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THE RELATION OF THE VEGETABLE AND ANIMAL TO THE INORGANIC KINGDOM.

A

LECTURE

DELIVERED AT

The Royal Institution of Great Britain.

ROYAL COLLEGE OF SURGEONS OF ENGLAND

PRESENTED by the AUTHOR

BY

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I THINK it right to mention that in printing this Lecture I have, without interfering with the sense, altered some of the forms of expression, and introduced a few additional sentences; for in the delivery I was of course anxious to avoid all technical terms, and certain details which could not prove interesting to those whom I had the honour to address.

A

LECTURE,

&c.

Plants and animals, when viewed in the relation in which they stand to inorganic substances, may fairly be regarded as together constituting one great kingdom of nature—the organized. For however widely their more advanced members may be separated, there can be no denial of the fact that plants and animals are connected by common characters—those very characters by which they are especially distinguished from the inorganic kingdom.

Whatever may be thought of Schwann's exposition of it, there is no doubt that his view of the uniformity in structure of plants and animals is, in the main, correct—that is to say, in their elementary tissues may be recognized the existence of homologous parts. How far this homology may be actually traced is at present doubtful, and will probably remain so for some time to come, for its complete solution will involve much additional labour; but in the simplest tissues at least the existence of corresponding parts appears obvious. If, for example, we compare vegetable cellular tissue and cartilage, an uniformity of structure may be demonstrated. In young specimens especially the resemblance is occasionally such that it may be difficult to distinguish between them. In either case we recognize cavities, each containing a certain substance in a matrix which is more or less homogeneous. Now, whatever view be adopted of the absolute nature of these parts, whether the cavities be regarded as cells or mere spaces, it is generally admitted that there is an homology between the "cells," "cell contents," and "nucleus" of cartilage on the one hand, and the "cells," "primordial utricle," "protoplasm," and "nucleus" of the vegetable tissue on the other. I say, how far this homology can be traced between the more complex vegetable and animal tissues is at present very doubtful. It necessarily becomes obscured as development advances.

As with their structure, so with their chemistry. The farther we investigate, the more obvious the relation. Witness, for examples, the facts which have been long since disclosed of the composition of the protoplasm and primordial utricle; of the relation of the vegetable and animal so-called proteine principles; and, lastly—while starch appears to be absent from the fungi—of the discovery of substances amongst animal tissues possessing the composition and reactions of starch and cellulose, and the formation of sugar in the animal system.

Need I stay to show the relation of plants and animals in their physiology? Why, we speak familiarly of the vegetative functions of animals. And concerning what are called the animal functions—motion and sensation,—while movement, and even locomotion, dependent on the action of contractile tissue, occur in many vegetable structures, the lowest forms of animal life offer no evidence whatever of the existence of a nervous system. The clear recognition of this grand fact has proved the basis of some of the soundest doctrines in animal physiology. We all know how the study of the vital functions of plants has assisted in the interpretation of the vital functions of animals.

Every one who is familiar with the recent progress of physiology will admit, I think, that the latest steps in knowledge have effaced those lines of demarcation which were formerly drawn between the vegetable and animal kingdoms. The history of this subject is an interesting and instructive one. If but only a few years since the question had been asked, What are the points of distinction between a plant and an animal? it would have been met by a clear, full, and apparently satisfactory answer. Yet of these marks of difference, once so much relied on, what remains? It is a most significant circumstance that they have gradually disappeared as science has advanced. From the time when Linnæus curtly dismissed the question with the aphorism that "Stones grow—plants grow and live—animals grow, live, and feel," to the present, the history of the subject has been but a series of supposed distinctions raised upon the basis of one set of observations to be destroyed by the next.

Look even at those which have held their place most firmly, and are generally considered the best: I mean those drawn from the existence of a stomach and the power of assimilating food. We cannot assert that simple cavities for the reception of food are peculiar to the animal kingdom; but a stomach is something more than this. Yet, again, if we considered the existence of an internal receptacle in which food is dissolved as essential to the character of an animal, we should have to hand over to the vegetable kingdom not only many of the simplest forms of life now reckoned among animals—as Gregarina and others, and indeed Rhizopoda generally,—but also those holding a more advanced place: the Tæniæ, for example. Nay, we should be even driven to separate the sexes; seeing, for instance, that in the males of all Rotifera at present known the alimentary canal is entirely abortive.

It is interesting to observe here that the agastric animals may be divided into two classes: those whose term of life is naturally so short that it may be continued the necessary length of time without the use of food at all, as the males of Rotifera and the parasitic ones of Cirripedia; and those which assimilate food, independently of a stomach or intestinal apparatus, by simple imbibition from without, as the Cestoid entozoa. In the first case there is an absence of stomach consequent on the absence of food; in the second, there is assimilation of food independently of a stomach.

So, again, concerning the nature of their food and its assimilation. Although it is unquestionably generally true that plants possess the power of converting inorganic into organic compounds—with which power, so far as we at present know, animals do not appear to be endowed,—yet, in the first place, it may be observed that while inorganic compounds enter largely into the food of animals, organic compounds are by no means excluded from the food of plants. The most recent researches have confirmed the older ones, that organic matter is freely absorbed by plants from the soil; and they have rendered it more than doubtful whether this is always reduced to inorganic forms before it becomes assimilated into vegetable tissues.

Again, during germination and flowering, the embryo and bud assimilate the stores of organic matter laid up for their supply.

