sympathetic nervous system, and mingled with the cerebrospinal nerves in which they sometimes pursue a long isolated course, owe their gray appearance, according to the investigations of Remak, "to the peculiar structure of the primitive fibres, which arise in the ganglia. They are not tubular, that is, surrounded with a sheath, but naked, being transparent, almost gelatinous, and much more minute than most of the primitive tubes. They almost always exhibit longitudinal lines upon their surface, and readily separate into very minute fibres. In their course they are very frequently furnished with oval nodules, and covered with certain small oval or round, more rarely irregular, corpuscles, which exhibit one or more nuclei, and in size almost equal the nuclei of the ganglion-globules." (Observationes anat. et microsc. de system. nervos. structura. Berol., 1838, p. 5.)[1]

These corpuscles may at once be recognised, both in Remak's delineations, and when examined in the natural state, to be cell-nuclei, which are round or oval, and frequently furnished with one or two nucleoli. They are attached to the most minute fibres, and as they are thicker than the fibres, they often appear to be situated only on their outside. Observation, however, does not warrant the conclusion that such is actually the fact. In the secondary muscle-cells (in which the nuclei decidedly lie within the cell) it frequently appears, and especially in the later periods of development, previous to the disappearance of the nuclei, as if the nuclei lay externally to the cell, inasmuch as they become pushed towards the outside. But no doubt the cell-membrane is at the same time elevated upon them, as we saw to be so distinctly the case in the fat-cells. (Pl. III, fig. 10.) Now, these most minute organic fibres, furnished with nuclei, precisely resemble the earlier condition of the white nervous fibres, as they were represented in pl. IV, fig. 8, *a b*. Both have the same pale, minutely-granulated appearance, and both present cell-nuclei in their course. The only difference is, that the organic fibres are much more minute and the nuclei smaller. Each single nucleated organic fibre (I do not mean an entire fasciculus of them) corresponds to a white primitive fibre, and is probably, like it, a secondary cell, which has been generated by a coalescence of primary cells, whose nuclei are the nodules described by

[1] Remak's discovery of the peculiar structure of the organic nervous fibres explains an observation previously communicated by me upon some extremely minute, pale, nervous fibres, which did not appear tubular, and were nodulated at different spots, and which I discovered in the mesentery of frogs. No doubt they were organic fibres.

Remak as existing upon these fibres. The similarity between the organic fibres and that which I have described as the earlier condition of the white nervous fibres, might be adduced as an objection to my description of the formation of nerves, and it might be said, that that form seemed to be the earlier form of the white nervous fibre, because the organic nerves were developed earlier than the white, and, therefore, organic fibres were the only ones present in the first instance. Observation of the actual transition, as represented in pl. IV, fig. 8, *c d*, would, however, refute this argument. Each pale, nucleated fibre becomes a white nervous fibre, as an immediate consequence of the formation of the white substance, which is probably a secondary deposit upon the internal surface of the hollow fibre. The formation of this white substance, which, according to analogy, must occur in every one of the minutest fibres, either does not take place at all in the organic fibres, or does so at a much later period, and their peculiarity therefore consists in their remaining stationary at an earlier stage of development, and either never attaining to the higher development of ordinary nerves, or only at a much later period, (a point which might be decided by comparing their numbers in old and young individuals.) One can conceive that the function of the organic nerves, whether it be actually a chemico-vital one, or consist merely in the production of involuntary motion, requires less-developed nerves, in the same way that the involuntary muscles do not attain the same degree of development as the voluntary.

2. *Ganglion-globules.*

These occur in the gray substance of the brain and spinal cord and in the ganglia, having generally the appearance of comparatively large granulous globules, enclosing a round vesicle, placed eccentrically, and which again exhibits in its interior one or two small dark points. According to Remak, two of these vesicles sometimes occur in one globule. Valentin (Nov. act. Acad. Leopold. xviii, p. 196), calls attention to the similarity between their composition and that of the egg, he compares the vesicle of the ganglion-globules to the germinal vesicle, their parenchyma to the yelk-substance, and ascribes a protecting investment of fibres resembling areolar tissue to both structures. This is certainly a very striking comparison, but the external investment must not in either instance be regarded as a something *unessential*, as a structure composed of other elementary parts, for the ganglion-globules, like the yelk, are true cells, and their external covering is an essential component part of them; it is the cell-membrane. The vitelline membrane of the bird's egg, while contained in the ovary, is perfectly structureless, not composed of more minute elementary parts; the same is the case with the investment of the ganglion-globules. They are both of them true simple cells. The parenchyma of the ganglion-globules forms the cell-contents, and the vesicle in their interior is the cell-nucleus; the small corpuscles which it contains are the nucleoli. The vesicle of the ganglion-globules lies, as in other cells, eccentrically upon the internal surface of the cell-membrane. This cell-membrane may be most distinctly observed in the ganglion-globules of the sympathetic nerves of the frog, previous to their junction with the sacral plexus. (See pl. IV, fig. 10, *a*.) It there appears comparatively dark, and sharply defined, both externally and internally, so that its thickness may be readily measured. Valentin has already remarked, that the capsule of the ganglion-globules is thicker in the lower animals. In the situation before mentioned in the frog, it seems as though a ganglion-globule were sometimes formed within another cell. (See fig. 10, *b*.) The ordinary contents of these ganglion-globules is a minutely-granulous, yellowish substance. On one occasion, however, I saw a ganglion-globule from the head of an ox (I do not precisely know from what part it was taken), in which the granulous appearance was confined to the surface, the interior being clear,—a fact which was rendered distinctly perceptible by causing the globule to roll about. It is nothing remarkable that two nuclei should sometimes occur in one ganglion-globule; we have observed this already in several cells, in those of cartilage for instance. In those instances, however, only one of them was the true cell-nucleus, the cytoblast of the cartilage-cell, the other being a subsequent formation within the cell.

3. *Capillary vessels.*

Plate II, fig. 9, represents two stellate pigment-cells, which have coalesced at *a*. In that instance two cells had been generated at some distance from one another, their bodies may still be distinguished as two spots somewhat thicker than the rest of the structure. These cells became elongated on different sides into hollow processes, which, like the cavities of the bodies of the cells, are filled with pigment. Two processes of the two cells came into contact at *a*, and then coalesced, the separation at the point of union appears to have been absorbed also at the same time, so that the cavities of the two cells communicate immediately with one another; at all events there is no apparent interruption to the pigment, which forms the contents of the cells and their prolongations. (See page 78.) Now, if we imagine several such stellate cells to be developed on a large surface at similar distances from one another, and the several prolongations issuing from each separate cell to coalesce with those issuing from the other cells, in the manner represented in the figure at *a*, the result will be a network of canals extending over the entire surface, and all communicating with each other. The size of the meshes of the network is determined by the distance of the cells from each other, and by the number of the prolongations issuing from each cell. Such, then, appears to be the process by which the capillary vessels are formed.

The observations, on which this mode of formation of the capillary vessels is based, were made partly on the tails of very young tadpoles, and partly on the germinal membrane of the hen's egg. They are as follows:

1. The capillary vessels, in the tail both of the fully-developed and young tadpoles, are seen to be surrounded by a thin, but distinctly perceptible membrane, which does not exhibit any fibrous arrangement. (See pl. IV, fig. 11.) The variety in the thickness of this membrane in different instances sufficiently explains why we cannot distinguish it in all capillary vessels, just as we cannot detect the cell-membrane even in the blood-corpuscles, although there can be no doubt of its existence. Where the capillary vessels exhibit a fibrous

structure, they have arrived at a more complicated stage of their formation, and I regard such fibres as distinct from their cell-membrane.

2. Very distinct cell-nuclei occur at different spots upon the walls of the capillaries, both of the young and fully-developed tadpole. They appear to lie either in the thickness of the wall, or on the internal surface of the vessels, on which they often form a projection. (See fig. 11.) They admit of a double explanation. They are either the nuclei of the primary cells of the capillaries, or nuclei of epithelial cells, which invest the capillary vessels. It is true that epithelial cells occur in vessels which have a great resemblance to capillary vessels, if they are not actually such, as may be very distinctly seen in the vessels of the membrana capsulo-papillaris in a fœtal pig of from four to six inches long, where some of them project, in the form of half-spheres, into the cavity of the vessel; but there were no epithelial cells perceptible surrounding the nuclei in the capillaries of the tadpole's tail. On the contrary, these nuclei frequently seemed to lie free upon the internal wall of the vessel, and must have been much more abundant had they been nuclei of epithelial cells. That these are the nuclei of the primary cells of the capillaries is, therefore, most probable, although this exclusive argument by no means decides the question.

3. In the tail of very young tadpoles, the capillary network presents, besides the ordinary cylindrical canals which have an equal diameter, and in which the blood flows in a regular current, other vessels of an irregular form. Unfortunately I neglected to make a drawing of them; they accord, however, in all essential particulars with the capillaries of the germinal membrane of the hen's egg represented in pl. IV, fig. 12, except that the meshes of the vascular network are much larger in the tail of the tadpole. They are not regularly cylindrical. They are generally widest in situations where branches are given off, sometimes wider even than the ordinary capillary vessels. (See *a*, *b* in figure 12.) The branches diminish very rapidly as they leave those broad parts, and widen again as they approach another dilated portion They present every degree of narrowing from vessels in which it could scarcely be remarked, to those which are reduced so

much as to be scarcely thicker than a fibre of areolar tissue (as in *c*). Branches are also sometimes given off from these wider parts, which likewise diminish very rapidly to the same degree of minuteness, without reaching another dilated part (as at *d e*), and which are, therefore, blind ones. According to the above view of the development of the capillaries, these appearances may be explained in the following manner: the wider portions, *a, b,* &c., are the bodies of the primary cells. Hollow processes, as at *d,* are sent out from the bodies of the cells as the result of a more vigorous growth in different situations, precisely as is the case in all stellate cells. These prolongations meet with similar ones from other cells, and thus produce the form *c.* But being hollow, they are capable of expansion during their growth, and thus the canal *c* becomes converted into *f,* and at length into *g,* which is as wide as an ordinary capillary vessel. A more accurate analysis of the observations, however, is necessary to enable us to judge of the correctness of this explanation. It might be doubted, in the first place, whether these were really capillaries. The blood flows uninterruptedly through the ordinary capillaries, but there are no blood-corpuscles in these canals, at least in the more minute ones; they are, therefore, more difficult to discover, and readily give rise to a doubt whether they are canals. But their direct continuity with the ordinary capillaries may be clearly demonstrated, and blood-corpuscles actually enter the wider ones. If they be true capillary vessels, they may either be ordinary ones in a state of contraction, or they must represent a certain stage of their development. But if it be difficult to conceive that a capillary vessel can have the power to contract itself almost to the minuteness of a filament of areolar tissue, such an assumption cannot be supported at all in respect to the blind branches, which do not join any other vessel, as at *d.* This form might, indeed, be admitted to be a certain stage of development, although not of the kind described above; but branches might be sent off from the capillaries already existing, which again might give off others. The objection, that such an explanation does not account for the varying width of these capillaries, might be met by assuming that circumstance to depend upon the surrounding substance. It is, therefore, necessary to see the primary cells previous to their union with the actual capillaries. Now it is certain that a great many stellate cells are found in the tail of the tadpole. They lie beneath the epithelium and pigment-cells on the same plane with the capillary vessels; are smaller than the pigment-cells, and contain a colourless or palish yellow substance; they send off processes on different sides, which vary in number very much in different instances, but are generally short, and for the most part do not join with processes from other cells. Their shape has no sort of connexion with that of the pigment-cells which lie above them, for when, as is the case in many larvæ, the latter only send off prolongations on two sides, these cells exhibit several processes on different sides. They cannot, therefore, be young pigment-cells. Such branches of the capillaries, as those at *d*, sometimes appear to be connected with one of those stellate cells, and the others might, therefore, be regarded as young cells of capillary vessels which had not as yet begun to anastomose. These anastomoses, however, are not sufficiently evident to enable me positively to assert their existence. The great number of these stellate cells, and their presence at all ages of the tadpole, are also circumstances unfavorable to the supposition that they are primary cells of capillaries. They might, indeed, be conceived to indicate a lower stage of development, as not having yet undergone any change, and that eventually capillary vessels may be developed from some, whilst others continue their existence without such a transformation, and fill the place of cells of areolar tissue. That, however, would be somewhat too hypothetical, and I shall, therefore, not adduce these cells as proof of the existence of primary cells of capillary vessels. The uncertainty which attaches to the observations on this point in the tail of the tadpole appears, however, to be removed when we examine the incubated hen's egg.

4. When the germinal membrane of an hen's egg which has been subjected to thirty-six hours' incubation (at which period the formation of red blood has commenced, and is distinctly perceptible), is placed under the microscope, and the area pellucida examined with a magnifying power of 450, the capillary vessels are readily distinguished in it by their yel-

lowish-red colour. Notwithstanding repeated endeavours, I cannot succeed at this season of the year when the hens are moulting, in subjecting eggs to incubation for so long a period, I can, therefore, only give a representation of these vessels from a recollection of what I observed in the early part of this year. (See pl. IV, fig. 12.) In some situations the capillaries are perfect, and connected with the larger vessels; at others they have the appearance represented in the figure, and illustrated previously by observations on the tail of the tadpole. In addition to these capillaries, which form a network of canals of irregular caliber and give off blind branches, some separate irregular corpuscles are seen, such as *h* and *i*, which do not appear to be connected with the vascular network. These bodies send off blind processes of various forms in different directions, and have the appearance, therefore, of stellate cells. They have a yellowish-red colour, like that of the bone-capillaries, which circumstance is alone sufficient to suggest the supposition that they are cells of capillary vessels in progress of development. This becomes much more probable, when we observe some of these corpuscles, such as *k*, already connected with the true capillaries. We may, therefore, with a high degree of probability at least, regard them as the primary cells of capillary vessels; and in that case the description of the formation of these vessels, previously given, would be the correct one. The following would, therefore, be the mode in which the formation of the capillaries and of the blood takes place in the germinal membrane: among the cells which compose the germinal membrane, some which are deposited at certain distances from one another, are developed into the primary cells of capillary vessels by becoming elongated on different sides so as to form stellate cells. The processes of the different cells come into contact and coalesce, the septa are absorbed, and in this manner a network of canals of very irregular caliber is produced, the prolongations of the primary cells being much thinner than the bodies of the cells. These processes of the cells or passages of communication undergo expansion until they and the bodies of the cells all attain one equal width, until, in fact, a network of canals of uniform caliber is formed. The fluid portion of the blood constitutes the contents of the primary cells, as well as of the secondary ones—the vessels produced by their coalescence; and the blood-corpuscles are young cells which are developed in their cavities.

