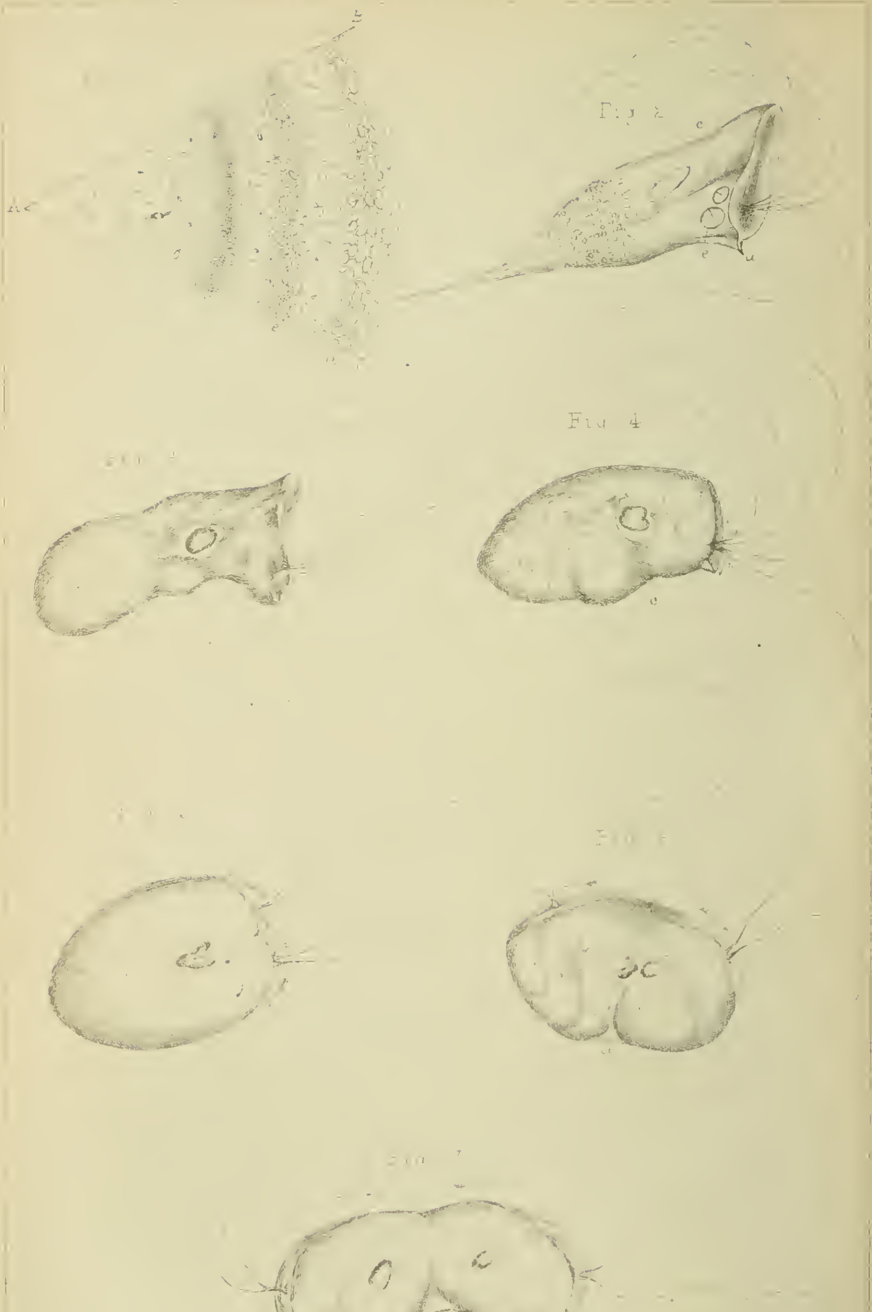

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Life history of a monad.

THE

MONTHLY MICROSCOPICAL JOURNAL.

MAY 1, 1875.

I.—*Further Researches into the Life History of the Monads.* By W. H. Dallinger, F.R.M.S., and J. Drysdale, M.D., F.R.M.S.

(*Read before the* Royal Microscopical Society, *April* 7, 1875.)

Plates CII., CIII., and CIV.

