MINUTE FORMS OF LIFE

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BIOLOGY—the science of life—is as profoundly concerned with the minutest and simplest organisms in nature as with the largest and most complex; and it is now well-known to all that there exists a realm of organised nature beyond the utmost reach of unaided human vision, which is without known bounds as to its extent, and without ascertained limits as to minuteness.

The progress of human research in many departments is absolutely dependent upon the perfection of its instruments. You know what splendid accessions to human knowledge have been poured in upon us by means of the spectroscope, which must have remained for ever beyond us without it. It has, as it were, endowed science with a new sense.

It is manifest then, that it can only be by the aid of accurate optical instruments that we can know anything certain of this profoundly interesting region of minute living forms.

The microscope, in a general way, is a familiar instrument. It is an instrument which should make the invisible visible, and in doing so open up the details of invisible structures.

Up to a comparatively short time since this was quite well secured for us by the optician, when the magnifying power did not exceed certain limits. The lenses made were, more or less perfectly, the embodiments of mathematical optics. But when a given limit of magnifying power was exceeded there was manifest failure. The object was made to appear larger. It was, so to speak, amplified, but no further detail was revealed. It was not, in the sense in which I like to use the word, properly *magnified.*

But during the last fifteen years English opticians have made wonderful progress. They have gradually increased the perfection of lenses of great magnifying power until now they have made them instruments of real accuracy, which help us to search and penetrate almost to the known limits of the organic world; to touch, indeed, its very fringe and margin.

I may fairly assume that comparatively few of my audience have followed nature into these depths. It will help me immensely in the object I have in view to-night if I can convey to your minds anything like a conception of the analysing power of our best and latest lenses. And this shall be my first effort.

I want you to see then how a good lens of any power must not only enlarge the object, but as it does so must open up its structure. To enlarge an object a thousand times is of no advantage if you cannot see more of its details by that means than you can when it is enlarged five hundred times.

For example, I have projected here* the scabbard or sheath of the wasp's sting; and I have magnified it and its contents. I choose it because it is a familiar object. Everyone has seen its rapid protrusion and withdrawal in the living wasp, and has a conception of its actual size. This one was the one-twentieth of an inch in length. You see the scabbard here quite plainly. You see also the delicate barbed sting protruding from the point. This is the method in which the sting is used. Here is the second sting, which is always concealed in the scabbard, wholly withdrawn, in order to show its nature. You observe the disclosure of structure and form which is thus given us.

By the side of this sting I have placed the point of the finest cambric sewing needle that ever British manufacturer produced or English maid or matron used. It is broken off to about the same length as the sting, and magnified to the same extent. Observe, we have not merely enlarged the needle point, but we have opened up its details. To the naked eye it is beautifully finished, burnished with intense brightness, and without a scratch; but under the lens its outline becomes broken, its surface riven and torn, and the process by which it was produced made manifest. This is what I mean by magnification. By this illustration we learn that while the beauty and finish of art break up and cease, under the scrutiny of the lens, the finish of Nature's products

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* A series of illustrations were thrown upon a screen, and were constantly referred to.

cannot be impeached by analysis, but is as beautiful under the lens as to the naked eye.

Again, you all know the appearance of a piece ot ordinary chalk, and that it is composed of millions of minute shells, or *tests*, produced by little specks of living jelly, which secrete the carbonate of lime that is in the ocean, and build it up into minute and beautiful forms; and chalk is largely the accumulated result, through incalculable ages, of the building and cementing together of these minute *tests*.

But there is another kind of chalk found in many parts of the earth, especially in Barbadoes, which is not composed of carbonate of lime, but is silicious. It is known generally as *Barbadoes earth*. It is composed of incalculable myriads of delicate and beautiful skeletons, such as these on which you are now looking. They inhabited the tertiary oceans in inconceivable multitudes, and as they died their minute skeletons fell down in a continuous rain upon the ocean bed, and became cemented together. Such were their numbers that they formed a solid rock, which geologic action has brought to the surface in the Barbadoes and many other parts of the earth. When a small piece of this earth is boiled in dilute acid and washed, it falls into an almost impalpable powder, the grains of which are simply such skeletons as you now see.

The illustration now before you has great refinement of detail, all of which is brought out. If you take the smallest toilet pin you can find, and pass it gently over a polished steel surface, burnishing the point into a visible metallic speck, that will roughly represent the natural size of the object which is now before you. These on which we now look are beautiful in detail, and they are still smaller. What I would have you note is that we have here, not merely specks of form made bigger to the eye—it is not mere beauty of outline enlarged—but there is perfect opening up of otherwise invisible details.