Thus this last class, comprising tissues, which, in their functions, are the most characteristic of the animal kingdom, exhibits the same principle of development that we have met with in all the others; namely, that cells originate in the first place, and that these become transformed into the elementary parts of the tissues. The elementary cells in this class, however, undergo more essential changes during their transformation than those of any previous one. They not only do not remain, as in the first two classes, independent, that is provided with a special cavity and particular wall; not only does a coalescence of the walls of neighbouring cells take place, as in the third class, but the cavities of the different cells also unite together in consequence of the absorption of the coalesced partition-walls of the several cells, so that the primary cells cease to exist as distinct objects. It is to a certain extent the opposite process to that which occurred in the fourth class, where, in addition to the prolongation of the cells, a splitting of them into several, probably hollow, fibres, a sort of division of the cells took place. The type of the transformation of the primary cells, as presented by nerve, muscle, and capillary vessels, is not, however, altogether limited to this class, but has been already exhibited by previous classes, and even in plants. Some of the pigment-cells have been cited before as examples, and the generation of the cells of the liber observed by Meyen was brought forward as an instance of perfect analogy in vegetables.

The independent existence of each separate primary cell is, no doubt, lost as a consequence of this perfect coalescence of several cells; not so, however, its character as Cell in general. On the contrary, several primary cells contribute to form one secondary cell, having the full signification of *one* independent cell. Each secondary cell in muscle and nerve forms a closed Whole, and the distinction between cell-membrane and cell-contents or secondary deposit seems to continue throughout life. In this way the nerves bring every part of the body into connexion with the central portions of the nervous system by means of a single uninterrupted cell. The different parts of the body, however, are connected together by another kind of uninterrupted secondary cell, namely, the capillaries. The capillary system, generated from several primary cells, forms one single secondary cell. The cavity of the secondary cell communicates with that of the large vessels. Researches are still required to decide the question whether these latter are mere dilatations of the capillaries, or whether they are formed simply by the junction of other elementary parts. In the latter case the capillary vessels would open into a cavity altogether distinct from their own, just as a vegetable cell opens into an intercellular space. It sometimes occurs that the cavities of certain vegetable cells open directly outwards, but such instances are very rare.

As a primitive muscular fasciculus, a nervous fibre and a capillary vessel are corresponding formations in this class; we may also compare these structures with the elementary parts of other tissues. The elementary cells of all tissues correspond with one another, being formed universally according to similar laws. A blood-corpuscle, an epithelial cell, a cartilage-cell, an elementary cell of areolar tissue (therefore, also a fasciculus of areolar tissue formed from it), correspond to an elementary cell of muscle, &c. There is no structure analogous to an entire primitive fasciculus of muscle or a secondary muscle-cell or a nervous fibre amongst the principal component parts of the tissues previously discussed, because with them the formation of secondary cells only occurs as an exception. A muscular fasciculus differs, therefore, from a fasciculus of areolar tissue, and a primitive fibre of areolar tissue has no analogy with a primitive muscular fibre.

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 clongated 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.

SUPPLEMENT

(REFERRED TO AT P. 46)

ON THE SIGNIFICATION OF THE GERMINAL VESICLE.

WHEN treating of the different parts of the ovum, in the foregoing work, it was found impossible to give a positive solution to the question as to whether the germ-vesicle was a young cell or the nucleus of the yelk-cell. Most of the facts before us were in favour of the latter view; but if this were the correct one, the yelk-cell ought to be developed around the previously existing vesicle in such manner, that it in the first instance closely encompassed the latter, and afterwards became gradually expanded. This decisive observation was wanting, and the researches communicated by R. Wagner, in his 'Prodromus,' rather tended to show that, in the formation of the ovum around the germinal vesicle, the membrane was not formed immediately around the vesicle, but that it inclosed at the same time a quantity of the granular mass in which the germ-vesicle lies. I was not at that time acquainted with a work of Wagner's, which contained the facts necessary to a solution of the question, viz. his 'Beiträge zur Geschichte der Zeugung und Entwickelung., Erster Beitrag:' from the 'Mathematisch-physikalischen Klasse der Königl. Baierschen Acad. der Wissenschaften in München.' Speaking of the ovaries of insects, Wagner says, at page 45:—"At the spot where the oviduct widens, the granular mass, which resembles the vitelline mass, becomes more plentiful; the separate germ-vesicles seem to be imbedded in it. I have so represented it in the 'Prodromus,' fig. 18. Lately, however, it has appeared to me, as though the germ-vesicles with their germinal spots were actually already surrounded by a chorion and a perfectly pellucid yelk." The accompanying illustration from Agrion virgo exhibits clearly how that which Wagner calls chorion, or the cell-membrane of the yelk-cell, closely encompasses the germ-vesicle at first and then gradually expands, while between it and the vesicle a transparent fluid collects; in which, at a later period, a turbidness commences, occurring first in the neighbourhood of the germ-vesicle. Wagner had thus discovered in the course of his observations that the details of the process were just what must have been expected according to the theory of the unity of the principle of development for all elementary particles of the organism. That the germ-vesicle is the nucleus of the yelk-cell appears to me therefore to be scarcely dubitable. The illustration given by Wagner also shows that the germinal spot is first developed, then the germ-vesicle around it, and around this again the yelk-cell. It is not surprising that granulous contents may form within the germ-vesicle at a subsequent period, since the same thing occurs in the indubitable nucleus of the adipose cells of the fish, and the formation of the cell is probably nothing more than a repetition of that same process around the nucleus, by means of which the nucleus was originally formed around the nucleolus.

REMARKS

UPON A STATEMENT PUT FORTH BY PROFESSOR VALENTIN, RESPECTING PREVIOUS RESEARCHES ON THE SUBJECT OF THIS WORK.

After I had finished this Treatise, I received the first part of Wagner's 'Lehrbuch der Physiologie,'[1] Leipzig, 1839; which was just then issuing from the press, and which contained (at page 132) *an outline of the development of the animal tissues,* communicated by Professor Valentin. The author introduces the subject with some historical remarks, in which he represents my researches as giving an essential completeness to the analogies between animal tissues and vegetable cells which had been previously pointed out, more particularly by himself. There are very many ways of drawing a comparison between two objects, and similitudes may be discovered which are opposed to the whole internal construction of the things in which they are observed. Everything, therefore, depends upon the sort of comparison drawn. If Valentin's historical representation be justified, the idea of a comparison, similar in its kind to that on which my researches are based, must have a previous existence in his earlier investigations. I have endeavoured to analyse the fundamental idea of my investigation in the commencement of the Third Section of this treatise; it was this—that one common principle of development forms the basis of all the elementary particles of organisms. It originated in a comparison being drawn between a cartilage-cell and a vegetable cell, in such sense, that the molecules are united together for the formation of both of them, in accordance with similar laws, since in both instances a nucleolus is first formed; around this

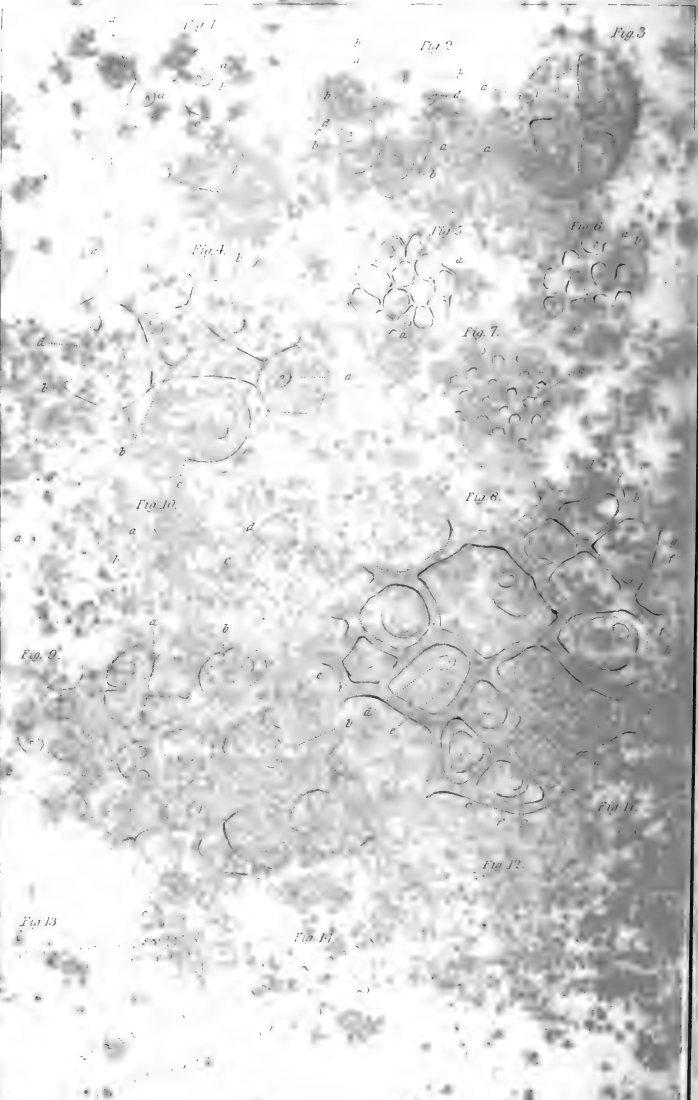
[1] Rudolph Wagner's Elements of Physiology, translated by R. Willis, M.D., p. 214.

a nucleus, and around this again a cell. The accordance in the mode of development of two so different elementary particles, first led to the deduction of the principle of a similar mode of formation for all elementary particles, and then to its proof by observation. Therefore, what we have to decide is, first, whether the idea of comparing an animal elementary structure with a vegetable cell, with reference to a similar mode of development, does occur in Valentin's earlier observations; and, secondly, whether Valentin has recognised the principle which is contained in the similar mode of development of two elementary particles which, in a physiological sense, are very dissimilar. In my preface I have given a brief historical sketch of the subject from my own point of view, and Valentin's remarks do not convince me of the necessity of making any alteration in it. Impartiality, however, requires that Valentin's representation should follow this statement, and I therefore append the passages cited by him, word for word, from his works:

"*In my first histogenetic researches, I observed certain peculiar granules lying in a transparent gelatinous substance, as the primordial matter of all the tissues. I pointed out the difference between these granules in the serous and mucous layers, at the period of the earliest separation of the layers from one another. In the vascular layer I found large globules or cells, which, in respect to their form and juxtaposition, I compared, as early as the year* 1835, *with vegetable cellular tissue.* (Entwickelungsgeschichte, 287. The vascular layer seems to be composed of large globules having a mean diameter of 0·001013 Paris inch, which are perfectly transparent in their interior, and so closely crowded together, that they are flattened against one another at many of their points of contact, and assume an hexagonal form like the cellular tissue of plants.) *I also first directed attention to the resemblance in form of the cartilages in which ossification was commencing, and particularly* (*from observations made in conjunction with Purkinje*) *of the branchial cartilage of the tadpole to the vegetable cellular tissue.* (Ib. 209-10. The cartilages of the labyrinth present a variety of form whilst passing through the process of ossification, which differs very essentially from most of the other cartilages of the body, which will be described at greater length presently. In place of the ordinary cartilage-corpuscle, they contain large bodies which are not so well defined in form, most of them furnished with linear boundaries, being roundish, semilunar, tetrahedral, or polyhedral in shape, with a mean diameter of from 0·000405, to 0·000650 Paris inch. But so soon as they ossify, the calcifying portion, or that which is already ossified, consists of a tissue of beautiful six-sided prisms (Balken), closely resembling vegetable cellular tissue, upon and within which are small granules of a round figure, with a diameter of about 0·000152 Paris inch. The last described form, was observed both by Purkinje and myself long since in the cartilages of the tadpole also, especially in the branchial arches.) *I described the round cells of the globules with their interposed cellular substance from the chorda dorsalis of young embryos.* (Ib. 157. Although the external appearance of the chorda dorsalis clearly presents a certain resemblance to a cartilage, the microscopical investigation of its structure most distinctly disproves similarity. In every instance in which it is present, it consists of an external, symmetrical, perfectly transparent envelope and globules of variable size, but always very numerous, and lying closely packed together. A gelatinous and perfectly transparent mass occupies the interspaces left between them. These globules are largest in fishes and amphibia, smaller in birds, and smallest in mammalia." In the second passage, which Valentin cites on this point (Repertor. i, 187), the researches of J. Müller, which I have noticed at page 7 in this treatise, are referred to and quoted, the following also is from the same source:—"which (chorda dorsalis) the reporter (Valentin) has also observed in fœtal pigs of eight lines in length, in the form of a thick cord lying within the cartilaginous vertebræ, its internal structure, in the embryos of mammalia, birds, and amphibia, being, according to his observations, essentially similar to the permanent analogous formations of the cartilaginous fishes.) *Soon after this J. Müller, from his own independent investigations, gave a more detailed explanation of the cells in the spinal cord of fishes* (*Myxinoiden,* 74, *&c.*) *In the epithelia, which Purkinje and Raschkow* (Meletem. c. mammal. dent. evol. 12), *as well as I* (Nov. act. ac. N. C. vol. xviii, p. 1. 96)——These (the tuft-like groups of the choroid plexus) do not lie free, but they, as well as the connecting granulous membrane, are covered with a very delicate and transparent epithelium, the separate globules of which have the most regular six-sided cell-border, and are perfectly colourless and transparent. Each of them, however, contains, in the mass in its interior, a dark round nucleus, or formation, which reminds the observer of the nucleus occurring in the cells of the epidermis, the pistil, &c., in the vegetable kingdom. In man, whose choroid plexus exhibits a more blackish or dark colour even to the naked eye, the epithelium itself has a similar formation to that just described, but the centre of each cell contains in its exterior a round pigment-globule, corresponding to the central point of the situation of the nucleus in its interior. Similar pigment-globules exist in most birds, but not being so regularly deposited, it is more difficult to detect the cell-shaped and more rounded globules, although they are quite as certainly present. When the object has not been at all damaged, the cells, and especially the pigment-globules adhering to the outside, exhibit an arrangement like that of the vegetable cells in general, and particularly in the earliest stages in the formation of the leaf, that is, a disposition corresponding to spiral lines projected on the surface in accordance with the strictest rules) ——*compared to the cellular tissue of plants, I chose, expressly* (l. c. 77. Each of these globules (ganglion-globules), wherever observed, has an external, more or less distinct, areolar tissue-like envelope, and contains a parenchymatous mass proper to itself, an independent nucleus or kernel (nucleus oder Kern), which again encloses a second roundish, transparent nucleus)——*on account of this resemblance in form, the uniform appellation of the nucleus (Kernes), just as I afterwards described the nucleolus which was observed by me.* (Repertor. i, 143. In every cell without exception there is a somewhat smaller and more compact nucleus of a round or oval form. It usually occupies the centre of each cell, consists of a minutely granulous substance, but encloses a well-defined, round corpuscle, which thus forms a sort of second nucleus within it.) *In the study of the epithelia, prosecuted particularly by Henle and myself, there was no want of analogies with vegetable cellular tissue, the individuality of the cell-parietes was also distinctly demonstrated.* (Ib. 284. Roundish, hexagonal, flat, aud tolerably thin cells lie (in the external skin of the proteus) close upon one another, disposed in regular arrangement, and always connected together with their lateral edges and angles in mutual correspondence. The interior of these delicate bodies is filled by a granulous or yellowish mass, which represents a sort of nucleus. But the separate granules of this nucleus, however closely they may lie together, may be accurately distinguished from one another. With a very strong magnifying power, each one of these granules may be seen to be more transparent in its centre than it is in its periphery. It may then also be most distinctly ascertained, that the somewhat delicate parietes of each cell are perfectly isolated from the central cavity. No trace of granules or fibres can be observed on the walls themselves ; there is merely a clear, transparent, vitreous, and homogeneous mass.) *I had also remarked that the nuclei (pigment-vesicles) were the parts first formed in the pigment of the choroid coat*——(Entwickelungsgeschichte, 194. The following is the mode in which, according to my observations, the stratum of pigment is formed in man, mammalia, and birds ; separate, round, colourless, and transparent corpuscles are first deposited upon the internal surface of the substance they are to cover, in the earliest period (up to the tenth week) these corpuscles in the human subject measure from 0·000355 to 0·000405 Paris inch in diameter. They are the future pigment-corpuscles or pigment-vesicles.

Pigment-globules of a black colour are soon, however, developed on their periphery, so that the corpuscles or vesicles just mentioned are transparent in their centre when they have ceased to be so, and have become dark on their circumference. It is plain that von Ammon and R. Wagner have seen this condition as well as myself. The globules are so small from the commencement, that they . . . . . This process of deposition of the black-coloured globules upon the pigment-corpuscles goes on afterwards continuously, and to such an extent that the latter are enveloped and covered on all sides by them, and are only rendered visible when the globules are removed by pressure or washing.); ——*and I compared the pigment-cells with the cellular tissue of plants.* (Repertor. ii, 245. The pigment here (in the choroid) has the same character which it has in most other parts of the body, that is, a round, clear, transparent, and colourless nucleus, or the pigment-molecules lie closely crowded together around a pigment-vesicle. These heaps of pigment composed of pigment-vesicles, and the molecules of pigment deposited around them, are extended out sidewise, and in man, the dog, the rabbit, the horse, the ox, and such like, form unequal pentagons or hexagons, which are placed close together in a similar manner to the cells of the parenchymatous cellular tissue of plants. Langenbeck de retina, 38.) *Schwann gave an essential completeness to these analogies, by showing that the gelatinous primordial mass of the tissues was composed of cells, that the bodies imbedded in it are nuclei, and that these and the cells often exhibit analogous laws of development.* (Froriep's Notizen, 1838, Mikroskopische Untersuchungen über die Struktur der Thiere und Pflanzen, Heft i, 1838.) *As early as* 1837 *I had observed the cells of the germinal membrane in the ovum of sepia, with their nuclei and nucleoli, and the areas surrounding them, and had communicated my researches in a letter to Breschet. Shortly after I became acquainted with Schwann's first communication I commenced the investigation of the subject. The chief results of my inquiries are contained in the following communication. I have, at the same time, referred to the corresponding passages in the first part of Schwann's treatise, which I have received this day."*

I will only add that the second part also, (consisting of sheets 8 to 13, and Plates III and IV,) therefore the whole of the portion of my treatise containing the observations, had appeared previous to Valentin's researches, and had been communicated to the Parisian Academy in the year 1838; a remark which does not appear altogether superfluous, since Professor Wagner has communicated an epitome of my observations (which I sent to him four weeks after he had requested it from me) in his Physiology, with the remark that it had arrived later than the observations of Valentin. Moreover, even my first communications in Froriep's Notizen contained the fundamental laws for the formation of all the tissues, and the details also respecting by far the most of them.



Th. Schwann del.

EXPLANATION OF THE PLATES.

WHERE no other measurement is given, the figure represents the object magnified about 450 diameters, linear measurement.

PLATE I.

Fig. 1. Parenchymatous cellular tissue, with cell-nuclei from an onion, magnified 290 times.

2. Matrix of the pollen of Rhipsalis salicornoides.

3. Do. do.

I am indebted to the kindness of Dr. Schleiden for the last two delineations.

4. Cells from the chorda dorsalis of Cyprinus erythrophthalmus.

5. Cartilage from the point of a branchial ray, from the same.

6. Cartilage from the middle of a branchial ray, from the same.

7. Cartilage from the root of a branchial ray, from the same.

8. Branchial cartilage from the larva of Rana esculenta.

9. Cranial cartilage (ethmoid bone) from the larva of Pelobates fuscus.

10. Cells from the crystalline lens of a fœtal pig four inches long.

11. An isolated nucleus of the cells of the crystalline lens.

12. Cells from the crystalline lens of the same fœtus, exhibiting their prolongation into the fibres of the lens.

13. Fibres from the innermost layers of the lens of a pike.

14. Cell from the epidermis of a species of grass.

PLATE II.

Fig. 1. Ovum of a goat, after Krause (Müller's Archiv, 1837, Pl. I, fig. 5).

2. Cells from the yelk-cavity of a mature hen's egg.

3. Cells from the interior of an egg measuring a line and a half in diameter, taken from the ovary of a hen.

4. Portion of the germinal membrane of a mature hen's egg before incubation, viewed from above.

5. Portion of the germinal membrane from a hen's egg after sixteen hours' incubation. It is folded in such a manner that the external surface or serous layer forms the margin.

6. Cells from the serous layer of the same germinal membrane in the neighbourhood of the area pellucida, after separation of the mucous layer.

7. Cells from the mucous layer of the same germinal membrane on the outside of the area pellucida.

8 and 9. Pigment-cells of different kinds and stages of development, from the tail of the tadpole.

10. Cells from the interior of the shaft of a fully developed wing-feather of the raven.

11. Earlier stages of development of the same, from the portion of the shaft of an immature feather which has not as yet become hard.

12. Cell-nuclei, from the same, around which no cells have as yet formed.

13. Flat cells splitting into fibres, from the cortex on the side of the shaft of a raven's feather in progress of formation.

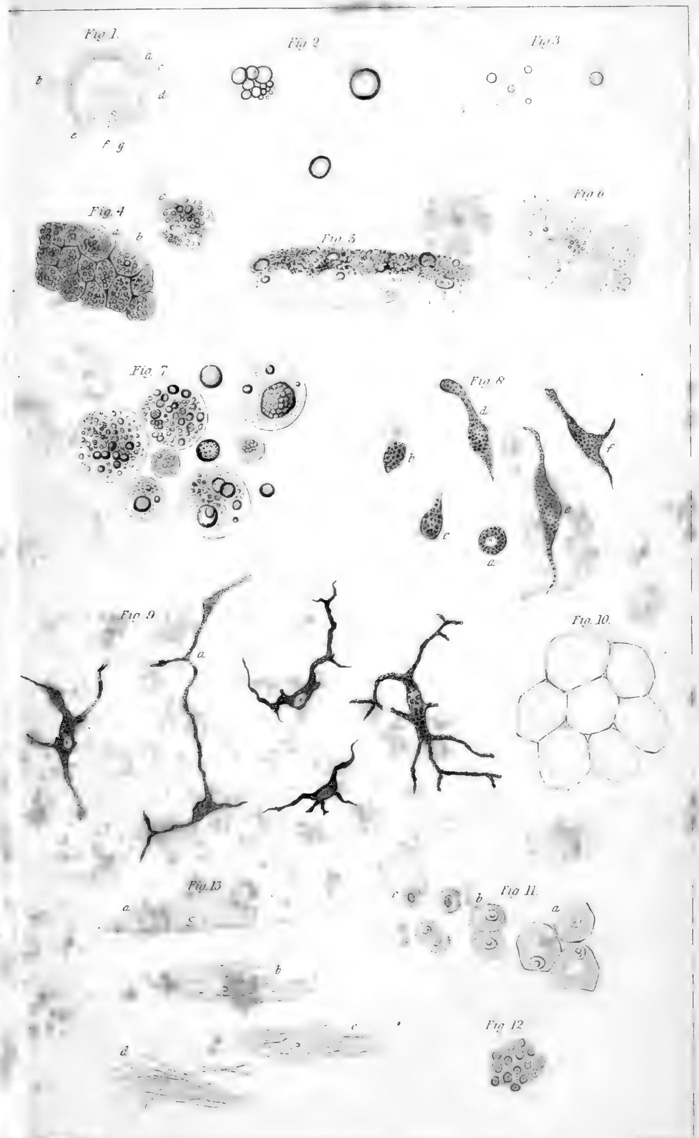


Fig. 1.
a
b
c
d
e
f
g
Fig. 2
Fig. 3
Fig. 4
Fig. 5
Fig. 6
Fig. 7
Fig. 8
Fig. 9
Fig. 10.
Fig. 11.
Fig. 12
Fig. 13

Schwann del. Adlard

PLATE III.

Fig. 1. From the point of a branchial cartilage of Rana esculenta. The lower margin of the delineation exhibits the natural border of the cartilage.

2. Cartilage from the ilium of a fœtal pig five inches long, after the application of acetic acid.

3. Enamel fibres from immature teeth of a fœtal pig.

4. Cells from the surface of the enamel membrane.

5. Fibres which compose the substantia propria of the human tooth, isolated by maceration for two days in dilute hydrochloric acid.

6. Fibre-cells from the areolar tissue lying beneath the superficial muscles of the neck of a fœtal pig measuring seven inches.

7. A more fully developed cell of areolar tissue.

8. Cells from the gelatinous substance between the chorion and amnion of a fœtal pig seven inches long.

9. Larger and very pale cells from the areolar tissue of the orbital cavity of the same fœtus.

10. Fat-cells from the cranial cavity of the young of Cyprinus erythrophthalmus.

11. Fibre-cells from the tendo achillis of a fœtal pig three and a half inches long.

12. From the middle coat of the aorta of a fœtal pig measuring seven inches in length.

13. Cells from the interior of the quadratus lumborum muscle of a fœtal pig three and a half inches long.

PLATE IV.

Fig. 1. Dorsal muscles of a fœtal pig three and a half inches long.

2. The fibre *c* from the previous figure, after the application of acetic acid.

3. From the brachial muscles of a fœtal pig seven inches long.

4. Primitive muscular fasciculus from the cockchafer.

5. Muscular fasciculus from a pike.

6. A portion of the ischiatic nerve of a fœtal pig measuring four inches.

7. Fasciculus of nervous fibres from the brachial plexus of a fœtal pig four inches in length.

8. Single nervous fibres: *a,* from the nervus trigeminus of a fœtal pig measuring six inches and a half; *b, c, d,* from the nervus ischiadicus of the same.

9. Nervous fibre from the vagus of a calf.

10. Ganglion-globules from the lowest ganglia of the sympathetic of a frog.

11. Capillary vessels in the tail of the tadpole.

12. Ideal representation of the formation of the capillary vessels in the area pellucida of a hen's egg.

Schwann del.

CONTRIBUTIONS TO PHYTOGENESIS,

TRANSLATED FROM THE GERMAN

OF

DR. M. J. SCHLEIDEN,

PROFESSOR OF BOTANY IN THE UNIVERSITY OF JENA.