And, lastly, one important class, the Fungi, and indeed parasites generally, appear to subsist entirely, and to be dependent on organic compounds. Nay, it further appears that in some cases at least, as in the familiar instance of the yeast plant, not only is organic, but even a nitrogenous, substance essential to their prolonged existence. This fungus, whose cells of course contain protoplasm, a nitrogenous compound, will go on multiplying, as is well known, for an indefinite time if placed in a liquid containing saccharine matter, and an albuminous substance at a moderate temperature. But in a solution of pure sugar, in the absence of any nitrogenous matter, the plant will multiply its cells for a short time only, the protoplasm of the old cells being transferred into the new ones as they are successively evolved; but under these latter circumstances the cells gradually become smaller, and at length cease to multiply, a portion of the nitrogenous matter being wasted in the reproduction until it becomes insufficient to carry on the growth.

Although, then, the distinction founded upon the nature of their food and their relative power of assimilation is, on the whole, the least exceptionable, and certainly the most important in regard to the natural position in which plants stand to animals, yet, as we see, this is by no means absolute and universal, and admits only of general application.

But it may be said that it is not now by one, but by several characters taken together, that the point is determined. It is admitted that there is no one mark of distinction which will apply to all cases. To decide the question in any given instance we must apply several tests, and judge according to the direction in which the weight of evidence inclines. But does the evidence in one direction always preponderate? And observe, the doubt and difficulty depend not only on the absence, in the simplest forms, of characters which we might be enabled to recognize as distinctive. The resemblance is not merely a negative one. We may indeed construct special definitions, whether anatomical, chemical, or physiological, but which are necessarily, to an equal extent, arbitrary, and each of which will draw the supposed boundary line at a different latitude.

Under these circumstances a question may be fairly raised behind this one—Is there of necessity a line of demarcation at all between plants and animals? Why must it be? Is it in accordance with nature? After many years of patient research there is no better evidence of its existence than of the philosopher's stone. The eager endeavour to discover it reminds one of the fable of the treasure hidden in the field. It has been most diligently sought for, yet never found; but the labour has not been in vain, for in the search the ground has been well tilled.

Would it not, then, be more consistent with our present knowledge, and allow of a classification more conformable to the characters exhibited, to admit that the two great kingdoms are connected by common forms—to recognize the existence of an intermediate group, neutral in the centre, and passing by its confines into either kingdom?

But the question which I propose to consider more especially, is one that must be answered before the other can be profitably discussed. I mean, the distinction between the organized and the inorganic kingdoms. Does this admit of a clear and satisfactory answer? As in the former case, it is true—and here, indeed, much more commonly so—that a case of difficulty may be solved by the application of the several tests at our command. We are not unfrequently puzzled between a plant and an animal. We are seldom at a loss to distinguish between an organized and an inorganic body. Yet this difficulty may arise; it has arisen.

The study of living beings is divided into the three great subjects of Anatomy, Chemistry, and Physiology: the first comprising a knowledge of the structure; the second, of the composition of their various tissues and organs; and the third, a knowledge of their actions—of the functions they perform. Under these heads, then, let us examine the relation which organized bodies—that is to say, plants and animals, hold to the other great kingdom of nature, the inorganic, with a view of distinguishing and defining them.

In a review of what has been put forth on this subject, it will be seen that the simplest forms of life have not been present to the minds of those who have attempted to define them. Very many of the proposed means of distinction between organized and inorganic bodies apply with great force to the more advanced animals and plants, but they are found to be at fault when tested by those cases in which organization and life appear to be reduced to their simplest terms.

What has become of the former attempts at distinction drawn from an examination of their physical characters—such as their size, form, and consistence? These more obvious characters serve, it is true, in the majority of cases where no confusion could possibly arise as general distinguishing features; but they are subject to far too many exceptions to make them of much value or importance in those more doubtful cases where they are most required.

The supposed essential difference in structure between organized and inorganic bodies claims more consideration. It has been, and is still very generally stated, that here the great distinction is, whereas the structure of an inorganic substance is homogeneous, the structure of organized bodies is heterogeneous, even the simplest forms presenting at least a distinction of cell wall and cell contents.

Here we directly encounter, in all its influence, the great cell doctrine. In the contemplation of the simplest condition of organic structure our ideas have been for a long time either wittingly or unwittingly governed by the brilliant theory of Schleiden and Schwann, that a nucleated cell is its primary and simplest form, and the origin of every other structure. Thus it is laid down, "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 [1]." Or, "The simplest form which animal matter assumes in its organization is that of a nucleated cell." Again: "The simplest and most elementary form with which we are acquainted, is that of a cell, containing another within it (nucleus), which again contains a granular body (nucleolus)." "This appears from the interesting researches of Schleiden and Schwann to be the primary form which organic matter takes when it passes from the condition of a proximate principle to that of an organized structure."

And again: "The most important of all these forms which can be included in the category of *simple elementary parts*, are cells, which are not only the starting.point of every vegetable and animal organism, but also, either as cells, or after undergoing divers metamorphoses, make up the complete animal body; and, in the most simple vegetable

[1] Schwann, 1838.

and animal formations (unicellular plants and animals), even possess individuality[2]." And, lastly: "The chief point in this application of histology to pathology is to obtain a recognition of the fact, that the cell is really the ultimate morphological element in which there is any manifestation of life, and that we must not transfer the seat of real action to any point beyond the cell[3]."

This doctrine, in spite of the vigorous assaults it has from time to time sustained,—and its vast power is shown in the way it has withstood them,—is dominant now; in some respects more so than ever, warmly supported as it is by some of the highest living authorities.