I can strengthen this evidence by a familar illustration. I know it is somewhat impolite to assume that an audience like this knows anything about the human flea; but the facts of nature are at times impolite, in spite of all our efforts. Here we have the magnified image of this organism. There is nothing remarkable revealed by this amount of magnification, excepting the complex and curious organ which you see at the end of the tail. We can make little out with this amount of magnifying power, but there are traces of structure which we should like to learn more about. Let us then carefully cut off this small organism, and so prepare it as to be able to examine it with a lens ten times as powerful as this. You now see that the whole organ has a distinct form, and that its surface is carved into delicate wheel-shaped bodies, the centres of which give rise to scythe-like hairs which remind us of the wheels of the war chariots of Boadicea's braves. The organ is known as the *pygidium* of the flea; but what its function is we have yet to discover. Suppose we take two or three of these wheel-like bodies, and put them under a lens that will magnify 40 or 50 times as much as the lens which has magnified the pygidium as a whole. What then do we see? Still completer and more perfect detail. You perceive, in fact, that we have reached the limit of structure, and that we are profoundly indebted to the increasing analytical power which is now the quality of our most advanced and powerful lenses.

Let me complete this series of illustrations by a still more delicate illustration. Most of my audience will have seen some of those remarkable little organisms known as *Diatoms*. They are very minute and beautiful vegetable products, inhabiting water and moisture almost everywhere on the surface of the globe. Some of the lesser ones are so small, that to be seen distinctly, as atoms possessing beautiful forms at all, they must be magnified at least 40 or 50 diameters. During life they are covered with a greenish body-substance; but this encloses a beautiful glass-like skeleton of silex, taking, in various species, an immense variety of form, all, however, being exquisitely beautiful. But the great point of interest is that these minute atoms of organic form are engraved, and chased, and carved with a delicacy and mathematical refinement so great that our most perfect and powerful lenses cannot yet, in certain instances, perfectly open it out—that is to say, the lines are carved too finely, and the dots are too small, and too close together, to be detected as separate items of structure.

I have had some special forms of *Navicula*, for instance, in my possession for years, and they have been examined by myself and by several skilful experts repeatedly, but it is only within the last four years that, by the aid of vastly improved lenses, I have been able completely to resolve them—that is, to disclose clearly the structure of the surface.

It will be instructive for us to study the facts. Here, then,* we

* Referring to the projection of the magnified image of a very minute form of *N. rhomboides*.

have a projection of a *Navicula rhomboides*, which is extremely minute. You will observe that the form only is made manifest here. No traces of structure are visible. We have the outline and the mid-rib and nothing more, and with this power (600 diameters) no wizardry of manipulation will get more. If there is more structure to be discovered we must have a higher power. Here, then, is the same object magnified 1,200 diameters. You now see that a delicate line engraving, as it were, begins to show itself, and even in this state it is one of the most beautiful objects upon which the eye can rest. But we can get no further results with this magnification. Let us examine the result with a magnifying power of 1,800 diameters. We now see not simply what appeared to be delicate horizontal lines, but we perceive that they are in some places crossed at right angles, and at the points of intersection there is a tendency to break out into dots or beads. But we have reached the limit with even this power, and to clearly define the structure we must go beyond it. I therefore put on a lens so arranged as to give 2,400 diameters. Now you perceive that the image of the structure has been so widened out that where the definition is best and the illumination finest all lines have vanished, and we perceive that the apparition of lines was caused by the mathematical arrangement of minute silicious hemispheres, which the present lens enables us to see. This is known as the *ultimate structure* of the diatom. This great magnification is not a mere enlargement, as would have been the case with the older lenses, but it is a gradual opening out of details by optical analysis. The capacity to do this is what I mean by high magnifying power. When I tell you that with lenses now in my possession I have been able to detect and measure a delicate fibre of organic structure less than the $\frac{1}{204000}$ of an inch in diameter, you will see that we are possessed of an agency with which to enter with confidence on the study of the minutest forms of life.

But now come the questions, What are these forms? where are they found? and what are the questions involved in the study of their life history? I answer, they are septic or putrefactive organisms—that is to say, organisms that everywhere accompany putrefactive action in fluids.

Such putrescence and decay, in all their stages, are associated with teeming myriads of excessively minute and intensely active living forms, that multiply with inconceivable rapidity. The question is, How do they come? Put a piece of fish, or beef, or vegetable, into water, and leave it for forty-eight hours, and it will be found teeming with countless billions of the smallest living things known in nature, the majority of which are in the intensest action. Here is a representation of a group of these organisms.* You perceive that most of the organisms have a fibre at either end, by means of which they move in the fluid with the greatest freedom. This spiral form darts through the fluid like an animated corkscrew. Some of the forms move more slowly. These (pointing to *B. termo*) are the minutest form which the biologist is able to reach in Nature. The question is, How do these arise? Does the dead matter which is breaking up in the putrescent fluid change by some unknown force into these wonderful organisms? or does Nature act here as in all the regions where her vital processes are known to us, and are they the outcome of true parental products, eggs or spore, which from their minuteness must be universally diffused?

This is a most important problem, and we must put it plainly. The question is, Do the lowest and minutest forms of life under any circumstances originate in not living matter? From which comes the larger question, Does that which is possessed of the distinctive properties of life originate in that which is absolutely without those properties?