CONTRIBUTIONS TO PHYTOGENESIS.[1]

THE general fundamental law of human reason, its undeviating tendency to unity in its acquisition of knowledge, has always been evinced in the department which treats of organized bodies as fully as in all other branches of science; and manifold have been the endeavours to establish the analogies between the two great divisions of the animal and vegetable kingdoms. But eminent as the men have been who have devoted their attention to this subject, it cannot be denied that all attempts which have been hitherto made with this view must be regarded as entirely unsuccessful. If, indeed, the fact has of late been pretty generally admitted, still the reason of the circumstance has not always been quite correctly apprehended and put forth in its full precision and clearness. The cause of this, however, is, that the idea of individual, in the sense in which it occurs in animal nature, cannot in any way be applied to the vegetable world. It is only in the very lowest orders of plants, in some *Algæ* and *Fungi* for instance, which consist only of a single cell, that we can speak of an individual in this sense. But every plant developed in any higher degree, is an aggregate of fully individualized, independent, separate beings, even the cells themselves.

Each cell leads a double life: an independent one, pertaining to its own development alone; and another incidental, in

[1] [These first appeared in Müller's Archiv für Anatomie und Physiologie, Part II, 1838. But as they have been republished with some additional notes in a collected edition of Schleiden's papers, entitled 'Beiträge zur Botanik,' I have made use of the latter work as my text; with the exception of the notes, I believe it corresponds precisely with the paper in Müller's Archiv; which, it is also right I should state, has been already most faithfully translated by Mr. Francis, in Taylor's 'Scientific Memoirs,' vol. ii, Part VI.—TRANSLATOR.]

so far as it has become an integral part of a plant. It is, however, easy to perceive that the vital process of the individual cells must form the very first, absolutely indispensable fundamental basis, both as regards vegetable physiology and comparative physiology in general; and, therefore, in the very first instance, this question especially presents itself: *how does this peculiar little organism, the cell, originate?*

The great importance of the subject is the only excuse I can adduce for venturing at the present moment to publish the following remarks, feeling as I do only too well convinced that more extended researches can alone impart to them their proper scientific value. Perhaps, however, I may succeed by these remarks in drawing attention to this very important subject.

Since no real advance in science results from the attempt to explain natural phenomena hypothetically, and least of all, where all the conditions for the erection of a tenable hypothesis, namely, guiding facts, are wanting, I may omit all historical introduction; for, so far as I am acquainted, no direct observations exist at present upon the development of the cells of plants. Sprengel's pretended primitive cells have long since been shown to be solid granules of amylum. To enter upon Raspail's work appears to me incompatible with the dignity of science. Whoever feels any desire to do so, may refer to the work itself.

The only work connected with this subject, the highly distinguished one by Mirbel, I shall have occasion to refer to subsequently, since even he does not make any allusion to the process of cell-formation. It is to be regretted that Meyen, who perhaps has studied vegetable anatomy more comprehensively than any one up to the present time, should have confined himself almost exclusively to the investigation of developed forms, and not yet have brought the formative process itself in any degree within the sphere of his enquiries. I still have many doubts, the solution of which I had hoped to have found in his Physiology, but hoped in vain.

It was Robert Brown who, with his comprehensive natural genius, first realized the importance of a phenomenon, which, although observed previously by others, had yet remained totally neglected. He found, in the first instance, in a great many of the cells in the epidermis of the *Orchideæ*, an opaque spot, named by him areola, or *nucleus of the cell.* He subsequently pursued this phenomenon in the earlier stages of the pollen-cells, in the young ovulum, in the tissue of the stigma, not only in the *Orchideæ*, but also in many other *Monocotyledons*, and even in some *Dicotyledons*.

As the constant presence of this areola in the cells of very young embryos and in the newly-formed albumen could not fail to strike me in my extensive investigations into the development of the embryo, it was very natural that the consideration of the various modes of its occurrence should lead to the thought, that this nucleus of the cell must hold some close relation to the development of the cell itself. I consequently directed my attention particularly to this point, and was fortunate enough to see my endeavours crowned with success.

Before, however, I proceed to the communication of these observations, I must first give a somewhat more detailed description of the nucleus. As I have to treat of a peculiar and, I think, universal elementary organ of vegetables, I do not consider it necessary to apologise for applying a definite name to this body, and therefore call it Cytoblast (κυτος, βλαστος) in reference to its function, which will be described hereafter.

This formation varies in its outline from oval to circular, according as the solid which it forms passes from the lenticular into the perfectly spheroidal figure. I have found the oval and flat cytoblasts more frequently in *Monocotyledons*, in the albumen and pollen; the globular chiefly in the *Dicotyledons*, and in the leaf, stem, articulated hairs, and similar structures; no exclusive rule, however, can be laid down on this point.

The colour of the cytoblast is in general yellowish, but it sometimes passes into an almost silvery white. I remarked it as being most transparent in the albumen of some water plants, in the unripe pollen, in some *Orchideæ*, and also in the rudiments of the leaf of *Crassula portulaca*. Its excessive transparency renders it scarcely perceptible in the spores of some *Helvelloids*. It is coloured by iodine, according to its various modifications, from a pale yellow to the darkest brown.

It varies considerably in size. It is in general largest in *Monocotyledons*, and in the albumen; and smallest in *Dico-*

tyledons, in the leaf, stem, and their metamorphosed parts. The largest which I have seen measured 0·0022 Paris inch in diameter (in *Fritillaria pyrenaica*); the smallest, in the embryonal extremity of the pollen-tube of *Linum pallescens*, from 0·00009 to 0·0001 Paris inch. In the albumen of *Abies excelsa* I found the average of several admeasurements of examples, which appeared of equal size, to be 0·00034-0·00059-0·00079. In the young leaves of *Crassula portulaca*, 0·0003; and in the albumen of *Pimelea drupacea*, 0·00095-0·001055. Little importance, however, can, on the whole, be attached to these admeasurements, since they increase and diminish, and we cannot determine in what period of its existence the cytoblast may be at the time.

Its internal structure is in general granulous, 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. The more recent its formation, the softer it is; and this also applies to cases in which its existence is merely transitory. It is denser and more sharply defined when it endures throughout the whole vital process of the plant as a permanent tissue, as in the *Orchideæ*.

These peculiarities have been more or less fully described by R. Brown (Organs and Mode of Fecundation in Orchideæ and Asclepiadeæ; Linn. Trans. 1833, p. 710), and recently by Meyen (Physiologie, &c., Bd. I, p. 207). A phenomenon, however, has escaped both of these most acute observers, which I am notwithstanding disposed to regard as one of the most essential. In very large and beautifully developed cytoblasts, for example, in the recently formed albumen of *Phormium tenax* and *Chamædorea schiedeana* (pl. I, fig. 5), there is observed (whether sunk in the interior or on its surface, is not yet clear to me) a small, sharply defined body, which, judging from the shadow that it casts, appears to represent a thick ring, or a thick-walled hollow globule. In examples which are not so well developed, only the external sharply defined circle of this ring can be observed, and in its centre a dark point; for example, in the stipes of the embryo of *Limnanthes Douglasii*, *Orchis latifolia* (pl. I, fig. 21), *Pimelea drupacea* (figs. 14, 15).

In still smaller cytoblasts it appears only as a sharply circumscribed spot; this is most frequently the case, as in the pollen of *Richardia æthiopica*, in the young embryo of *Linum pallescens*, and in almost all *Orchideæ* (fig. 16); or, lastly, only a remarkable small dark point is observed. I have not, as yet, succeeded in discovering it in the very smallest and most transitory cytoblasts (in the leaves of *Dicotyledons* for instance). I have also found two in some very rare cases, but they occurred as exceptions to the general rule, and always where the majority exhibited the simple nucleus; for example, in *Chamædorea schiedeana* (figs. 6, 7), *Secale cereale, Pimelea drupacea* (fig. 14); in the two latter I have sometimes found even three (fig. 15). The observations I have made upon all plants in which it was possible to trace the entire process of formation completely, lead to the conclusion, that these small bodies are formed earlier than the cytoblast (pl. I, figs. 1, 2); and I am almost inclined to conjecture that they are not altogether unallied to the nuclei which Fritsche has shown to exist in starch, and may probably indeed be identical with them.[1] The size of this corpuscle also varies considerably, from the extent of half the diameter of the cytoblast to the most minute point, whose size could not be measured in consequence of the thread in the diaphragm of the microscope exceeding it so much in thickness. In the albumen of *Abies excelsa* I found it to average from 0·000045-0·000095 Paris inch; in *Pimelea drupacea*, from 0·00029-0·0003. Sometimes it appears darker, at others brighter, than the remaining mass of the cytoblasts. In general it has more consistency than the rest of the cytoblast, and continues sharply defined after that has been changed by pressure into an amorphous mass, as in *Pimelea drupacea* for example.

There is a second point, on which I must say a few words, in order to be enabled to express myself more briefly hereafter without being unintelligible, which relates to the different inorganic substances that occur during the vital process of plants, and pertain to the series of starch and woody fibre. I make no pretensions whatever to a complete enumeration of all

[1] More accurate investigation of the structure of the starch granules has shown this supposition to be quite untenable.

the substances which differ in a chemical sense; and just as little do I require that chemists should approve all my terms and characteristics (independent of this, perfection at the present time would be an impracticable task); I shall merely notice in a few words the most important modifications, their consequence and signification in the course of the development of vegetable organization, in order to avoid repetitions in future.

In the plant starch appears almost to take the place of animal fat. It is superfluous nutritive material, which is deposited for future use; and we therefore usually find it in places where a new formative process is to commence after a short repose, or where a too luxuriant life has generated a superabundance of nutritive material. It has of late been the subject of such deep research that it is unnecessary for me to enter upon it more fully; I will merely refer the reader to the most recent and practical summary of the results in Meyen's Physiologie, Bd. I, p. 190, &c.

The starch is sometimes supplanted by a semi-granulous substance; for instance, in pollen, the albumen of some plants, and frequently in the cells of the leaf, as matrix of the chlorophylle. It is chiefly distinguished by its occurrence in irregular, granulous forms, which have no internal structure, and from its being coloured a brownish-yellow or brown by tincture of iodine. This substance, which I shall call mucus, is probably identical with that of which the cytoblasts are composed, and with the small granules in gum, which I shall presently mention. Meyen has already remarked the probability of the first supposition (Physiologie, Bd. I, p. 208).

But when the starch is to be employed in new formations, it becomes dissolved, in a manner as yet quite unknown in chemistry, into sugar or gum, the latter sometimes appearing to pass into the former, or *vice versâ*. The sugar appears in the form of a perfectly transparent fluid, which is almost as clear as water, is not rendered turbid by alcohol, and receives from tincture of iodine only so much colour as corresponds to the strength or weakness of the solution of the reagent.

The gum appears as a somewhat yellowish, more consistent, and less transparent fluid, which is coagulated into granules by tincture of iodine, assuming a pale yellow permanent colour.

In the further progress of organization (in which process the gum is always the last, immediately preceding fluid), a quantity of exceedingly minute granules appear in it, most of which, on account of their minuteness, look like mere black points. Iodine then seems to colour the fluid a somewhat darker yellow. The granules, however, when their size is sufficiently large to render their colour perceptible, become of a dark brownish-yellow under its influence.

It is in this mass that organization always takes place, and the youngest structures are composed of another distinct, perfectly transparent substance, which presents an homogeneous colourless mass when subjected to pressure; when dried it imbibes water and swells; it is not at all affected by tincture of iodine, nor does it ever imbibe it; after pressure it appears as colourless as before, and is so completely transparent as to be altogether invisible when not surrounded by coloured or opaque bodies. This substance frequently occurs in plants (for example, in great quantity, together with a little starch, in peculiar large cells in the tubers of *Orchis*); for brevity's sake I shall call it vegetable gelatine; and am inclined to class under this head, as mere slight modifications, pectine, the basis of gum tragacanth, and many of those substances which are usually enumerated under the term vegetable mucus.

It is this gelatine which is ultimately converted by new chemical changes into the actual cellular membrane, or structures which consist of it in a thickened state, and into the material of vegetable fibre.

I now pass on to our subject itself. There are two situations in the plant in which the formation of new organization may be observed most easily and clearly, in consequence of there being cavities closed by a simple membrane, viz. in the large cell, which subsequently contains the albumen of the seed, the embryonal sac, and in the extremity of the pollen-tube, from which the embryo itself is developed. The embryonal sac never contains starch originally, but probably, in most instances, the saccharine solution (which gives the sweet taste to unripe pod-fruits and the *Cerealia*), or gum.

The pollen, on the contrary, always contains starch, or the above-mentioned granulous mucus representing it, as an essential constituent part. The so-called vegetable spermatozoa will, probably, on more accurate investigation, be mostly reduced to one of these substances. These substances, however, soon become dissolved, and converted either into sugar or gum; both changes take place at times, even before the pollen-grain has commenced to send forth tubes upon the stigma, frequently during the gradual descent of the pollen-tube through the style to the ovule; so that in some cases unaltered starch may still be found even in the embryonal extremity.

At both these situations the before-mentioned minute mucus-granules are very soon developed in the gum, upon which the solution of gum, hitherto homogeneous, becomes clouded, or when a larger quantity of granules is present, more opaque. Single, larger, more sharply defined granules next become apparent in the mass (fig. 2, the upper part); and very soon afterwards the cytoblasts appear (fig. 2, the lower part), looking like granulous coagulations around the granules. The cytoblasts, however, grow considerably in this free state; and I have observed, in *Fritillaria pyrenaica* for instance, a gradual expansion from 0·00084 to 0·001 Paris inch.