I would say to this theory—not proven. On the contrary, there is, I think, conclusive evidence that it is not fundamentally and universally true.

Passing over the state of solution, the simplest condition in which organic matter appears in living bodies is as the substance called plasma, protoplasm, or blastema, these terms being indifferently applied to a structureless, soft, semifluid substance, yielding nitrogen upon analysis, and in its composition most closely resembling albumen and fibrine. The characters and properties of this substance, the changes it undergoes, and, above all, its homogeneousness, may be most conveniently and naturally studied in the interior of certain vegetable cells or spaces.

[2] Kölliker, 1860. [3] Virchow, 1860.

Passing from this, we may next notice primary or basement membrane; clear, transparent, structureless, homogeneous. Many examples of this are found even amongst the tissues of the most complex animals and plants. Such a membrane exists beneath the epithelium, and may be clearly demonstrated in many parts. I may mention also, the limitary membrane of gland tubes and follicles, perhaps the sarcolemma of muscular fibre, the posterior layer of the cornea, and the capsule of the lens.

But it has been asserted that this is formed from cells. There is no evidence of this: such an origin has not been demonstrated. It is little more than a supposition arising out of the cell theory. The nuclei or germ centres which have been described as existing in it, and which have been imagined to represent the coalesced cells out of which it is assumed to be formed, and into which it is sometimes said to break up under favourable circumstances, are assuredly not always, perhaps not even generally, present. For example, they cannot be discovered in the structureless membrane of the Malpighian tubes of insects. In truth, there is better evidence for the belief that this primary or basement membrane is formed out of blood plasma by direct conversion. It never at any period exhibits distinct traces of structure.

Look, again, at the common white fibrous tissue. Although there exists at present great difference of opinion concerning its mode of formation, there is strong and increasing evidence to show that it may be produced by a simple and direct fibrillation of structureless, amorphous plasma or blastema, without the intervention of cells of any kind. It is admitted even by the chief advocates of the cell doctrine, that the fibrous matrix of fibro-cartilage is thus formed. The earliest stages of this fibrillation are, I think, often satisfactorily seen in the changes which healthy blood-clot undergoes at the completion of the act of coagulation.

But why should I endeavour to establish the existence of these simpler tissues independently of the agency of cells, inasmuch as I believe it may be shown, that in the development even of the most complex tissue cells have no share ?

I would cite the case of striated muscular fibre, for we cannot choose a stronger one, a more elaborate tissue even in the most complex animals, and the history of its development has long been the favourite illustration of the cell doctrine. Lastly, I can here speak more positively, from my own observation.

I will not trouble you with this story at greater length than is necessary to my present purpose.

The original description which Schwann gave is well known, and has been generally accepted. According to this, round cells, furnished with a nucleus, arrange themselves close together in a linear series, then coalesce at their points of contact; the septa become absorbed, and thus a hollow cylinder is formed. This secondary cell, as he termed it, is then supposed to pass through all the stages of a simple one. A deposit of a peculiar substance, the proper muscular substance, takes place 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. They are gradually absorbed. This 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.

The description which I will venture to give you of this process, as the result of investigation, is completely at variance with this one.

In an early embryo, if a portion of the substance in which muscular fibre is formed be examined, free nuclei or cytoblasts scattered through a clear and structureless blastema in great abundance will be seen. The first stage in the development of striated muscular fibre consists in the aggregation and adhesion of these cytoblasts, and their investment by blastema so as to form elongated masses. In these clusters the nuclei are not at first generally arranged in a single series, but two or three, or even more, occasionally lie side by side in apparent disorder. Almost if not quite as soon as the cytoblasts are thus aggregated into these long masses, they become invested by the blastema, and this substance at the same time appears to be considerably condensed, so that the outlines of the nuclei become almost or completely obscured. The fibre thus appears to be irregularly cylindrical or somewhat flattened, with a rough and uneven surface. In some cases, before the nuclei come into contact, a layer of apparently condensed blastema may be already discerned forming around them, and this external investment, if not very carefully examined, will occasionally give them the appearance of nucleated cells.

These nuclei, thus aggregated and invested, next assume a much more regular position. They fall into a single row with remarkable precision, and the surrounding substance at the same time becomes arranged principally in the form of two bands bordering the fibre and bounding the extremities of the nuclei. The tissue bounding the nuclei, at first thin and pellucid, soon increases in thickness by the addition of the surrounding blastema to its external surface. Its increase is due, I repeat, to the addition of fresh material upon its exterior, and not to a deposit on its inner surface. Subsequently the nuclei separate, and after a while degenerate and disappear, and the fibres increase in length and decrease in diameter; changes to which I need not now further allude. The striæ first become visible at this period.

The further growth of the fibre and its development are continued by means of the surrounding cytoblasts, which are numerous. These may be seen to become attached to its exterior, and then invested by a layer of the surrounding blastema. Thus, as it were, nodes are formed at intervals on the surface of the fibre. In some specimens the adherent nuclei may be seen attached to the fibre at very regular distances, but in many cases no such uniformity can be detected. More frequently, however, the nuclei are so near to each other that the investing material of one, as it spreads, becomes blended with that of its neighbour; and so a continuous layer of fresh material, of greater or less extent, is added to the exterior of the fibre. It is at first clear and pellucid, like the original substance of the fibre when first formed, and contrasts strongly with its present aspect. It is at this period readily detached by a little rough manipulation, but it soon becomes intimately connected and indefinitely blended with the exterior of the fibre. The striæ and other characters of the adjacent portions of the fibre are soon acquired. The nuclei, at the same time, gradually sink into the substance of the fibre, and an ill-defined elevation, which soon disappears, is all that remains.