There can be no doubt that this question *seems* to be intimately linked with the integrity and coherence of the great doctrine of Evolution.

All matter, living or not living, has chemical elements in common; and all matter that is living is compounded of practically unvarying elements. The matter in which alone life is found to inhere is in reality the same in the fungus and in the human brain; but matter possessed of the properties of life is absolutely distinct from matter that is not living.

Now is there any line along which, to-day, and in our sight, matter, that is not living, does, without the intervention of living things, change into matter possessing the properties of life? Some few evolutionists answer imperatively, "Yes, it must be so. The doctrine of evolution is in peril without it." Evolution involves an unbroken progression from the beginning. There could be no break—no discontinuity. Its hidden processes were carried forward until it had transmitted the not living into that

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* Giving the principal forms of *Bacteria*.

which became endowed with life. But they wish to demonstrate this by showing that *now* this process is continued.

I want you to observe that all the foremost biologists in Europe and America to-day are profound believers in the doctrine of evolution. Superficially, at least, it seems to be strongly in the interests of that doctrine that we should be able to prove in our laboratories that the not living can, without the intervention of living things, be caused to enter upon the condition known as living. And there are a great many so-called *facts* presented by certain scientific men to prove that this does happen; and they are fairly before the biological world. But do biologists accept these so-called facts? I answer without hesitation, No. Then what does this prove? Why that our great biologists are not hunting through nature for props to a theory, but are searching sternly and for ever for facts. It is not a question of what will best support the doctrine of evolution, or what will not support that doctrine, but, first and pre-eminently, *what is true.* And knowing this to be the case, you may surely place the profounder confidence in the hypotheses which they put forward.

In the present issue of the "Encyclopædia Britannica," Professor Huxley, in an article on Biology, distinctly affirms, in the light of the latest research, "that the properties of living matter distinguish it absolutely from all other kinds of things, and that the present state of our knowledge furnishes us with no link between the living and the not living."* This is a sufficiently bold and clear statement, and is made by one who has philosophically mastered the results of researches up to the latest date.

Now less philosophical and more eager evolutionists marvel at this affirmation. They appear, as I have said, to conclude that the doctrine of evolution is imperilled by such an admission; and some of them—Dr. Bastian, for example—have gone so far as to ask, with some fervour, why Professor Huxley and other leading physiologists should promulgate an opinion "which seems to involve an arbitrary infringement of the uniformity of nature."† Plainly, they promulgate the notion because, after the most careful investigation of facts, they feel it would be false to promulgate any other—because, in short, they have no alternative. It is a statement of the facts of nature as they now know them; and he would be a bold man who would question either their competence or

* Vol. iii., p. 679. 9th Ed. 1875.
† "Evolution and the Origin of Life." Pp. 15, 16.

their honesty. On the other hand, Professor Huxley plainly shows the error of forming any opinion detrimental to the great doctrine of evolution, from the absence of any power now known to be in operation in nature competent to change the not living into the living. He strongly and philosophically affirms that spontaneous generation now is by no means necessary to evolution. His words are—"If all living beings have been evolved from pre-existing forms of life it is enough that a single particle of living protoplasm should once have appeared on the globe as the result of no matter what agency. In the eyes of a consistent evolutionist any further independent formation of protoplasm would be sheer waste."*

In principle, then, the great biological hypothesis that distinguishes our generation is untouched by the question of so-called *spontaneous generation;* and the conviction to-day of the largest number by far of the most competent biologists is, that down to the uttermost verge of organised existence, out to its very edge, and in its lowliest condition, it is yet true that only that which is living can produce that which shall live.

It would be impossible, of course, now for me to adduce the whole of the evidence on which this judgment rests. There are two ways of approaching the solution of the problem. One is by making heat experiments on putrefactive fluids that give rise to the organisms that are said to originate *de novo*. Endeavour, for example, to fix the death point of the organism. Let us suppose that that should be found to be the boiling point of water. Subject the infusion containing the organism to this, taking care that it should afterwards come into contact with nothing from without, which could either be, or carry, germs. If this be perfectly done, it is inevitable that if the organisms do originate in germs, as the germs would all have been destroyed and the access of more would have been rendered impossible, no living thing would subsequently appear. This method seems simple of application, but it is this apparent facility that has made it so fatal. It abounds in potential errors, and only a master in precise experiment can use it with scientific results. Professor Tyndall, Dr. W. Roberts, and some others, have brought into play the requisite skill, and they firmly pronounce that the living organism does not originate in not living matter.

The other method of reaching the solution of the difficulty is to treat the minute organisms here presented to us just as we treat

* "Encyclopædia Britannica." Vol. iii., p. 689. 9th Ed. 1876.

those that are immensely bigger—study the history of their life, from its beginning to its close, and find out how they originate, just as you find out how an oyster or a crab originates. Follow them from their earliest to their latest condition. Both methods, you see, are essential. The first affirms that the organisms do not originate in dead matter. The second must declare whether they do or do not originate in germs.