So soon as the cytoblasts have attained their full size, a delicate transparent vesicle rises upon their surface. This is the young cell, which at first represents a very flat segment of a sphere, the plane side of which is formed by the cytoblast, and the convex side by the young cell, which is placed upon it somewhat like a watch-glass upon a watch. In its natural medium it is distinguished almost by this circumstance alone, that the space between its convexity and the cytoblast is perfectly clear and transparent, and probably filled with a watery fluid, and is bounded by the surrounding mucus-granules which have been aggregated together at its first formation, and are pressed back by its expansion, as I have endeavoured to represent it in plate XV, figs. 4, 5, 6. But if these young cells be isolated, the mucus-granules may be almost entirely removed by shaking the stage. They cannot, however, be observed for any length of time, for in a few minutes they become completely dissolved in distilled water, leaving only the cytoblasts behind. The vesicle gradually expands and becomes more consistent (fig. 1, *b*), and, with the exception of the cytoblast, which always forms a portion of it, the wall now consists of gelatine. The entire cell then increases beyond the margin of the cytoblast, and quickly becomes so large that the latter at last merely appears as a small body enclosed in one of the side walls. At the same time the young cell frequently exhibits highly irregular protrusions (fig. 1, *c*), a proof that the expansion by no means proceeds uniformly from one point. During the progressive growth of the cell, and evidently arising from the pressure of the neighbouring objects, the form becomes more regular, and then also frequently passes into that of the rhomboidal dodecahedron, so beautifully defined *à priori* by Kieser. (Compare fig. 1, from *b* to *e*, with fig. 8.) The cytoblast is still always found enclosed in the cell-wall, in which situation it passes through the entire vital process of the cell which it has formed, if it be not, as is the case in cells which are destined to higher development, absorbed either in its original place, or after having been cast off as a useless member, and dissolved in the cavity of the cell. So far as I could observe, it is only after its absorption that the formation of secondary deposits commences upon the inner surface of the cell-wall (fig. 9).

As a general rule, it is rarely that the cytoblast accompanies the cell which it formed through its entire vital process; nevertheless, it is,

1. Characteristic of the families of the *Orchideæ* and *Cacteæ*, that in them a portion of their cellular tissue remains in a lower stage of development during the entire period of life.

2. In various plants it occurs that cellular tissue, which has merely a transitory signification, is not perfectly developed, but retains the cytoblast, and is absorbed together with it at a subsequent period. Yet I have also remarked that the latter in the middle period of its existence lost much of its distinctness and sharpness of outline, which, however, reappeared when absorption commenced; for example, in the nucleus of the ovule of *Abies excelsa, Tulipa sylvestris,* and *Daphne alpina.* It is most extraordinary that some physiologists should have felt prepared to deny the fact, that absorption takes place in plants, since even very considerable portions of cellular tissue of the nucleus of the ovule, for instance, become completely fluid again, and are received into the common mass of the sap. It is true this only takes place so long as the cell still consists of the simple original membrane, and is not so far advanced

in its individual development that its wall is thickened by secondary deposits.

3. The cytoblasts also remain persistent in the pollen-granules in some rare instances; such is the case in some, perhaps in all the *Abietinæ*. The lenticular cytoblast has already been observed by Fritsche in *Larix europæa*, but the true nature of it was not recognised.

4. Lastly, many hairs, particularly such as exhibit motions of the sap within their cells, retain the cytoblasts (*c, f*, fig. 25). It is at the same time remarkable, and a proof of the close relation which the cytoblast bears to the whole vital activity of the cell, that the little currents which frequently cover the entire wall like a network, always proceed from and return to it, and that when *in statu integro* it is never situated without the currents (fig. 25).

I have observed the above-described development of the cells throughout its entire course in the albumen of *Chamædorea schiedeana, Phormium tenax, Fritillaria pyrenaica, Tulipa sylvestris, Elymus arenarius, Secale cereale, Leucoji spec., Abies excelsa, Larix europæa, Euphorbia pallida, Ricinus leucocarpa, Momordica elaterium*, and in the embryonal extremity of the pollen-tube of *Linum pallescens, Œnothera crassipes*, and many other plants. It was in the summer of 1837, after this treatise had been written, that I first began to examine the *Leguminosæ*, and found to my surprise that these plants, so constantly investigated and everywhere employed as illustrations for the history of vegetable development, afforded the most beautiful and ready opportunities for the study of this process, which had been overlooked by all observers. No one, however, had considered the saccharine fluid contained in the embryonal sac as worthy of examination.

Without exactly tracing the entire course of the formation of the cells through all its details, I found the cell-nuclei, previous to the appearance of the cells, floating loose in the fluid in very many plants. Finally, I have not met with a single example of newly-developed cellular tissue, the cambium excepted, in which the cytoblasts were wanting. I therefore consider that I am justified in assuming the process above described to be the universal law for the formation of the vegetable cellular tissue in the *Phanerogamia*.

My observations are much more limited with respect to the *Cryptogamia;* nevertheless, I found the cytoblasts in the sporidia of the *Helvelloids,* where, however, in consequence of their great transparency, they are only perceptible with a very strong magnifying power, and after the field has been much darkened. I have seen them in the large yellowish cells in the interior of the so-called anthers in *Chara vulgaris.* I also observed their development into cells in the sporules of *Marchantia polymorpha,* one of which, pushing the original wall of the sporule before it, forms the long capillary root (pl. I, figs. 18-20).

It is evident from the foregoing, that the cytoblast can never lie free in the interior of the cell, but is always enclosed in the cell-wall, and (so far as we can learn from the observation of those cytoblasts which are sufficiently large to allow of this very difficult investigation) in such a manner that the wall of the cell splits into two laminæ, one of which passes exterior, and the other interior to the cytoblasts. That upon the inner side is generally the more delicate, and in most instances only gelatinous, and is also absorbed simultaneously with the cytoblast (figs. 8, 16, 21). In making a section, they are sometimes detached and scattered over the object, which might lead to the supposition that they lay free. It is probable also that subsequently, when absorption commences, they do become disengaged from their connexion with the cell-wall, and a slight touch may then be sufficient to move them from this position. The cell-wall is often considerably thickened in their neighbourhood, especially when they are somewhat globular; for instance, in the pollen-tube, which has become cellular in certain *Orchideæ* (figs. 16, 20).

Meyen, who should always be consulted with reference to anatomical questions, has endeavoured, in his Physiologie, vol. i, p. 45, &c., to establish the opinion, that the cell is formed of spiral fibres which lie closely one upon another, founding his view in a most ingenious manner upon his own beautiful observations on the relations of structure in fully-developed cells. My direct observation, which may easily be repeated by every one, shows, it is true, quite a different mode of formation; I must, however, bring the facts related by Meyen into unison with my discovery, in order not to permit an apparent contradiction to remain unresolved.

Meyen himself correctly observes, when treating of those spiral tubes whose very narrow fibres lie close upon one another, that an enveloping membrane could not indeed be observed, but that this by no means justified our concluding on its absence. For if the thickenings of the cell-walls which are formed in most, perhaps in all, cases in spiral lines, in those instances in which they make their appearance early, whilst the original cell-wall itself is yet *in statu nascentiæ* and soft, become firmly connected with the latter; and if at the same time the separate coils of the spiral fibre lie perfectly close one upon another, so that with our present microscopes no space remains perceptible between them,—it naturally follows that on tearing the entire membrane (the so-called unrolling of the spiral vessels), the fracture in the direction of the coils of the fibre must be so sharp that our instruments could not possibly show the inequalities. At the same time it should be remembered that the original cell-membrane, especially in long hair-cells, frequently undergoes so great an expansion that it must at last become infinitely delicate, so that even the thinnest and apparently most simple cell-wall does not exclude the possibility of its being composed of the original membrane and the secondary deposit. If, then, we proceed from those spiral cells and vessels whose coils are so far distant from one another as to admit of no doubt with respect to the existence of an external enveloping membrane, and if we trace the presence of this membrane through all the forms of the constantly approximating coils of the fibre, until only the feebleness of our optical instrument renders further direct observation impossible, the laws of sound analogy require that we should, in such instances, also admit the presence of a similar membrane. There is yet a more direct mode of proof, namely, the investigation of the history of the development.

It is an altogether absolute law, that every cell (setting aside the cambium for the present) must make its first appearance in the form of a very minute vesicle, and gradually expand to the size which it presents in the fully-developed condition; an extended investigation of this formative process also invariably shows that a cell never exhibits a trace of spiral formation, discoverable either from its aspect, or on tearing it, previous to its complete development, i.e. before it has absorbed the cytoblast. In all spiral cells, particularly such as exhibit detached fibres, we find the walls of the fully-developed cells to be perfectly simple at the commencement. For instance, I remarked this in the outer parchment-like layer of all aërial roots.[1] Meyen discovered the spiral fibres in *Oncidium altissimum, Acropera Loddigesii, Brassavola cordata, Cyrtopodium speciosum, Aërides odorata, Epidendron elongatum, Cattleya Forbesii, Colax Harrisonii,* and *Pothos crassinervia.* This is still more evident in the true cortical layer of those aërial roots, where I discovered in *Colax, Cyrtopodium,* and *Acropera* the far more beautifully developed and much broader spiral fibres. There is no trace of them to be found in quite young aërial roots, and their formation pertains decidedly to a process of lignification.

We find further evidence that the spiral fibres do not occur until a subsequent period in the pericarp of the *Casuarinæ,* the cells of which, previous to or shortly after impregnation, do not evince a trace of spiral formation. Meyen, in his Physiologie, has taken too little notice of these fibre-cells in the envelopes of many seeds, which is the more to be regretted, as these interesting and sometimes extremely pretty formations promise some explanation respecting the physiology of the cell-life, especially if the opportunity should occur of investigating the individual development of several of them accurately. I may be permitted to communicate a few observations on this subject.

Their occurrence is more extensive than is generally supposed. They are found in the hairs of the pericarp in some *Compositæ,* where they were found by Lessing in *Perdicium taraxaci* and *Senecio flaccidus,* and by myself in *Trichocline humilis* and *heterophylla.*

[1] Meyen, in his Phytotomie, p. 163, called this an outer cortical layer, which was situated on the true epidermis of the aërial roots. Some doubts have recently been raised as to the correctness of this view. It may, however, be almost incontestably proved, since the cellular layer, which Meyen calls epidermis, possesses actual stomata, which, in consequence of their being covered, usually indeed occur only in a rudimental form, frequently exhibit a more complicated structure, although deviating only in appearance, as in *Aërides odorata,* but often likewise appear of quite the ordinary form, as in *Pothos crassinervia.* Moreover it was not Dutrochet, as would seem from Meyen's Physiologie, p. 48, but Link, who first drew attention to this layer.

They occur in the epidermis of the pericarp in many *Labiatæ*, as in *Ziziphora, Ocymum;* in most *Salviæ*, for instance, *limbata, hispanica, Spielmanni,* &c.; and lastly, in *Horminum pyrenaicum.* My uncle Horkel was familiar with them in all these many years ago; Baxter noticed and published their occurrence in *Salvia verbenacea* only. I can add to these *Dracocephalum moldavica.*

R. Brown discovered them in the parenchyma of the pericarp in the *Casuarinæ*, and I in the spongy inflated cellular tissue in *Picridium vulgare*, where they mostly occur in a reticular form, and present an extremely beautiful appearance.

Horkel also discovered them in the epidermis of the seed itself in the *Polemoniaceæ* long before Lindley made known their presence in *Collomia linearis.* They occur in *Collomia, Gilia, Ipomopsis, Polemonium, Cantua, Caldasia,* and perhaps in the entire family, with the exception of *Phlox*, with which genus *Leptosiphon*, in which are the first indications of them, is closely allied. Horkel had also studied them in the seeds of *Hydrocharis*, where they occur in the highest degree of development, long before Nees von Esenbeck published the fact. Robert Brown mentions them in the *Orchideæ*, which statement I find confirmed as to most of our native species of *Orchis.* I have also discovered very beautiful spiral fibre-cells in the epidermis of the seed of *Momordica elaterium*, and a very delicate reticular formation of fibres in *Linaria vulgaris, Datura stramonium*, in *Salviæ*, and in several other *Labiatæ;* probably it is common to the whole family.

Lastly, they occur, according to Horkel's discovery, in the parenchyma of the integuments of the seed in *Cassyta* and *Punica.*

Whether these formations be studied in their individual development in a single species, or in their progressive stages in a series of allied plants, some highly interesting general results will be obtained in either case. The universal and altogether absolute fact at which we first arrive is, that the fibres are never formed free, but are developed in the interior of cells; and that the walls of these cells in the young state are simple, and generally very delicate. Corda's statement respecting spiral cells without an enveloping membrane (*Ueber*

Spiral faserzellen, &c., pp. 7, 8) is based upon inaccurate observation.

These cells are at first generally filled with starch; rarely with mucus or gum. The starch always passes into the latter substance in the progress of development; and this is converted into jelly, the change, as it would seem, taking place from without inwards. This jelly finally is converted at its outer surface into vegetable fibre, following the direction of a spiral line, the coils of which are sometimes narrower, sometimes wider. When these forms are observed in their different stages of development and in their various conditions, the idea involuntarily forces itself upon the mind that the spiral formation is the result of a spiral movement of a fluid on the walls of cells between them and the central jelly. Horkel once actually observed the motion of small globules between the coils of the fibre in progress of formation in *Hydrocharis*.