All these changes may often be traced in the same specimen: first, the attachment of nuclei to the exterior of the fibre; secondly, their investment by blastema; thirdly, the gradual sinking of the nuclei into the substance of the fibre, the corresponding subsidence of the elevation, and the development of striæ.

Although I have avoided all unnecessary detail [4], yet I fear that even this short description must have proved a tedious one. Let me ask you only to bear in mind the following facts. Muscular fibre is formed by the aggregation of cytoblasts, and their investment by surrounding blastema. No nucleated cells are concerned in any way in the process. The further growth and development of the fibre is by the addition of fresh substance to its exterior.

Now in justice to Schwann, or rather to Valentin, it is only fair to remark that his original statements have been, in this instance at least, somewhat overstrained. Moreover, it is important to observe that Schwann's description of the earlier stages of the development of muscular fibre was not drawn from direct observation—the very stage upon the correct description of which the whole question turns.

Speaking of the development of muscle, Schwann says—"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

[4] See Philosophical Transactions, 1856, for the facts and arguments by which I have endeavoured to support the statements given in the text.

being able to obtain any very young embryos; but the deficiency in my researches may be supplied from the description given by Valentin[5], from which the following passage is extracted:—'Long before separate muscular fibres can be discerned, the globules (kügelchen) of the primitive mass are seen arranged in parallel lines, particularly when they are lightly pressed between two pieces of glass. The granules (kornchen) then appear to be drawn somewhat nearer together,'" &c. Then Schwann argues to show that by the terms "globules" and "granules" of the primitive mass, Valentin could not have meant nuclei, and must therefore have meant nucleated cells[6]. Was not what Valentin saw and described as "globules" the nuclei simply invested by blastema in the manner I have attempted to indicate? In describing the formation of a cell around the nucleus, Schwann himself states that a stratum of substance, which differs from the cytoblastema, is deposited upon the exterior of the nucleus. In the first instance, this stratum, which varies in thickness, is not sharply defined externally, but becomes so in consequence of the progressive deposition of new molecules. We cannot, he says, 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

[5] "Entwicklungs Geschichte," p. 268.

[6] See Schwann, Untersuchungen, &c.

when it is thick only the external portion, becomes gradually consolidated into a membrane. This account, variously modified, has been repeated by many observers.

It appears to me that a nucleus thus simply invested by blastema has been sometimes described as a nucleated cell; the well-defined outline which the blastema after a time acquires being regarded as a distinct cell wall, and the blastema itself as the cell contents. Kölliker formerly described, after Schwann and others, this aggregation of blastema around a nucleus under the term "investing globule," and he went on to say that around it a distinct cell wall is subsequently produced—"cell development round investing masses." In many cases I doubt this. Even Schwann declares that many cells 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. In some instances I believe it to be utterly impossible to distinguish a wall from the so-called contents. But under the idea of the cell theory, unless their formation be traced, they have all the appearance of nucleated cells. Nevertheless, I believe the distinction to be an important one, more especially as it concerns the relative functions of cells and nuclei.

But it may be said, admitting the fact that certain tissues in the more complex animals are formed without the direct agency of cells, still that the original, primary, and simplest condition of each being is that of a nucleated cell—the germinal vesicle or germ cell, and so, after all, it is merely a question of indirect instead of direct agency. But this I conceive to be all-important to the issue. The cell doctrine, as it ever has been, and is still by many upheld, does not rest upon this broad fact, even assuming the fact itself concerning the nature of the germ to be, in every case, beyond question. It has plainly contended not only for the original agency of cells in the genesis of every living being, but for their direct and continual influence in the formation of each individual tissue. But although that portion of the cell doctrine which asserts the direct and continual agency of cells in tissue development is therefore no longer tenable in the face of these facts, yet there still remains the other section—and in reference to my subject the far more important one—which declares a nucleated cell to be the original, primary, and simplest condition of every living form; that nothing which possesses life is simpler than a cell.

Let us turn then from this glance at the formation of some of the individual tissues of the more complex beings, to a consideration of the complete structure of the simplest.

It would, I think, be difficult to find more striking illustrations of the influence of theory on the observation of fact, than the descriptions which have been given of the structure and functions of the simplest forms of life.

It is impossible to contemplate the result of Ehrenberg's careful and patient labour, without regret that such extraordinary power of observation should have been fettered by the conviction that organs which are found only in the higher animals must exist also in the Infusoria. Hence the difference between his observations and his interpretation of what he saw. Hence the imaginary parts and attributes with which he has invested many of these minute beings. He could conceive any thing except simplicity.

Nor is Ehrenberg at all singular in his conception of the structure and endowments of these simple organisms. Less distinguished, but more recent observers have outstripped him in this respect. Thus arose the extravagant hypothesis of a "diffused nervous system." Witness again, for example, the accounts still, to a great extent, current, of the structure of the common Hydra. These descriptions of organs and attributes of the simplest forms of life remind one forcibly of the old theory of generation, which supposed all the parts and organs of the mature being to exist in miniature in the ovum, and according to which, development was regarded as a mere process of evolution.