Early in the recent history of this question I determined to approach its solution by the second method. I resolved to work out, if possible, the life history of the organisms. The difficulties were not a few; but I was possessed of the finest lenses, and had striven by constant labour for proficiency in their use.

But this was not all that was needed in order to secure scientific results. There must be, ultimately, an unbroken and continuous watching of the same individual form through every phase of its development from its beginning to its close: that is to say, that after a series of separate observations had been made on different individuals of the same "species," indicating by separate parts a life history, it would not do to be content with that; but the truth of the inferences would have to be shown by the uninterrupted following of one individual through the complete cycle of its life. There must be no inference—there must be absolute demonstration. To do this it is quite plain that some means would have to be devised by which a minute drop of fluid containing an organism might be kept from evaporating for an indefinite time; and yet it must be so arranged that it would admit of its being constantly examined with the highest and most delicate lenses.

I can only say that these conditions were fully met and carried into practice. To complete the whole it was pre-eminently desirable to call in the aid of a second observer—first, to verify, test, and confirm every fact observed; and secondly, to make continuous observation possible. In this matter I was fortunate in securing the zealous assistance of Dr. Drysdale, of Liverpool, who first made himself master of the instrument, and then in my laboratory went side by side with me earnestly to work.

Our plan was to accept nothing which we had not both of us confirmed; and to relieve each other in order to work out to the end the various metamorphoses of the same individual.

The most common putrefactive organisms are the Bacteria. But the *monads* are organisms of precisely the same kind, only they accompany the later stages of putrefaction. The Bacteria, as a group, are extremely complex, and some of them are of uttermost

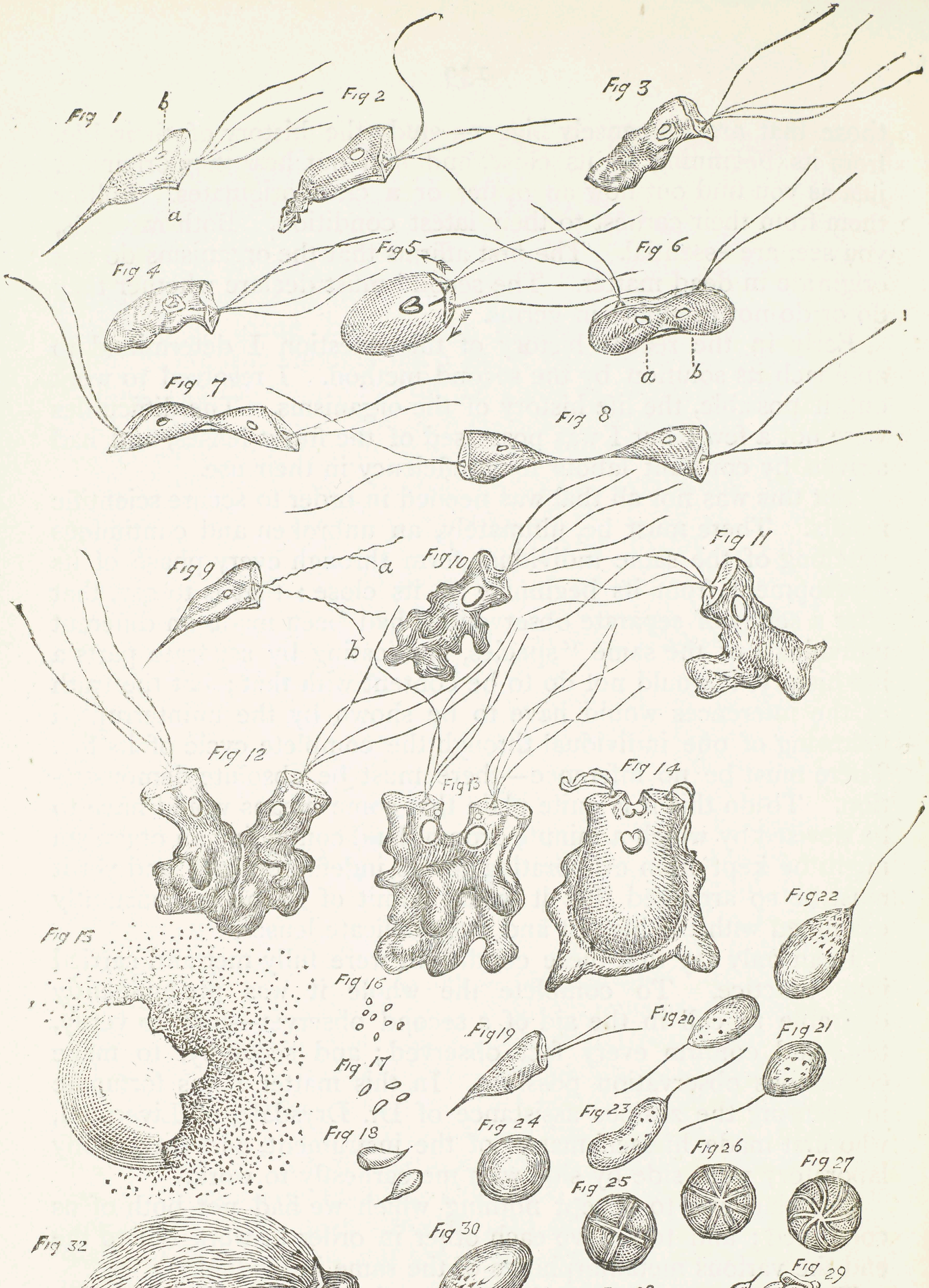
Fig 1
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minuteness. The monads, on the other hand, are apparently simple and slightly larger, and we determined on making them the subjects of our research. We secured the material in which these organisms abound in such inconceivable numbers from the putrescence of fish in water; and we were able in the course of four years' steady work to complete the life history of six distinct forms.