The great variety in the appearance of the fibres seems to depend upon the period of their origin, and on modification in the chemical changes of the formative material. It probably depends solely upon the former circumstance whether the spiral fibre lies free in the cell, when it is formed very late, or whether it is blended with the membrane of the cell, if its development commence at a period when the cell-membrane itself is yet very soft and gelatinous, and may consequently become agglutinated to the fibre, which is likewise still in a gelatinous state.[1] This is the case in *Casuarina, Cassytha, Hydrocharis, Trichocline, Orchis*, &c.; in most cases, however, the cell-wall is too far developed to unite with the fibre, and the latter then lies loose in the interior of the cell. In rarer instances the material is almost entirely applied to the formation of the fibre (always indeed when the fibre coalesces with the wall), for example, in *Salvia Spielmanni, Momordica elaterium*. I have reason to suppose that this complete consumption almost always takes place in spiral vessels, and is the cause of their subsequently conveying only air. More frequently, however, one or more fibres are formed; but then a great portion of the jelly has still remained uncon-

[1] Subsequent researches have produced important modifications in this opinion. Consult my essay on the Spiral Formations in Vegetable Cells. Flora, 1839, Nos 21, 22, Pl. V.

sumed, which, when the cell is moistened with water, comes forth in form of an intestine (wie ein Darm hervortritt), and in swelling expands itself over the fibres, thus appearing to surround them; this is the case in most *Salviæ* and *Polemoniaceæ*, in *Senecio flaccidus*, *Ocymum polystachyum* and *polycladum* (*Lumnitzera*, Jacq.) There is an intermediate form between this and the former, when the jelly itself forms a broad spirally-wound band, which appear upon its surface to be composed of innumerable delicate fibres; their occurrence in this state is very beautifully shown in *Perdicium Taraxaci* and *Ziziphora*. A still less advanced stage of development exhibits merely a cylinder or cone of gelatine in the interior of the cell, the surface of which, however, is marked with delicate spiral lines. This is seen in some *Salviæ*, in *S. verticillata* for example, and in *Leptosiphon androsaceum*. Finally, the lowest stage of development is where the gelatinous cylinder, which is furnished with spiral striæ, has a cavity in its interior containing starch, which has not as yet undergone decomposition; this instructive phenomenon is found in *Dracocephalum moldavica*, *Ocymum basilicum*, and some allied species. In illustration of the above, consult plate 2, figs. 1-10, with their explanations.

Before quitting the subject of spiral fibre, I will merely add, what indeed has been of late admitted by every good observer, that the only difference between spiral cell and spiral vessel consists in the dimensions, although constant transitions may be observed between them just as well as between the cells of the liber and the parenchyma; and consequently, as regards this doctrine at least, there is no longer any place for natural-philosophical phantasies about the arrestment of ideal forms of higher types, and such like empty words. That which forms a liber-cell out of a round cell, the preponderating expansion of an organ lengthwise, is also that which transforms the spiral cells (the vermiform bodies) into spiral vessels. The function of the spiral fibre, however, is, as every candid vegetable physiologist will certainly admit, entirely unknown to us at the present time. It is certain that spiral vessels and spiral cells occur in the living plant quite as frequently filled with sap (in the younger vegetating portions) as with air (in the older organs which have attained their full size); and it is this which has given rise to the conflicting views of authors. But the same also occurs in all cells under certain circumstances, and the influence of the spiral fibre remains meanwhile altogether obscure and unexplained. Perhaps the foregoing may render it probable that the spiral is everywhere only a secondary variation of form in the product of the vital power (the fibrin) produced by a different tendency of the vital activity of the cell, so soon as this is compelled, as a certain stage of its development, to give up its independent individuality, and enter as an integral portion into the complex of the entire plant.

I also think that we may venture, in conclusion, to deduce from the data above enumerated, that this indication of a spiral formation is the surest sign that we have no longer anything to do with the simple cell-membrane.

I now return, after this somewhat lengthy digression, to my subject. The process of cell-formation, which I have just endeavoured to describe in detail, is that which I have observed in most of the plants which I have investigated. There are, however, some modifications of this process which make the observation of many parts very difficult, and sometimes indeed render it impossible, although, notwithstanding this, the law remains undisturbed and universally valid, because analogy requires it, and we can fully explain the causes of the impossibility of direct observation.

The difficulties which I now notice depend especially upon the physical and chemical properties of the substance which precedes the formation of cells. The materials enumerated above are to be regarded as scarcely anything more than separate facts, which, for the purpose of giving a general view and rendering the classification more easy, I have intentionally selected from the organic chemical processes of vegetable life, which are constantly in operation, and with which we are as yet totally unacquainted. Almost all these materials constantly exist together in the living plant, and it is merely their preponderance in a greater or lesser degree which enables us to say that the cell contains amylum or gum, and so forth. Only towards the termination of the individual life of the cells do we find them filled with a less number of different substances; the cells which contain ethereal oil are probably the only instances in which we find but a single one.

If we now assume a cell to be completely filled with a transparent solution of sugar in which there is rapidly generated just so much gum, as may form, by an equally quick conversion into jelly, a delicate cell-membrane, the existence of which we cannot possibly recognise with the microscope, in consequence of the similar refracting power of the wall, the contents, and the surrounding medium; it then becomes exceedingly probable that a number of such formative processes may go on which escape our observation, and become known to us only in their results, when, after the absorption of the parent-cell, we suddenly find two new ones in its place. If, on the other hand, our attention has been previously directed to this process, we have, in the application of reagents, especially iodine, which is quite indispensable to the physiological botanist, several means of rendering it visible in instances where it is suspected to be going forward. Gradual transition to the completely invisible processes are readily found by more extended investigation; I will just mention one of the most difficult instances which I have met with, by way of example. It occurs in the germination of the sporules of *Marchantia polymorpha.* Only a few, generally only from two to four of the cell-nuclei which appear in the sporules, serve for the formation of cells; the others become quickly enveloped with chlorophyll, and are thus withdrawn from the vital process. The transparent fluid, however, in which these cytoblasts float, passes through the remaining stages of the metamorphosis into cell-membrane only just at the boundary of the latter, and with such rapidity that the exceedingly delicate young cells cannot be distinguished by anything else than a minute, generally more or less uninterrupted circle of infinitely small, black granules, and by a scarcely perceptible greater transparency of the contents of the newly-formed cells in comparison with that of the parent-cell, and finally, under the most favorable circumstances, by the spot at which the newly-developed cells come into contact, the point of juncture being still covered by the membrane of the parent-cell. (Pl. I, figs. 18-20.) This may perhaps be general in the *Cryptogamia*, and especially in water plants, and probably Mohl's division of the cells of *Conferværa* may be thus explained.

If we consider, however, that there are undoubtedly many plants, among which the *Fungi* and infusorial *Algæ* should probably be classed more especially, in which we are, as yet at least, totally unacquainted with the cytoblasts, in consequence of their absolute minuteness and transparency; if we further bear in mind that the nucleolus in the cell-germ, even in the larger cytoblasts, frequently appears immeasurably small, or even entirely escapes the eye with the highest magnifying power; and, lastly, if we deduce from what has been previously stated, that nevertheless this granule, which can no longer be rendered perceptible, probably furnishes in the suitable medium a sufficing cause for the formation of a cytoblast which serves as an introduction to the whole formative process of the cells; then, indeed, we are forced to confess that the imagination obtains ample latitude for the explanation in every case of the generation of infusorial vegetable structure, even without the aid of a *deus ex machina* (the *generatio spontanea*). But my present object is to communicate only facts and their immediate consequences, and not to dream; I will therefore rather add a few more observations on the growth of the plant.

What is meant by to grow? is a question to which every child quickly replies, "when I am getting as big as father." There is truth in this answer, but not sufficient to satisfy science. Words have no value in themselves, but are like coin, merely tokens of a value not exhibited in specie, in order to facilitate commerce. And to carry the simile further, insecurity in this intellectual property, and frequently bankruptcy results, if this coinage has not its unchangeable, accurately-determined standard; in a word, the utility of a scientific expression depends upon the accurate definition of the idea on which it is based. Unfortunately the perplexity of our social relations has caused us to forget entirely the original meaning of money, the sign has become to us the thing itself; may some good genius protect us from similar mistakes in our intellectual life. We must here be on our guard against two dangerous rocks: first, when we transfer words from one science to another, without first accurately testing whether they fit their new situation as respects all their accompanying significations also; and, secondly, when we voluntarily lose sight of the signification of a word consecrated by the spirit of the language and its historical development, and employ it without further ceremony in compound words, where perhaps, at the most, only some unessential part of its signification suits.

Thus E. Meyer, for example (Linnæa, vol. vii, p. 454), after repeating the well-known experiments of Duhamel, lays down this position: "the law of the longitudinal growth of the internodes is to grow in a direction from above downwards." He requires this position for his theory, and must consequently defend it in every way, although he himself confesses that this reversed growth must appear paradoxical to every one of his readers. He would never have arrived at this position if he had more accurately analysed the word "grow" (with which animal physiology had rendered him familiar), with reference to its applicability to the plant; he would soon have discovered that the generation of new cells, and so far the actual growth of the plant, constantly takes place in its outermost portions in an upward direction, and that his very simile of the building up a voltaic pile is exceedingly well adapted to refute himself. The experiments of Duhamel and Meyer would have no further result than to show that the inferior, that is, the earliest generated, older cells of the internode possess a greater capability to extend in the longitudinal direction, and retain this power longer than the younger cells.

We have an excellent illustration of the second point in the proposition so frequently expressed of late, that the stem of the plant is composed of the *coalesced* petioles. The word "coalesce" (*verwachsen,* to grow together) has possessed, however, from time immemorial, both in ordinary life and in science, the signification that two or more originally and naturally separate parts have become by the process of growth either abnormally or, under certain circumstances, normally united. If therefore the word "coalesce" be applied to the stem of the plant, an organ, which, in every period of its existence, under all forms of its appearance, is a simple and undivided one, and at the origin of the plant even constantly appears earlier than the leaves with their petioles, it certainly involves a mischievous abuse of language, by which science itself can gain nothing, and will even lose in the estimation of the intelligent non-professional man, who sees through such a play upon words. What would the zoologist say were we to regard the trunk as a coalescence of the extremities.

I return then to my question: what is the meaning of to grow? In hackneyed phrase we are told, "To grow signifies increase of the mass of an individual, and takes place in the inorganic world by juxtaposition, in the organic by intussusception." Have we gained anything for vegetable physiology by this reply? I think not. If the plant is to grow by intussusception, then I say it consists of an aggregate of single, independent, organic molecules, the cells; it increases its mass by new cells being deposited upon those already existing; consequently by juxtaposition. But the single cell in the progress of its expansion, which frequently reaches an enormous bulk in comparison with its original size (I will merely remind the reader of the pollen-tubes), also increases in substance in the interior of its membrane, and by this means also the mass of the entire plant is increased; it consequently grows by intussusception also. Finally, after a certain period the cell deposits new organic material in layers upon its primitive membrane; thus another form of juxtaposition, which still, however, belongs to the cycle of vegetable vitality. It hence becomes readily apparent that, in respect to scientific botany, the idea "grow" still requires a new foundation in order to be capable of being applied with certainty.

Of the three instances just cited, the second and third belong more to the individual life of the cells, and are of secondary importance only, as respects the idea of the whole plant, regarded as an organism composed of a certain number of cells. The plant considered in its totality increases its mass, that is, the number of the cells composing it, in the first way only.

We must therefore here discriminate three processes essentially distinct from each other in a physiological sense, which, when strictly regarded, scarcely find an analogy in the other kingdoms of nature.

1. The plant grows, that is, it produces the number of cells allotted to it.

2. The plant unfolds itself by the expansion and development of the cells already formed. It is this phenomenon especially, one altogether peculiar to plants, which, because it depends upon the fact of their being composed of cells, can never occur in any, not even the most remote form in crystals or animals.

3. The walls of the fully-developed cells become thickened by the deposition of new matter in layers, a process which, in accordance with the old rule, *a potiori fit denominatio,* may be most aptly termed the lignification of the plant.

If, in respect to the growth of the plant, we now hold to the literal sense conveyed under No. 1, then this question must arise,—Where are the new cells formed? Here three instances comprise all possible replies. Namely, the new cells are either formed outside on the surface of the entire previous mass, or in its interior; and in that case again either in the intercellular spaces or in the cells themselves; *quartum non datur.*

Mirbel, in two extremely ingenious and profound memoirs on the *Marchantia polymorpha,* which he presented to the French Academy in 1831 and 1832 (p. 32), has expressed the opinion, that all the three cases just now mentioned as possible do actually occur in plants. Without intending here to anticipate what follows, I must remark that only one case (the formation of new cells within the old ones) appears to be proved by his direct observations. The second case is merely a conclusion drawn, and the germination of the sporules of the *Marchantiæ,* which was to elucidate the third case, has been observed by me to be quite different, as I have already represented above.

Finally, however, we have yet to examine whether the difference of the organs may not establish such a physiological difference of growth as may merit our attention. We may distinguish here four instances. We observe: 1. The development of the plants in the upward direction (*in puncto vegetationis,* C. Fr. Wolff). 2. The elongation downwards. We thus comprise the formation of the necessary organs of the plant, the stem, the leaves (with their metamorphoses), and the root. 3. We have to keep in view the production of accidental organs, for example, bulbs, &c. And, 4. We find an annual thickening of the axile formations, the development of the woody stem.

Let us now see which of the three possible modes of formation of new cells is actually realised in each of the cases just enumerated. I have already explained how the new cells are developed in the embryonal sac; in other words, within a large cell. A similar process occurs in the embryonal end of the pollen-tube, consequently in a highly elongated cell; I shall now proceed to describe the further development of the embryo. After the first cells, generally few in number, are formed, they rapidly expand to such an extent that they fill the pollen-tube, which soon ceases to be perceptible as the original enveloping membrane; but at the same time several cytoblasts originate in the interior of each of these cells, and generate new cells, on the rapid expansion of which the parent-cells also cease to be visible and become absorbed. The same process is repeated indefinitely. But since the newly-generated cells have continually less room to expand, and therefore constantly become smaller, the previous transparency is soon lost in consequence of the continual production of new cytoblasts in the interior, and the tissue becoming more and more compressed; and from this stage to the perfect completion of the embryo we are conducted by the clearly logical inference that the process thus introduced continues the same, since no new force comes into operation which could induce us to assume a sudden variation of the vital action, more especially as we soon meet with the same manifestation of the vegetative power again.