In like manner has the cell doctrine influenced the views which have been taken of the structure and nature of the simplest forms of life. They have been studied under the dominant idea, that nothing can be simpler than a nucleated cell; that an unicellular organism must be the simplest possible condition of life. Yet there are living forms, as, for example, the common Amœba or Proteus, in which no distinction of cell wall from cell contents can be discerned or demonstrated. This is admitted by the most skilful observers, and by powerful advocates of the cell theory. What then? It is assumed that such a distinction nevertheless exists, only here it cannot be clearly recognized. It must be so; at least according to the cell theory. Or others, willing to compromise in such cases as these, while acknowledging the impracticability of demonstrating an actual cell, assert that there is here a tendency to the production of a cell, although not one fully formed. Surely an objection may be fairly raised to such an argument as this. Why is there a tendency to the production of a cell? Because otherwise a cell would not be the simplest and primary form of life, as this grand doctrine proclaims.

In truth, nothing can be conceived simpler than the structure of Amœba, which may be taken as the type of Rhizopoda generally. It is less complex than an unicellular organism, for there is no distinction of cell wall and cell contents. In fact, it appears as the simplest condition of life, being nothing more than a minute mass of substance, or protoplasm, or sarcode—call it what you will—structureless and shapeless. The absence of any thing like difference, or the existence of a limitary membrane, seems to me proven by the Protean alteration of form, the movements and mode of progression, and above all, by the manner of feeding, and the fusion of different portions of the surface. The vacuoles, which are so often observed, appear as the first step towards that reticulation which exists throughout Actinophrys. Their nature is demonstrated by the changes to which they are continually subjected—division and fusion. One or more of these spaces is sometimes observed to undergo distinct changes in size and shape, owing to the contractility of the surrounding substance; but such a space can have no claim whatever to the title of contractile vesicle. Again, a portion of the substance is often described as being firmer and more resisting than that around it, and has, therefore, been considered a nucleus. But assuredly such a distinction does not always exist. And even granting, for the moment, its constant presence, this would not, as we have seen, imply, of necessity, the condition of a cell. The granular matter, which is, perhaps, always more or less apparent in the interior, and which is so commonly seen flowing hither and thither in strange currents, seems to me to be no essential part of the structure; for it is extremely variable in amount and position, and when the creature moves, the irregular processes which are extended are, almost invariably, for the first few seconds, perfectly clear and transparent before these granular currents flow into them. May not this molecular matter represent that portion of the food which is not assimilated into the homogeneous structure?

The study, too, of Actinophrys is a most instructive one. It consists throughout of a soft, delicate, structureless, homogeneous substance, like that of Amœba. This substance, at first sight, appears to be arranged in the form of most delicate round, or polygonal cells, out of which the whole animal seems to be constructed. But a careful examination will show that no such cells really exist. No distinct cell wall or limitary membrane whatever can be detected. The homogeneous substance, of which the animal is throughout composed, is every where continuous. The minute cavities are simply vacuoles or spaces produced by a reticulation of the substance. The number and regular arrangement of these spaces—the extent of the reticulation—produce an appearance which may be easily interpreted as a cellular structure. All this is rendered evident when the creature is torn or crushed. By this means the character of the substance, and the nature of the spaces are at once revealed. The supposed cells will, under pressure, either coalesce into larger, or be divided into smaller spaces, and these will be found to present, in all respects, the characters of the original ones.

Thus, then, the reticulation, which is so characteristic of Actinophrys, may be simply regarded as a more advanced stage of that vacuolation which commences in Amœba; and the numerous slender, delicate, and ephemeral processes which are extended every where from the surface may doubtlessly be regarded as akin in their nature to those ever-changing processes, remarkable in Amœba, which are so evidently but simple extensions of the substance.

It is most interesting, in relation to this arrangement of tissue in Actinophrys, to consider the view of the development and structure of vegetable cellular tissue which was long since enunciated by Wolff, and has been recently supported by the researches of Wenham—that it is formed by a simple reticulation of protoplasm; that the so-called cell walls are but intervening portions of this substance, and at first exhibit no traces of junction, and that the so-called cell cavities are merely vacuoles.

It may be worth while to regard for a few moments the changes which the protoplasm undergoes in this view, for it will be seen that it offers a clear and simple explanation of the existence of septa and spaces; in other words, of the formation of cellular tissue. You will remember that according to the cell doctrine, "it has usually been supposed that every leaf originates in the duplicative subdivision of a certain cell of the axis, and that its subsequent extension is due to the continuance of the like process of cell multiplication." But in the view to which I now ask your attention the process may be thus described.

If a portion of young vegetable tissue be placed in the compressor with a very small quantity of water, by applying sufficient force the mass will burst, and as the protoplasm flows forth from the living plant it exhibits a remarkable tendency to separate itself into cavities and ramifications which speedily acquire some degree of consistency, apparently from the formation of a membrane by the partial coagulation of the external portion exposed to water. At the point of rupture the protoplasm will sometimes form a membranous tube through which the discharge takes place.

On dissecting out the centre of the bud at the extreme end of a stalk of the common Anacharis Alsinastrum — a very convenient subject for investigation, chiefly from its size and transparency— a kind of cellular cone will be found. In the first formation of a leaf from the main stem, a small nodule or protuberance appears, which is entirely filled with protoplasm alike throughout. A number of cavities next become disseminated through the mass. These are formed apparently in the most random and irregular manner both as to size and position; small spaces being indiscriminately mixed with larger ones of perhaps ten times their bulk, much resembling the cavities in a slice of bread crumb. They appear filled with fluid. No further explanation of these changes can be offered than that they arise from some inherent property that protoplasm seems to possess of separating itself from its more fluid admixture, and so of forming cavities and thread-like divisions.