I will now endeavour to give the life history of two of these as clearly, as simply, and as concisely as I can.

The first difficulty one always has is to convey anything like a conception of the size of these extremely minute forms. It is utterly impossible to do this clearly, or at all. No definite idea of size is conveyed by minute fractional measurements. But ten or fifteen thousand of these forms laid side by side would only occupy an inch linear.

Now I want you to notice on this projection the difference between the ordinary Bacteria, which are all round here (Diagram), and these three forms, which are distinct and typical representatives of the monads.

Let it be remembered that we take a minute drop of the fluid containing the monads, such as you could suspend from a fine needle point. We put that upon the field of the instrument, carefully cover it with the thinnest glass, and enclose it and the front of the lens in a chamber of saturated air, which prevents evaporation and admits of continuous observation. The organisms are at once seen to be swimming with intense rapidity and freedom.

The organism shown here (*vide* Plate, Fig. 1) is one of those we steadily worked out. We must assume the coming in of this organism into the field with many others. We fix on one of them, and by a mechanical motion of the stage of the instrument we are able to keep pace with the movements of the object, so as to keep it always in the centre of the field of view. The organism is composed, as it were, of living jelly. You perceive that it has a remarkably pointed tail, which is unusual in this class of creature. It has a nucleus (shown at *b*)—that is the part of it supposed to be more intensely vital. At the point *a* we have a very remarkable organ, which we call the *eye spot*, for want of a better name, because it is a little round disc, constantly opening and closing like the human eyelid. You perceive also, in the front of the body, that there are four fine fibres, or flagella. It is by means of these fibres it accomplishes its wonderful motions. These flagella are decidedly the secret and source of the movements of all this class of creatures. The one before us could sweep across the field with majestic slowness, or dart with a lightning swiftness and a swallow's grace; it could gyrate in a spiral, or spin on its axis, and arrest or change its movements, with an ease and power which at once astonished and entranced us. And what is most marvellous in these forms is, I have never in all my observations detected a single collision. They come together apparently as if they would dart right into each other, but they go carefully to the right or left, very much more successfully than we do at times on London Bridge or in the streets of Manchester.

Fixing on one of these monads, then, we followed it doggedly by a never-ceasing movement of a *mechanical stage*, never for an instant losing it through all its wanderings and gyrations. We found that in the course of minutes, or of hours, the sharpness of its outline slowly vanished, its vacuoles disappeared, and at last it lost its sharp caudal extremity (as in Fig. 2), and was sluggishly amœboid. This condition intensified, the amœboid action quickened, the agility of motion ceased, the nucleus body became strongly developed, and the whole sarcode was in a state of vivid and glittering action. (This is shown in Fig. 3.) If now it be sharply and specially looked for, it will be seen that the root of the flagella splits, dividing henceforth into two separate pairs. At the same moment a motion is set up which pulls the divided pairs asunder, making the interval of sarcode to grow constantly greater between them. This is shown in its earlier and later stages in Figs. 4 and 5; the arrows indicating the direction taken by the divided halves of the root of the flagella. During this time the nuclear body has commenced and continued a process of self-division, as shown in the same figures. From this moment the organism grows rapidly rounder, the flagella swiftly diverge, a bean-like form is taken (as in Fig. 6), and the nucleus divides (as seen at *a b*, Fig. 6), and a constriction is suddenly developed. This deepens (as in Fig. 7), the opposite position of the flagella ensues (Fig. 7), the nearly divided forms now vigorously pull in opposite directions, the constriction is thus deepened, and the tail formed (as in Fig. 8). The fibre of sarcode, to which the constricted part has by tension been reduced, now snaps, and two organisms go free.

Now it must be remembered that this body is not a homogeneous rod of sarcode like a Bacterium. That it should by mere growth elongate, and then divide by fission, is not so wonderful. But here we have an organism of distinctive form and some structure; yet each part divides to form a counterpart to itself, and the whole process may be complete in five minutes, and in the separated individual commence again to divide in twenty minutes more. So that in a few hours a single form will in this way have given rise to an almost inconceivable host.