Meanwhile the seed germinates, and the embryo becomes a plant; and then indeed the question may arise,—Does the process of life continue the same thenceforward in the internodes and foliaceous organs? Now we are here very quickly convinced of the negative, that is, that a formation of new cells on the surface of the existing organs does not take place. The surface is always smooth, and generally covered in a very early state with a kind of epidermis, the outer layer being more transparent and almost as clear as water; and we never find even an indication of a newly-formed cell upon the surface.

But if the embryo be the type of the entire plant, and the latter do not present anything which is not a repetition of its organs, if we have found the growth of the embryo to consist only in the formation of cells within cells, we may then expect to find the same result also in the process of the growth of the whole plant. It is especially a foliaceous organ, the anther, which has hitherto been studied and followed in its development by many celebrated men (particularly well by Mirbel); and here it is quite decided that the increase of cells takes place within the old ones. It is also certain that in this case the formative process accords with that above described. R. Brown and Meyen have enumerated many instances where they observed the cytoblast in very young pollen-cells. In *Pinus, Abies, Podostemon, Lupinus* and others, I have traced the development of the pollen after Mirbel perfectly; I have distinctly observed the cell-nuclei and their development into new cells within one another in *Abies*, never having missed the cytoblast in young cells.

Now if the pollen-grains be nothing more than converted leaf-parenchyma, if the anther be merely a metamorphosis of the leaf, we may certainly infer inversely that the process which we have observed in it, and which characterized the formation of the embryo and cotyledons (as prototypes of the leaf) will be again found in all foliaceous organs. For the same reason which was stated with respect to the later stages of the development of the embryo, actual observation is infinitely difficult in this case. I have nevertheless examined a great many buds in reference to this point, and have most decidedly convinced myself of the identity of the process both in the constantly elongating apex of the axis, and in the leaves which always originate somewhat beneath it. Succulent plants, the *Aloineæ* and *Crassulaceæ*, are best adapted for this purpose. *Crassula Portulaca* seemed to me most advantageous, for in it I first succeeded in separating some cells from their connexion, in whose interior young cells were already developed, without, however, entirely filling the parent-cell. But having once become familiar with the subject, I was afterwards able to detect these individualities from amongst the apparently semi-organised chaos in all other plants. Another circumstance indeed presents itself here, which renders the subject much more difficult than in the case of the embryo. For, independently of the minuteness of the cells, their walls, in those parts of the plant which are just newly formed, still consist merely of jelly, and are so delicate that it is exceedingly difficult to separate the parts intended for examination without completely destroying the organization. (Compare plate I, figs. 22-4.)

This process is more easily perceptible in articulated hairs, and in such as have a head consisting of several cells, where the same appearances which I have so frequently observed in the young embryo, and such as Mirbel has so beautifully described in the development of the gemmæ in the cups of *Marchantia*, may be readily and beautifully seen; for example, in the common potato. Meyen has also made similar observations, although he still expresses himself with some doubt on the subject. (Wiegmann's Archiv, 1837, vol. ii, p. 22.)

It is not until after as many cells are formed as the organ requires for its completion that the cell-walls become firmer, and then commences the unfolding of the organ by the mere expansion of the cells already formed.

But I must here enter somewhat more into detail, in order to explain the probable origin of the vascular bundles and epidermis. At a somewhat early period a stripe of more transparent cells is defined in the axis of the leaf which is in the act of formation, within which no more new ones are developed, and these cells soon considerably exceed in size those of the remaining mass, which are constantly becoming smaller by continual division. These cells are the basis of the future vascular bundle which forms the midrib of the leaf; for whilst the parenchymatous cells subsequently expand in every direction, these are developed in their longitudinal dimension only, and are thus enabled, although fewer in number, to follow the expansion of the other cells in the longitudinal direction of the leaf. It is not till a later period that these cells, in consequence of a difference in the depositions in their interior, become distinguished into spiral vessels and cells of the liber. The spiral vessels are always first perceptible in the newly-formed parts, and in the entire bud also, in the immediate neighbourhood of the old, previously-formed spiral vessels; and they proceed in this manner downwards from the stem into the new parts. I do not understand therefore what is intended when the fibres of the stem are regarded as descending from the buds; one might just as well conceive the river to run from the ocean to its source.

A similar process occurs in the development of the side nerves of leaves. The formation of new cells generally ceases at an early period in the outermost layers of cells. The cells there are soon filled with a limpid fluid, and, by the expansion of the subjacent parenchyma, naturally become superficial, flat, and expanded.

The cells of the vascular bundle and of the epidermis appear in this way to be less potentialized,—are as it were cells of lower dignity than those of the parenchyma; and perhaps this physiological peculiarity is connected with the fact, that they more rarely secrete peculiar chemical substances, but for the most part become thickened only by depositions within their walls of new vegetable fibrous (or more correctly membranous) substance. I cannot forbear venturing some suggestions in this place, which are perhaps less closely connected with the subject of this memoir, but which may possibly at some future time be of importance for the understanding of the entire plant. Let us recapitulate the process of growth of the plant just now represented. A simple cell, the pollen-tube, is its first foundation. Within this, cells are generated; in them new cells are developed, and so forth, throughout the entire life. But here the above-mentioned mode of the origin of the vascular bundles and of the epidermis in relation to the parenchyma would indicate, that the lower the dignity of the cell, the greater power does it possess, in the first place, of expanding and extending in length, and the less capacity does it possess, in the second place, of forming peculiar finer substances in its interior. If now the potentialization (potenzirung) of the cells proceed throughout the entire growth of the plant, there thence results a constantly advancing approximation of organs otherwise kept asunder, and continually rising ennoblement of the substances developed in the cells. Consequently, the lower parts of the internodes will appear to be more elongated than the upper; the leaves and young shoots (*summitates herbarum*, Pharmacol.) to contain nobler saps than the stem; the members become shortened as they approach nearer to the upper terminal point of the plant, the leaves come closer together, and the result of the continually increasing potentialization of the cell, of the constantly diminishing expansion in length, of the constantly advancing approximation of the lateral organs, of the constantly rising ennoblement of the substances developed, is, finally, the flower in its individualised distinctness, with its splendour of colour, its perfume, and its mysterious capacity of determining, by means of its juices, a single cell to be developed afresh into an independent plant, and to pass anew though the same cycle.

I return, after this digression, to my subject. So far I believe I have demonstrated tolerably conclusively, and in accordance with nature, that the entire growth of the plant[1] consists only of a formation of cells within cells. Let us now pass on to the root. I can contribute but very little to the explanation of this part of the subject; for I have not as yet succeeded in arriving at any satisfactory result, from the somewhat limited researches which I have instituted; for instance, I have been altogether unsuccessful in deciding *the* question as to whether a fluid is secreted at the extremity of the radicle, in which new cells are developed. On the other hand, it is certain that there exists in the extremity of the root a concavo-convex mass (a *meniscus*) of cellular tissue, in which the process of cell-formation takes place in the same manner as in the parts of the plants which grow in the ascending direction. A chief cause of the elongation of the root consequently consists in this,—that new cells are continually formed in the interior of the existing cells, on the convex side of that mass of cells, while on the concave side, the cells already formed expand simultaneously, and chiefly indeed in the longitudinal direction, and in this way constantly push the extremity of the root before them.

The third case, the formation of the accidental organs of the plant, I must entirely pass over, as I am altogether unprovided with any personal observations upon the subject. Probably, however, the process here is the same as in the previous cases, for Meyen (Physiologie, vol. i, p. 209) observed the cell-nuclei in germinating tubers of *Orchideæ*. Analogy also leads to a similar conclusion, since all these parts are nothing more than morphological modifications of organs which have been already treated of in this memoir. The fourth point, however, still remains for discussion, namely, the increase in thickness of plants which form woody stems (Dicotyledons). The origin and signification of cambium is the nut on which so many young phytologists have already broken their milk-teeth, the Gordian knot which so many botanical Alexanders have cut instead of untying, and the enigma, for the solution of which almost all the Coryphæi of our science have laboured with more or less

[1] I beg to observe, that generally throughout the entire memoir phænogamous plants only are referred to.

success. My researches also with respect to this newly-arising formative layer between bark and wood are by no means concluded.

Before, however, I proceed to communicate my observations on this subject, it is necessary once more to take up the question of the individuality of plants. I have already remarked above that, in the strictest sense of the word, only the separate cell deserves to be called an individual. If we go a step further, we might define each axis with its lateral organs to be individual beings. If, however, we disregard this circumstance of the plant being composed of cells and similar axes, and conceive the term individual, as applied to the organic world, to signify a body which cannot be divided into two or more similar ones without the abolition of its idea of totality, and whose vital process has a fixed point of commencement and termination in definite periodicity, it thence follows that the herbaceous (*planta annua*) and the true biennial plants, which flower in the second year, and then die off *entirely*, are the only ones which can be regarded as individuals in the vegetable kingdom. The idea of individual life also necessarily requires as a characteristic that individual death should be a condition of the organization itself. But where such a death does not take place as a final termination from internal necessity, as an internal preconditioned cessation of the organizing force, there also must individuality be out of the question. This is the case, however, only in the above-mentioned plants, and from them solely, therefore, as from the *prototype*, must we set out, in all researches into the nature and life of the vegetable organism.

In order to facilitate the transition to what is to follow, I will now proceed to the exposition of the two different modes of propagation. It either takes place by a process which has hitherto been called impregnation in plants, and to which a sexual difference has been ascribed (Wiegmann's Archiv, 1837, vol. i, p. 290, &c.), or by division; the plant, for instance, developing on itself a perfectly similar individual, and then at an appointed time dismissing it. This latter, the formation of so-called bulbilli, &c. occurs, together with the former, in only a small number of plants. We must, however, make ourselves somewhat more intimately acquainted with it. This formation, for instance, does not always take place in such a manner that the parent plant separates itself entirely from them, and scatters them about singly, but it most frequently forms, previous to its own individual death, a peculiar organ, which places the offspring in a peculiar vital connexion with one another, and at the same time serves as a reservoir for a certain quantity of nutritive material, by which the first development of these young individuals is facilitated. But in most cases this organ is merely a metamorphosis of some other one with which we are already familiar, for example, the stem or the root, or, as in the potato, the axillary buds; and no scientific person has therefore ever hesitated to speak of these things as mere *portions of a plant*, which continue to live as connecting members between the younger *individuals* after the death of that one which has generated them. On the other hand, a different course has been taken, where stem and root simultaneously, and therefore almost the entire totality of the plant, take part in the formation; and although the result in this case may perhaps be that there can be no question at all of an heteromorphy of a known portion of a plant, still the physiological identity in the signification of this and the former part has not been maintained with precision, and the view has thus been obscured.

Most manuals are silent upon this subject, as though it were quite self-evident that the tree was to be regarded as the perfect plant; and I believe it not difficult to prove that, where vegetable physiology still lies very deep in error, this particular misconception is solely in fault. Two entirely distinct ideas have here been confounded, namely, the highest stage of development to which vegetable life can raise itself, and the type upon which the idea of the individual must be based. If, then, the first of these ideas may be maintained with regard to the tree, still the application of the second to it fails completely in every respect, as has been very correctly asserted before by E. Meyer (Linnæa, vii, p. 424). It necessarily pertains to the notion of a plant, that it produces foliaceous organs on its stem, yet there is no tree which has leaves. Paradoxical as this may sound, it is still not the less true. It is a fact, of which certainly no botanist is ignorant, that no lignified part of a plant, even though it be only in its second year, is capable of producing a leaf; but the direct consequence is by no means so generally acknowledged, that for that very reason the woody stem cannot come under the idea of plant. Much confusion has arisen in our physiology from the error of regarding the tree as a *single* plant, the ideal definition of root, stem, bud, &c. have become very vague, and bitter controversies have been carried on with respect to the functions of these parts, which could have no result, because the one party spoke of this, the other of that, this one of the stalk, the other of the stem, this of root-fibrils, that of ligneous root-substance.

The so-called lignified root is, however, just as little a root, as the lignified stem is still a stalk, but both together form an inseparable, and, moreover, altogether purely accidental organ for the plant, which has secreted the annual individual upon its surface, in order to bring into connexion, by means of a single organized membrane, the whole sum of the newly formed young individuals. The tree corresponds precisely to the polypidom, and it appears to me to be as unsound to set out from it as the type in plants, as it would be for the zoologist to take a Gorgonia as the ideal of animal individuality. This analogy, however, is in no way weakened by the circumstance, that we meet with this woody stem most frequently in precisely the highest developed plants; but, on the contrary, it is natural that, if the animal kingdom in a certain measure receive the vegetative part of its character from the vegetable kingdom, this should connect itself by the lowest stage of animals to the highest plants, whilst even this vegetative half of the vital phenomena in the higher animals is in like manner purified and ennobled by its individuality constantly gaining in independence.

With this explanation of the woody stem (the root included), it will henceforward appear by no means remarkable that this organ (as if it were a mere organized soil) can generate upon every part of its surface young vegetable individuals; that is, buds, so soon as it is in a condition to convey nutritive material to those buds from any part, whether it correspond apparently to the former root or to the stem; while this refined idea of the plant conducts to the law, that in the regular course of vegetation, neither root nor internode, but only the axilla of the leaf, is capable of generating a bud, i. e., a new axis with lateral organs.

But the following remarks, which in nature (who never, like a bad artist without a plan, fluctuates between the most opposite methods) would be, in the usual mode of treating it, an inexplicable contradiction and an absolute miracle, will serve for the decisive establishment of this view.