The spaces continue to increase in size, and assume a more regular form and arrangement, the intervening portions of protoplasm gradually becoming condensed. If at this period a portion of the leaflet be treated with alcohol, a membrane will separate from the wall of each cavity, and shrink together upon the cell contents, which now appear to be granular.

Thus the cavities are for the most part simultaneously developed in this simple manner, but it frequently happens that others afterwards appear, for wherever there is an accumulated mass of protoplasm, a space is sure to be formed in it subsequently. Wherever the division is unusually broad a new vacuole arises in its substance. On the other hand, when one of the first-formed spaces is unusually large it is often divided into two by the extension of a bridge of protoplasm across it. Thus cells, which otherwise in the process of growth would become exceedingly elongated and disproportionate in size, are divided across by a septum of protoplasm, which seems to accumulate at that part. In other instances, again, where the cell is of still greater length, a larger mass of protoplasm accumulates midway in the centre, in which a cavity appears, and thus the original space becomes separated into three. At length the septa attain their utmost degree of tenuity and consistency, and the whole structure acquires the uniformity and other characters of vegetable cellular tissue, the coloured particles appearing under the influence of light. It is not until the tissue has far advanced in development that any protoplasm is generated within the cell.

In this account of development in Anacharis I have closely followed the description drawn by Mr. Wenham from actual observation, and which he has confirmed by the study of other plants.

These familiar examples may suffice for our purpose. If it were necessary, others might be selected from allied forms, some of which find a place in the animal, some in the vegetable kingdom. Even in creatures more advanced than these in organization, we may still call in question the evidence of a cellular structure.

We may say, then, that the simplest forms of life, and the simplest tissues of the highest, reveal no difference in structure, no distinction of parts, to the severest scrutiny; that they cannot, therefore, as heterogeneous bodies be distinguished from homogeneous inorganic matter.

Nothing appears to be more certain than that organic matter in the course of development very commonly assumes the form of cells, and that these play most conspicuous parts in the vital processes. Although they can no longer be regarded as the primary and simplest form of organization, and the origin of every other, they are unquestionably, in many instances, its final and ultimate condition. As organic matter may tend directly to the production of a fibre, or some other form of tissue, so does it, but perhaps more commonly, tend to the production of a cell, which is not, in numerous cases at least, transformed into any other structure, but is itself the form in which development ends.

There was a time when it was generally believed that chemistry was able to determine whether a body were of organic or inorganic origin—that its composition declared its nature. Gradually, in the progress of knowledge, have the several supposed points of distinction been, one after the other, swept away. We are now well assured that the same simple laws of composition prevail throughout both kingdoms of nature; so that the differences which are still recognized appear to be of degree only, not of kind. Although, therefore, they are, especially in the aggregate, of great value and importance, still they cannot in any measure be relied on to establish a line of demarcation between the kingdoms.

Hunter said—and truly of his time—"No chemist on earth can make out of the earth a piece of sugar, but a vegetable can do it." Since the discovery of the artificial production of urea, the list of substances whose formation, so far as the chemist can reveal their composition, is common to the organism and the laboratory has been steadily extended, and now almost every month adds something to the number.

It is a significant fact, that very many of the presumed marks of distinction have been founded upon our ignorance. For instance, it is often said that the production of such substances as albumen, fibrine, and others, is characteristic of living bodies, because we have not yet succeeded in making them in the laboratory; yet a list like the present one[7] should teach us that such a distinction may be destroyed to-morrow. And here we look to chemistry for some of its most useful achievements —the artificial production of substances hitherto formed only in the laboratory of nature. We anxiously wait for the expiration of her patent. And probably, after all, the chief difficulty of the problem lies in the doubt of their exact composition.

It may here be observed that in the chemistry of organic bodies is to be found the explanation of that tendency to change which is their well-known general character. When we remember the influence which the number of elements, and the number of atoms of each element present, the

[7] A table of organic compounds which can be formed artificially, given by Dr. Frankland.

proportion of water and the presence of nitrogen, exert upon the stability of a compound, we have no difficulty in accounting for the easy and rapid decomposition of most organic substances. But be it remembered that in both organic and inorganic bodies are seen all degrees of this tendency to decomposition, which is the result of their composition, and of the conditions to which they are exposed. By withholding or supplying these conditions it may be, in either case, prevented or set on foot.

Thus far the relation of the organic to the inorganic kingdom has been considered without reference to life. The previous considerations apply to organized bodies under every condition Their anatomy and chemistry belong to them whether dead or living. Hitherto no abrupt line of demarcation has been discovered.

Life, after all, constitutes the grand distinction. The difference appears to be infinitely greater between living and dead organic matter than between dead organic and inorganic substances. And in order to appreciate this distinction, there is no need to exhibit one's ignorance in any attempt to define life, or to describe it. We are indeed baffled in the study of life, as we are by those subtler traits of structure with which vital phenomena are associated, yet we may recognize and distinguish it by its effects.

I would venture, then, to speak of life as being essentially a state of dynamical equilibrium; as consisting fundamentally and universally in a definite relation between destruction and renewal —in a regulated adjustment between waste and repair, whereby the condition is maintained notwithstanding constant change.

It will be observed that this is no pretence towards a definition of life. It is only an attempt to distinguish life by its essential features—when reduced to its simplest condition, and separated from those elaborate details which belong to it in its more complex forms—from those changes and their effects which are more or less visible in all inanimate bodies.