But it will have struck you that the new organism enters upon its career with only two flagella, and the normal organism is possessed of four. But in a few minutes—three or four at most—the full complement were always there. How they were acquired it was the work of months to discover, but at last the mystery was solved. The newly-fissioned form darted irregularly and rapidly for a brief space, then fixed itself to the floor, or to a rigid object by the free ends of its flagella, and with its body motionless an intense vibratory action was set up along the entire length of these exquisite fibres (indicated in Fig. 9), and as a result of this the ends split, one-half being in each fibre set free, and the other remaining fixed (shown at *a* and *b*, Fig. 9); and in 130 seconds each entire flagellum was divided into a perfect pair.

Now the amœboid state is a notable phenomenon throughout the monads, as precursive of striking change. It appears to subserve the purpose of the more facile acquisition and digestion of food at a crisis. And this augmented the difficulty of discovering further change; and only persistent effort enabled us to discover that with comparative rareness there appeared a form in an amœboid state that was unique.

It was a condition chiefly confined to the caudal end; the sarcode having become diffluent, hyaline, and intensely rapid in the protrusion and retraction of its substance, while the nuclear body becomes enormously enlarged. (This state is shown in Figs. 10 and 11.) These never appear alone; forms in a like condition are diffused throughout the fluid, and may swim in this state for hours. Meanwhile, the diffluence causes a spreading and flattening of the sarcode, and swimming gives place to creeping, while the flagella violently lash. In this condition, two forms meet by apparent accident—the protrusions touch, and instant fusion supervenes. The appearance presented by the first contact is shown in Fig. 12.

In the course of two minutes there is no disconnected sarcode visible (as Fig. 13 shows); and in five to seven minutes the organisms are completely united, the swimming being again resumed, the flagella acting in apparent concert. This may continue for two or more hours, when movement begins to flag, and then ceases. Meanwhile, the bodies close together, and the eye spots, or vacuoles, melt together (as portrayed in Fig. 14). The two nucleii become one, and disappear, and in eighteen hours the entire body of "either has melted into other," and a motionless, and for a time irregular, sac is left.

This now becomes smooth, spherical, and tight, being fixed and motionless. This is a typical process; but the mingled weariness and pleasure realised in following such a form without a break, through all the varied changes into this condition, is not easily expressed. The utmost power of lenses, the most delicate adjustment of light, and the keenest powers of eyesight and attention must do the rest. Before the end of six hours the delicate glossy sac opens gently at one place (as seen in Fig. 15), and there streams out a glairy fluid, densely packed with semi-opaque granules, just fairly visible when their area was increased six millions of times; and this continued until the whole sac was empty, and its entire contents diffused.

To follow with our utmost powers these exquisite specks was an unspeakable pleasure. A group seen to roll from the sac when nearly empty, were fixed and never left. They soon palpably changed by apparent swelling or growth (as in Fig. 16), but were perfectly inactive; but at the end of three hours a beaked appearance was presented (shown in different stages at Figs. 17 and 18). Rapid growth set in, and at the end of another hour—how has utterly baffled us—they acquired flagella (as seen in Fig. 19), and swam freely; in thirty-five minutes more they possessed a nucleus, and rapidly developed, until at the end of nine hours after emission a sporule was followed to the parent condition, and left in the act of fission. In this way, with what difficulties I need not weary you, a complete life cycle was made out.

And now I will invite your attention to the developmental history of the most minute of the six forms we studied. In form it is a long oval (as shown in Fig. 20), it is without visible structure or differentiation within, and is possessed of only a single flagellum. Its utmost length is the 4,000th part of an inch. Its motion is continuous, in a straight line, and not intensely rapid nor greatly varied, being wholly wanting in curves and dartings.

The copiousness of its increase was, even to our accustomed eyes, remarkable in the extreme; but the reason was discovered with comparative ease. Its fission was not a division into two, but into many. The first indication of its approach in following this delicate form was the assumption rapidly of a rounder shape (Fig. 21).

Then followed an amœboid and uncertain form with an increased intensity of action (seen in Fig. 23), which lasted for a few moments, when lassitude supervened; then perfect stillness of the body, which is now globular in form, while the flagellum feebly lashed, and then fell upon and fused with the substance of the sarcode; and the result is a solid, flattened, homogeneous ball of living jelly (as seen in Fig. 24).

To properly study this in its further changes a power of from three to four thousand diameters must be used; and with this I know of few things in the whole range of minute life more beautiful than the effect of what is seen.