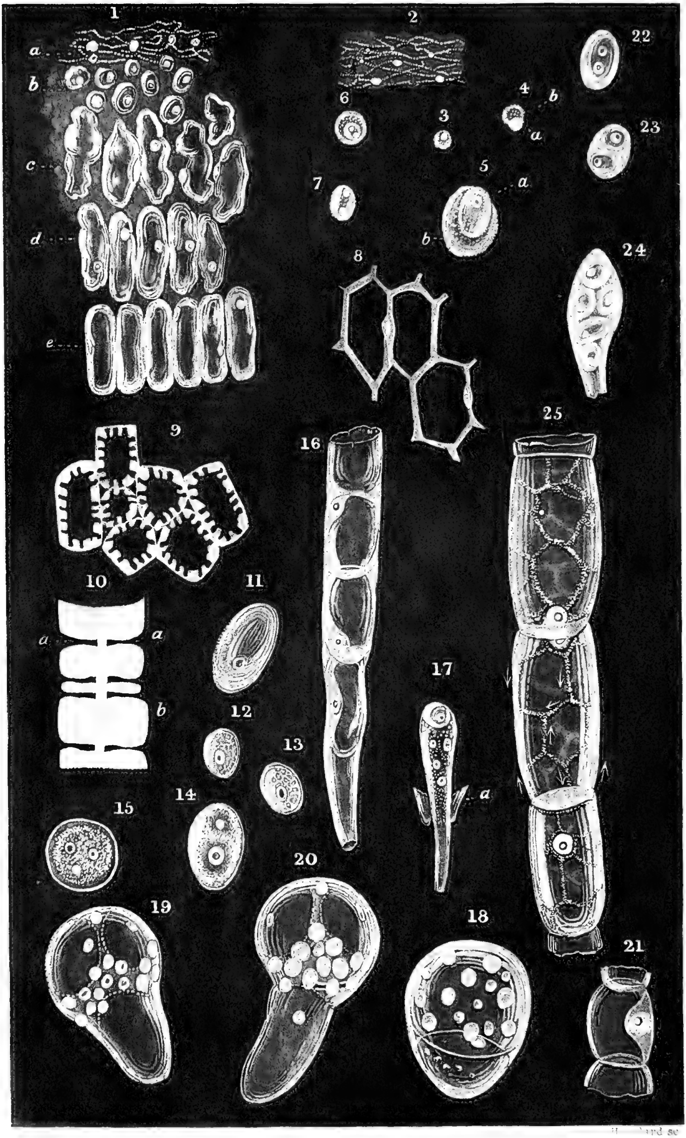
So soon as the secretion of this organized mass, the wood, takes place, for instance, we suddenly miss the influence of the law of formation, which, until then, had without exception directed the growth of the entire plant in all its parts. Here, so far as we are at present acquainted with the subject, there is no formation of cells within cells, here no expansion on all sides of the originally minute vesicle occurs, there is here no cytoblast upon which the young might be developed; but beneath the outermost layer of cells, which are comprised in the term bark, an organisable fluid is poured out, as it were, into a single, large, intercellular space, which fluid, as it seems, consolidates quite suddenly throughout its entire extent into a new, altogether peculiarly-formed tissue of cells, which are deposited one upon another, the so-called prosenchyma. Here, moreover, there is decidedly no formation of vascular bundles from cells of lower dignity, for all of them originate simultaneously and of their full size; and what has been called (spiral) vessels of the wood, is something which differs immensely from the spiral vessels of herbaceous plants, both in respect of their origin, and probably of their physiological signification also.[1] In like manner, no result has been obtained from the controversies which have been sometimes carried on with great warmth respecting the function of spiral vessels, nor could any be gained, because each party meant the spiral vessels of herbaceous plants, or of the wood, *ad libitum*, completely losing sight of the possibility that the two might be very different things. If, for instance, we examine the cambium in the earliest period at which it begins to acquire organisation,

[1] This position has undergone essential modifications, in consequence of subsequent researches which I have made with respect to the cambium, and which proved that a cambium, in the sense in which it had been previously used in physiology, namely, as denoting an amorphous formative fluid between the wood and bark, had no existence at all; that the wood and the bark, on the contrary, form one uninterrupted continuity, and their margin is merely denoted by a layer of delicately-walled, gelatinous cellular tissue.

we find that it consists throughout of gelatinous prosenchymatous cells which perfectly resemble one another. Shortly afterwards, some separate longitudinal rows of these cells appear to have increased somewhat in breadth, which is the only circumstance that distinguishes them from the adjacent mass. As development advances, we observe that some dark spots appear upon the walls of some of these expanded cells, which we soon recognise to be small, flat air-bubbles, that have been formed between their walls and those of the neighbouring cell. Gradually all the expanded cells which are so disposed one upon the other are changed in this way: the air-bubble gradually appears more sharply defined, assuming the circular or oval figure; and there appears in its centre a smaller circle which constantly becomes more distinct, and which originates in the following manner: when the deposition of new masses takes place upon the inner wall of the cell, the parts corresponding to the outer air-bubble remain free from the deposit, thus forming a small canal which traverses the newly-deposited mass. We now recognise the fully-developed porous vessel, the partition walls between each two superincumbent cells appearing at the same time to be more or less absorbed. This history of the formation of the porous vessels, which may readily be observed in limes and willows, greatly contradicts the general notion that the porous canals serve to facilitate the communication of the sap. As the air-bubble is first formed on the outside of the wall, it renders the passage of the sap at that spot impossible, and for this reason the origin of the porous canal might be most readily and naturally explained as a local atrophy of the cell-wall. At the same time the above shows that the distinction between fir-wood and that of trees which bear leaves, in respect to anatomical structure, cannot be of such vast physiological importance; since, with similar elements and development, the distinction is really based on the larger or smaller number of cells that are converted into porous vessels.

There are still, however, a great many gaps to fill up. In particular the origin of the medullary rays, and their relation to the wood; the formation of the new bark; and, lastly, the origin of the buds in the body of the wood, are so many questions for extended researches, to the execution of which, however, we may look forward at no distant time, when we consider the ardent and gratifying zeal which has been awakened and cherished, especially amongst our contemporaries, in favour of the sound and scientific study of the anatomy and physiology of plants.

I have attempted in this Memoir, so far as lay in my power, to solve many interesting questions in Vegetable Physiology, or, by more accurate definitions of the subject, to advance nearer to a future solution. May these observations meet with a friendly reception at the hands of the vegetable physiologists of Germany, and be speedily improved upon and extended.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EXPLANATION OF THE PLATES.

SCHLEIDEN'S TREATISE.

PLATE I.

Fig. 1. Cellular tissue from the embryo-sac of *Chamædorea Schiedeana* in the act of formation. *a.* The innermost mass, consisting of gum with intermingled mucous granules and cytoblasts. *b.* Newly formed cells, still soluble in distilled water. *c-e.* Further development of the cells, which, with the exception of the cytoblasts, may still coalesce, under slight pressure, into an amorphous mass.

2. The formative substance from fig. 1, *a,* more highly magnified, gum, mucous granules, nuclei of the cytoblasts, and cytoblasts.

3. A single and as yet free cytoblast, still more highly magnified.

4. A cytoblast with the cell forming upon it.

5. The same, more highly magnified.

6. The same. The cytoblast here exhibits two nuclei, and is delineated in

7, isolated after the destruction of the cell by pressure.

8. The same cellular tissue in a higher degree of development than that represented by fig. 1, *e.* The contiguous cell-walls have already united. By making a transverse section, it may be distinctly perceived that the cytoblast is enclosed in the cell-wall.

9. Cells from a delicate transverse section of the almost matured albumen.

Fig. 10. Common partition-wall between two cells from fig. 9, under a higher magnifying power. The stratiform depositions may be observed at *b*, and the porous canals produced by their local failure at *a*. I could distinctly enumerate from nine to twelve layers which had been deposited within fourteen days.

11. A sporule from *Rhizina lævigata Fries,* with the cytoblast.

12, 13, 14. Different cytoblasts from the embryo-sac of *Pimelea drupacea* before the appearance of cells.

15. A young cell with its cytoblast, from the same. The latter in this instance presents the unusual number of three nucleoli.

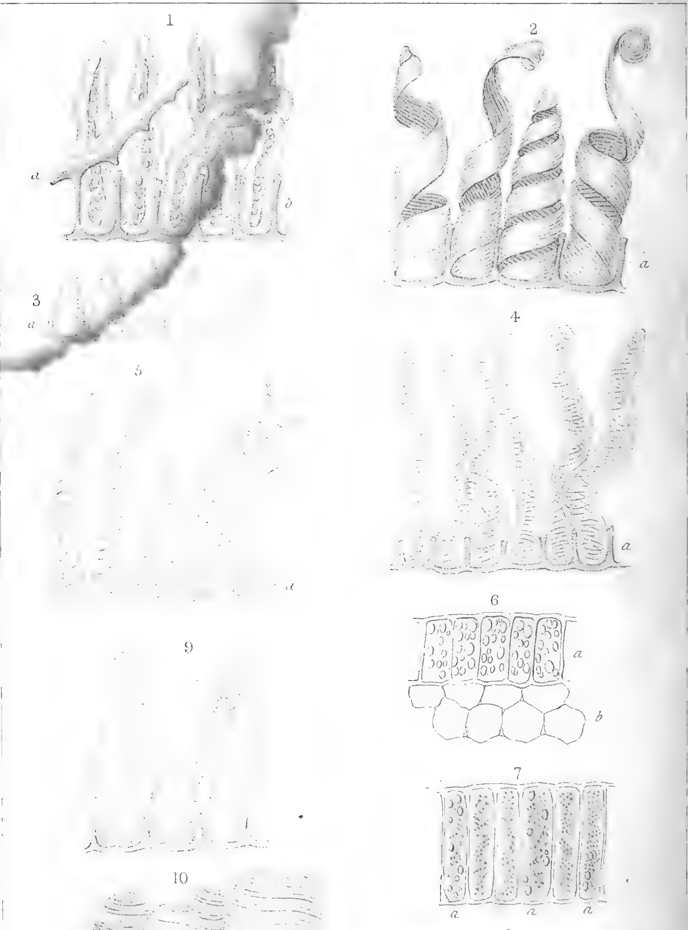
16. A portion of the embryonal end of the pollen-tube projecting from the ovulum in *Orchis Morio,* within which, towards the upper part, cells have been already developed. At the lower part, the original pollen-tube may still be distinguished. The almost globular cytoblasts are, in this instance, distinctly enclosed in the cell-wall.

17. Embryonal end of the pollen-tube from *Linum pallescens,* together with an appended lobule of the embryo-sac (*a*). The process of the formation of cells is commencing. Above, a young cell with its cytoblast is already perceptible, beneath this several cell-nuclei are seen floating free.

18, 19, 20. Commencing germination in the sporules of *Marchantia polymorpha.* Compare the text, p. 248.

21. Portions of the pollen-tube which have become cellular, from *Orchis latifolia,* in the highest stage of development; the investment of the pollen-tube is no longer perceptible. The cytoblast is enclosed in the cell-wall, just as in fig. 16.

22 and 23. Two isolated cells from the terminal shoot (*punctum vegetationis,* Wolff) of *Gasteria racemosa;* 22 exhibits two free cytoblasts; 23, two newly-formed cells within the original cell.



M. J. Schleiden, ad nat. delt   H. Adlard

Fig. 24. A very young leaf of *Crassula portulaca*, the five cells which solely compose it being still surrounded by a parent-cell.

25. Three cells from an articulated hair of potato, with a retiform current of mucus upon their walls. In the central cell the direction of the currents is partially indicated by arrows.

In all the instances in which I have observed the movements in the cells of phænogamous plants, I have constantly found the moving matter to consist of a yellowish mucous fluid, perfectly insoluble in distilled water, and mixed with minute black granules, but differing entirely from the other aqueous sap of the cells; and even when the currents were so small as to appear merely as excessively minute delicate lines of black points, I succeeded with higher magnifying powers in distinguishing the yellowish mucous fluid, especially when aided by the favorable circumstance (which not unfrequently occurs) of the current becoming arrested by some impediment, which causes a somewhat larger quantity of the moving material to accumulate, and is generally followed either by a change in the direction, or a division of the current.

PLATE II.

Fig. 1. Cells from the epidermis of the pericarp of *Ocymum basilicum*, moistened with water, so that the mucous globule has expanded, and torn the outer cell-wall (*a*) from the side walls (*b*).

2. Cells from the pericarp of the epidermis of *Ziziphora dasyantha*.

3. Cells from the pericarp of the epidermis of *Salvia verticillata*.

4. Cells from the pericarp of the epidermis of *Salvia Horminum*.

5. Cells from the pericarp of the epidermis of *Salvia Spielmanni*.

2, 3, 4 and 5, *a*, exhibit the remains of the side-walls of the ruptured cells.

6. A portion of the epidermis (*a*) and of the integument (*b*) of the ovule of *Collomia coccinea*. The epidermis-cells contain merely granules of starch.

Fig. 7. The epidermis-cells of the half-ripe seed of the same plant, for the most part containing gum; at *a*, some still undecomposed starch.

8. The same cells from the same seed nearly ripe. Beautiful spiral fibres have been formed from the contents, which are entirely consumed.

9. Cells of the epidermis of the seed of *Leptosiphon androsaceum*, moistened with water, so that the cone of jelly has come forth. *a*. The remains of the cell-walls.

10. Cells from the epidermis of the seed of *Hydrocharis Morsus ranæ*. In the lower part of the cells, where they are connected together, the spiral coils take a direction different from that in the upper and free part.

For the figures in Plate II consult the text, pp. 243-6.

THE END.

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