Life is not a state of resistance. Even now erroneous views too commonly prevail on this point. To say the least, changes are as active during life as after death. The proofs of this are clear and complete. We have only to remember that any man, under ordinary circumstances, in the course of a year, consumes, roughly speaking, something like 800 pounds of solid food, about an equal quantity of oxygen, and perhaps 1500 pounds of fluid; that notwithstanding this vast supply, amounting in the aggregate to more than 3000 pounds, his condition during the whole period remains the same, or nearly so; inasmuch as all this matter, after being assimilated into his structure, and forming a part of him, is excreted or cast off in quantity exactly equal to that taken in, but widely different in the forms which it assumes, and in the manner in which the several elements are arranged.

Waste or destruction is a necessary, an inevitable condition of the manifestation of life. It is involved in every vital act. And the power of compensating for this waste or change, the repair or reproduction necessary to the continuance of life, involves that of assimilation—that is, the power of converting foreign matters into the structure of the organism. In other language, the power of appropriating food.

We cannot conceive life without including both these conditions; destruction and renewal—consumption and supply. For instance, life is not a state of change only as opposed to stability, for this is simply a question of degree every where, and dependent on the conditions to which bodies are exposed. Neither dead organic nor inorganic bodies are immune from change. Again, life is not peculiar as a process of repair only; for it is well known that this may occur in inorganic bodies. If, for example, portions of crystals be broken off, and these, thus damaged, be placed under favourable circumstances in appropriate solutions, they will be repaired. They will not at first uniformly increase, but the edges, or angles, or portions of the surface which have been chipped off will be restored, so that they will recover perfectly their original geometrical form. This, therefore, is repair, or reproduction apart from life.

But in life there is the constant and concurrent operation of these two processes. Both actions are involved in the idea of life, whereby it is distinguished from mere change on the one hand, and from repair on the other. Thus while inorganic and dead organic matter tend to a state of statical equilibrium, during life the equilibrium is the result of opposite forces. It is dynamical.

Nor does it appear to me that we can at present safely venture further than this. If we attempt to define the vital process of repair, distinctions fail us. For instance, the nutrition of living organized bodies has been distinguished from the formation of inorganic bodies, such as crystals, or their repair, by saying that the nutrition of living bodies is interstitial, and thus distinguished from mere accretion.

But, to pass over more subtle objections to this distinction, allow me to recall your attention for a moment to the formation of muscle, and to the action of the cytoblasts as centres of nutrition. One cannot watch the manner in which they seem to attract the blastema, and aggregate it around themselves, without being reminded of the effect of what are called points of crystallization. In either case there is, as it were, a focus of attraction, upon and around which fresh substance is deposited. The origin of the nuclei themselves is certainly a more doubtful matter. The process is very differently described, and it is not impossible that it may vary under different circumstances. But, to say the least, in spite of strong statements to the contrary, there still exists good evidence in favour of the opinion that they may be formed by the aggregation and coalescence of granules or molecules, the minutest forms of organic matter with which we are acquainted.

Now I do not wish to seek for fanciful or strained comparisons, but we know that Schwann, who in this idea was anticipated by Wolff, was struck with, and dwelt at some length upon, the resemblance between cell development and crystallization. With our present most imperfect knowledge of the two processes, how shall we define between nutrition and crystallization? Understand, if you please, that I am not comparing crystals with cytoblasts. Nor am I in any way attempting to establish, or even assuming, that crystallization and nutrition are alike. My object now is only to show the impracticability of drawing a distinction between them, for at present we do not know in what the difference consists.

Amongst the various structures of animals there are some obvious examples of growth by accretion, as in shells. The calcareous plates and spines of Echinodermata, the shells of Mollusca, and the solid stem or sheath of Corals, have been shown to grow by simple addition to their edges and surface [8]. There is here no evidence of any interstitial deposit. Moreover, there are curious facts relative to the manner in which some of these parts—as the spines of Echini—fracture, which connect their structure very closely with that of crystals.

It may, however, be objected, that although these shells grow by simple accretion, thus increase by mere addition to the circumference of each plate through the formative membrane at the margins, yet, nevertheless, there is nothing like true crystallization; that the earthy matter does not assume any geometrical form, but under the higher powers of the microscope is found to be deposited in the form of granules or molecules. So in other cases, as, for example, amongst Tunicata in the tunic of Ascidia, earthy matter is deposited in what appear to be, under a low magnifying power, genuine crystalline forms; nevertheless these, under higher powers, are resolved into clusters of granules or molecules. But in relation to this subject, some striking observations and ingenious experiments by Mr. Rainey, on what he describes as the mode

[8] In the Lecture the structure and mode of growth of the shell and spines of Echinus were briefly described as an illustration; but if it were necessary, many other varieties of this plan of growth by superficial deposit or accretion might be brought forward, for it seems to be common in the hard parts of the Invertebrata.

of formation of shells by molecular coalescence, are especially interesting, and seem, as it were, to supply the missing link. He shows that carbonate of lime, when formed in a viscid solution, instead of appearing in the ordinary crystalline, takes on a globular form, and assumes the characters and aspect which are very commonly presented in many organized structures, as, for example, in the shells of some Crustacea. And he shows, moreover, that thus, by adopting the proper conditions, these natural structures can be accurately imitated by artificial means.