In the perfectly motionless flattened sphere, without the shimmer of a premonition, and with inconceivable suddenness, a white cross smites itself, as it were, through the sarcode (as in Fig. 25); then another, with equal suddenness, at right angles (shown in Fig. 26); and while with admiration and amazement one, for the first time, is realising the shining radii, an invisible energy seizes the tiny speck, and, fixing its centre, twists its entire circumference, and endows it with a turbined aspect, which Fig. 27 shows. From that moment intense interior activity became manifest; the sarcode was, as it were, kneading its own substance; and an inner whirling motion was visible, reminding one of the rush of water round the interior of a hollow sphere on its way to a jet or fountain. Deep fissures or indentures showed themselves all over the sphere, and then, at the end of ten or more minutes, all interior action ceased, and the sphere had segmented into a coiled mass (as seen in Fig. 28).

There was no trace of an investing membrane; the constituent parts were related to each other, simply as the two separating parts of an ordinary fission; and they now commenced a quick writhing motion like a knot of eels, and then in the course of from seven to thirty minutes separated (as indicated in Fig. 29), and, fully endowed with flagella, swam freely away, minute but perfect forms, which, by the rapid absorption of pabulum, attained speedily to the parent size.

It is characteristic of this group of organic forms that multiplication by self-division is the common and continuous method of increase.

The other and essential method was comparatively rare, and always obscure. In this instance, on the first occasion, the continuous observation of the same *field* for five days failed to disclose to us any other method of increase but this multiple fission; and it was only the intense suggestiveness of past experience that kept us still alert, and prevented us from inferring that it was the only method.

But eventually we perceived that while this was the prevailing phenomenon there were scattered amongst the ordinary forms of the same monad *larger* organisms than the rest, and with a singular granular aspect towards the flagellate end (as shown in Fig. 22). Its granulated fore-part may be easily contrasted with the normal or ordinary form. Now, by doggedly following one of these through all its wanderings, a wholly new phase in the morphology of the creature was revealed. This roughened or granular form seized upon and fastened itself to a form in the ordinary condition. The two swam freely together, both flagella being in action (as shown in Fig. 30); but it was shortly palpable that the larger one was absorbing the lesser. The flagellum of the smaller one at length moved slower, then sluggishly, then fell upon the sarcode, which rapidly diminished, while the bigger form expanded and became vividly active until the two bodies had actually fused into one.

After this its activity diminished, and in a few minutes the body became quite still, leaving only a feeble motion in the flagellum, which soon fell upon the body substance and was lost. All that was left now was a still, spheroidal, glossy speck, tinted with a brownish yellow (which is seen at Fig. 31).

A peculiarity of this monad is the extreme uncertainty of the length of time which may elapse before even the most delicate change in this sac is visible. Its absolute stillness may continue for ten, or it may be prolonged for thirty-six, hours. During this time it is absolutely inert; but at last the sac—for such it is—opens gently, and there is poured out a brownish glairy fluid. At first the stream is small; but at length its flow enlarges the rift in the cyst, and the cloudy volume of its contents rolls out, and the hyaline film that enclosed it is all that is left. (The cyst in the act of bursting is seen at Fig. 32.) The nature of the outflow was like that produced by the pouring of strong spirit into water; but no power that we could employ was capable of detecting a granule in it. To our most delicate manipulation of light our finest optical appliances, and our most riveted attention, it was a homogeneous fluid, and nothing more. This, for a while, baffled and disturbed us. It lured us off the scent. We inferred that it might possibly be a fertilising fluid, and that we must look in other directions for the issue. But this was fruitless, and we were driven again to the old point, and, having once more obtained the emitted fluid, determined to fix a lens, worked up to 5,000 diameters, upon a clear space over which the fluid had rolled and near to the exhausted sac, and ply our old trade of watching—unbroken observation.

The result was a reward indeed. At first the space was clear and white, but in the course of a hundred minutes there came suddenly into view the minutest conceivable specks. I can only compare the coming of these to the growth of the stars in a starless space upon the eye of an intense watcher in a summer twilight. You knew but a few minutes since, a star was not visible there, and now there is no mistaking its pale beauty.

It was so with these inexpressibly minute sporules. They were not there a short time since, but they grew large enough for our optical aids to reveal them, and there they were; and here I remark that these delicate specks were unlike any which we saw emerge directly from the sac as granules. In that condition they were always semi-opaque; but here they were transparent, and a brown yellow, the condition always sequent upon a certain measure of growth.

To follow these without the loss of an instant's vision was pleasure of the highest kind. In an hour and ten minutes from their first discovery they had grown to visible specks (seen relatively in Fig. 33; in two hours more the specks had become beaked and long (Fig. 34), and the pointed end was universally the end from which the flagellum emerged (as seen in Fig. 35), which was drawn ninety minutes after the last, and ultimately the perfect form is taken (shown in Fig. 36).

With the flagellum comes motion, and with that abundant pabulum, and therefore rapid growth. But when motion is attained we are compelled to abandon the mass and follow one in all its impetuous travels in its little world; and by doing so we were enabled to follow the developed speck into the parent condition and size, and not to leave it until it had, like its predecessors, entered on and completed its wonderful self-division by fission.