His plan of proceeding is a very simple one, and may be easily practised. After many experiments, and much patient investigation, he now adopts the following method:—A clear solution of gum is carefully purified from the salts it naturally contains, and to this is then added a small quantity of chloride of calcium, which of course is held in solution. In another portion of gum water, still denser, and similarly purified, a small quantity of carbonate of potassa is dissolved. Then these two solutions are simply brought together in a shallow glass cell, conveniently constructed for the purpose, and allowed to intermingle gradually, without any artificial mixture or disturbance. By placing the glass cell under the microscope from time to time, the formation of the globules of carbonate of lime can be very satisfactorily watched. The rapidity with which they appear, and afterwards increase in size, depends upon the density of the solution. The rate at which they are deposited seems to be inversely proportionate to the viscidity. The best results are produced when the solutions are as thick as possible. Still more recently, Mr. Rainey has advanced another step, in substituting albumen —the white of egg—for the solution of gum (in this case employing carbonate of soda instead of carbonate of potassa), with a most successful result. Indeed, the imitation is perfect, as the natural conditions are accurately fulfilled.

A modification of this experiment, which Mr. Rainey has practised, is too interesting in relation to my subject to be passed over. By managing matters in such a way as to have the solution of different degrees of density in different parts of the cell, he shows that the carbonate of lime assumes, in its deposition, all grades of form, from ordinary crystals, where the solution is scarcely more viscid than water, through various forms in which the crystalline character is gradually lost, the angles becoming rounded, and the surfaces variously curved, and then the dumb-bell shape assumed, to the genuine globules in their most perfect condition, where the viscidity is densest.

I may mention, in reference to this matter, that the characters of blood-crystals may be, in like manner, completely changed by the addition, during their formation, of water rendered viscid by gum or albumen.

And when to this is added the fact that in some rare instances genuine crystals are formed in shells, as rhombohedra of carbonate of lime in that of the common oyster in certain parts immediately beneath the internal surface, to say nothing of the constant formation of crystals in the interior of certain vegetable and animal cells, it assuredly becomes more than difficult to distinguish clearly, by any well-defined line of demarcation, the process of crystallization from that by which certain tissues of some living beings are formed.

I need not at this time and in this place observe that the investigation of the phenomena of life has not been in any way assisted, that our knowledge of the vital processes has not been in any measure advanced, by the assumption of what has been styled a "vital principle"—an empirical term, which, like some others, when employed in physiology, is, even at the best, equivalent to nothing more than the final letters of the alphabet in an algebraical formula; for it is, when used in its least objectionable sense, a mere expression of something unknown. But the assumption of such an agent or principle, however designated, annihilating or suspending the operation of forces acting elsewhere, has not proved altogether harmless in its influence upon the progress of knowledge. By referring all vital actions to this obscure agency, while nothing was thereby explained, inquiry was to a great extent and for a long while checked. Many, dazzled by the idea that the nature of vital phenomena was exalted by thus associating them with some mysterious and peculiar principle, apart from and opposed to those agencies which act elsewhere, missed the grander conception that even in the vital functions may be recognized the operation of forces, some of which, at least, are common to both kingdoms; while between these and others which appear to be peculiar to living tissues it is probable that a relation may exist, like that which prevails between the chemical and physical forces.

Again, it is needful to beware how we create artificial distinctions. Is there not much assumption involved in the confession that we are unable to construct the simplest form of living tissue? Men sometimes talk as if their power were limited only by life. But can we construct a crystal any more than a nucleated cell? We may fulfil certain conditions under which, as we have learned from experience, crystals are formed; but what is our share in the act itself? In like manner we may take a seed or an egg and place them under circumstances in which they will develope. In either case we are acquainted with the necessary conditions, and we fulfil them. We can do no more. Truly it is our own fault if the fact be not thoroughly impressed on us that our power is not limited by life only.

I know well that many find but little interest in labours which lead only to what may be called a negative result. To some perhaps it would appear to be more satisfactory if clear and precise distinctions could be drawn between the great kingdoms of nature. The discovery of these, indeed, has been the aim of many who have devoted no trifling amount of time to this very purpose. But why? While a belief in the absence of any abrupt line of demarcation, apart from life, could in no way tend to confusion, it would, I conceive, inevitably lead to more simple, sound, and true views of nature. More fruitful results would follow. The student of animal physiology would have more interest in the labours of the botanist, and both of these would find themselves, to their own great gain, in much closer relation with chemistry and physics. Who can doubt that the best effects would ensue from a clearer insight into, a more thorough appreciation of, the mutual relation of the natural sciences? How much valuable and essential knowledge is set aside by every student of any branch of science—for science is emphatically one whole—who toils blindly on without the light which studies so closely akin to his own would throw upon his labours! But if our knowledge of animal physiology has been rendered clearer by the light thrown upon it by researches into the nature of the vegetable kingdom, if our knowledge of the common physiology of the organic kingdoms has been advanced by appeals to the laws which govern the operations of inorganic matter, yet it is no less true that we can only safely avail ourselves of the evidence which is thus afforded by extended inquiry as we recognize the relation in which the natural kingdoms stand to each other.

The study of nature is conveniently and necessarily for our limited capacity divided into sections. Let us not confound an artificial distinction, drawn by and for ourselves, with a natural one.

Finally, then, I would ask, to what conclusion do the accumulated labours of centuries point? Is the gap between man and the animals around him ever widening as we work? Do the limits of the animal and vegetable kingdoms become more sharply defined as our knowledge advances? How numerous and important were the marks of distinction between the organized and inorganic kingdoms which the science of a former day set up! Have they been extended or established by subsequent research? The answer to these questions is at once obvious and unequivocal.

But the reply must not be merely a negative one. As these arbitrary lines have been gradually effaced, has not the plan of nature become more plainly revealed? Can we not more clearly discern its simplicity and uniformity—in a word, its unity?

THE END.

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