In that way its life history was known, and as it were re-entered.

It will be seen then that the equivalent of a genetic process of reproduction, universal, in some form, throughout the entire range of biology, is absolutely essential in the monads, and is thus carried to the very border and fringe of the outermost organised entity.

Nor is this all. There is no caprice even in *this* realm. There would be leaps, and halts, and uncertainties here, surely, if anywhere in the entire biological series. But it is not so. The cycle of a monad's life is as unvarying as that of a Batrachian. There is no unusual, no intense method—nothing more, indeed, than those issues resulting from the secular processes involved in the great Darwinian law.

I have already told you that we worked out six of these remarkable forms. They are all fairly represented in the histories I have given you. Five of them poured out from their genetic cysts spores, or ova, and one discharged living young. These spores or ova, and young, were, in every instance, followed from the moment of their emission from the sac through all their changes to the parent condition, or mature state, and each instance was several times repeated.

It will be manifest then that such a fertilised product—one of such exquisite minuteness—being found, it would be a matter of deep interest to ascertain if these spores possessed any power to resist the action of heat greater than that possessed by the adult. We determined to conduct experiments so as to discover directly what was the temperature beyond which the spore would not go through their developmental processes.

It was settled to our complete satisfaction that the death point of the adult organisms hovered extremely near 140° F. We could therefore start with this.

To determine the point of heat, after the endurance of which the germs could not develope, we made a series of delicate and careful observations, extending over a very long time. I can only give you the final results, and they will help us to something like a conclusion. They were these. In one case, the cyst of the monad producing living young, the highest temperature that could at all be borne, and that only feebly, was 180° F. In other cases the spore were seen repeatedly to become vital and perfectly develope after exposure for ten minutes to 300° F. These were the two extremes. In the remaining instances the highest temperature which the spore would bear, and afterwards develope, was 250° F., and 260 F. Thus if we include the young emitted from the cyst in a living state the genetic products of these six minute and lowly organisms possess a heat-resisting power greater than their parents in the proportion of 11 to 6. In other words the spore can resist heat nearly twice as intense as the adult.

You will see that this has a powerful and important bearing upon the question of "spontaneous generation," especially as considered within the last few years. If these creatures, which are closely allied to the Bacteria, have to be produced by spores, why must it not be so with the Bacteria? And if the spores of these can resist heat without destruction in the ratio of 11 to 6, why may not the spores of the Bacteria endure a heat equal to the boiling point of water, or some point slightly below it, while the adults are killed at 140?

To show the bearing of this I will take an illustration of a practical kind. Dr. Bastian has been an eager opponent of some of the leading biologists of our day in relation to this great question. He has throughout affirmed that living things may arise *de novo* from things which are not living. I shall not discuss his hypothesis, but will give you one of his latest, most important, and very typical proofs or experiments. He tells us that he put a strong infusion of common cress into a vessel hermetically sealed, and heated it to about 270-5 degrees. It was kept for nine weeks and then opened, and, in his own language, "there appeared more than a dozen active monads." Now, happily, he both measured and drew the portraits of these creatures. He says they were $\frac{1}{4000}$ of an inch long, provided with a rapidly-moving lash, with which they freely swam. Besides these, there were other motionless, tailless spherules, which he supposed to be developmental stages of the organism.

Now the illustration before you is an exact fac-simile of Dr. Bastian's drawing. It is magnified, according to his statement, 800 diameters. Both the monads and the motionless, tailless spherules are seen. But it turns out to be one of our now well-known monads, the last of which I described to you to-night, and here is my drawing of it, which is magnified about 2,500 diameters. We describe it thus: "Its exterior form is simple, being ovoid, with a single flagellum, and the long diameter never exceeds the 4,000th part of an inch;" while to make certainty more certain, the motionless spherules of which Dr. Bastian speaks are, as you will remember, stages in the development of its life.

Now Dr. Bastian says he took these monads, placed them in a suitable vessel, and raised the temperature to 140° F., and he says every monad finally and for ever perished. This is precisely our experience. But he says these same monads arose in a fluid which had been raised to a temperature of 270-5 degrees. Therefore, he says, they must have arisen from the dead matter in the fluid.

But what are the facts? This is one of the monads whose spore will develope after being heated to a temperature of 390° F.—that is to say, 25 degrees higher than the heat endured by Dr. Bastian's infusion. Therefore I contend that this monad arose from its natural spore, which the heat Dr. Bastian used was not competent to kill.

Let us finally, and at once, declare that none of us, certainly as biologists, as far as I know, have any fear of the doctrine of spontaneous generation—indeed, for that matter, I sincerely hope we are not afraid of any truth, come from whence, or lead to where it may; but it is a very important matter that a great principle like this should rest upon a basis which cannot be shaken; and it is a necessity in these days that, on so profoundly radical a subject, experts and specialists should give a patient life to the making out of one great truth, instead of submitting to the fascination of making a series of coloured inferences from feeble facts.