This paper will complete the present series of researches—commenced some four years since, and terminated at the close of last year—on the developmental history of monads. At the close of

DESCRIPTION OF PLATES CII., CIII., AND CIV.

Fig. 1.—Zonal arrangement of monads as seen in moist developing cell—a portion only of the field.
,, 2.—A typical calycine.
,, 3.—The semi-amœboid condition preceding fission.
,, 4.—The first stage of fission, where the base of the flagella has split into two, and the sarcode is opening in the direction of the arrows, carrying a *pair* of flagella, *a*, *b*, in each direction; and the nuclear body is also dividing.
,, 5.—Fission continued. The sarcode is still moving in the direction of the arrows. The "nucleus" is more parted.
,, 6.—Fission continued. The body of sarcode is now "bean shaped"; the motion is still in the direction of the arrows. The "nucleus" is wholly divided; and the first symptom of division of sarcode is seen at *a*.
,, 7.—Fission continued. The flagella are opposite each other; distinct constriction is visible at *a*, and each part is pulling in the direction of the arrows.
,, 8.—Fission continued. The aspect immediately before partition.
,, 9.—The halves produced by fission have only a pair of flagella instead of four. This figure shows how the pair are divided into two, each by attachment at the ends *b*, *c*, and rapid vibration along the whole length, causing splitting at the ends *b*, *c*.
,, 10.—The flagella split by vibration.
,, 11, 12.—The amœboid state which precedes sexual union.
,, 13.—The same in an extreme state, as often seen.
,, 14.—The blending of two in this condition.
,, 15.—The sac resulting from the perfect fusing of all the parts of each with the other.
,, 16.—This sac in its completely developed state, gently opening and pouring out sporules.
,, 17, 18, 19, 20.—The spores developing in different stages until they reach the parent form.

All the figures are magnified 2600 diam., except 9, 10, 15, which are magnified 5000 diam. and reduced. Figs. 17, 18, 19, 20, are each × 5000.

the work some general remarks may be admissible, and to make these we shall have to refer to the monads severally described; but as these are unnamed, and reference is therefore difficult, we will venture to distinguish them by the names by which for working purposes we designated them in our diaries. The first was the *cercomonad*, described in the tenth volume of the 'M. M. J.,' at p. 53. The next we called the "springing" monad, from its peculiar habit of coiling and uncoiling one of its flagella with a darting motion, not unlike the vorticella, carrying the body with it. This is described at p. 245, ibid. The third we designate the "hooked monad," from the presence of a persistent hook-like flagellum, described and figured in vol. xi., p. 7. The fourth we call the "*uniflagellate*" monad, being possessed of only one flagellum, and that at the anterior part of the body. It is described at p. 69, ibid. The next is the "biflagellate or acorn monad," being possessed of two anterior flagella, and at almost all stages of its development has the posterior end of its oval sarcode shaped like the cup of an acorn. This is described in vol. xii., p. 261. And the one we are now about to describe we name the "calycine" monad, from what will be seen is its peculiar calyx-like form. It has been before stated that the acorn-like form was the one which first arrested our attention; but we were unable to study its complete development either in this or the following summer. It was almost the only species that existed in the maceration for nearly three months; scarcely anything indeed existed with it save *Bacterium termo*. But at the end of the time named it was rapidly superseded by the form which we are now about to describe; and most of the other monads we have described appeared simultaneously with it.

At the end of the first year we had accumulated a large number of individual observations, the correctness of which was confirmed by subsequent work, but the connection, correlation, and interpretation of which at the time entirely baffled us. To the practised worker with high powers it is well known that it is very much more difficult to *discover* an obscure or delicate phenomenon than to see it again after once the actual discovery has been made. A minute striation or an exquisitely attenuated flagellum may cost immense labour and perseverance to *find*, but once found it is easy to see it again and again afterwards. And curious as it appears to us now, many of the processes with which we are now familiar and can easily discover, *then* eluded us; so that even into the second year of working it would not have been at all out of harmony with the *facts*, as we then saw them, to have inferred that the biflagellate monad, the springing monad, the hooked monad, and the calycine, described below, were all connected in one cycle of generation, or at least in some way related to each

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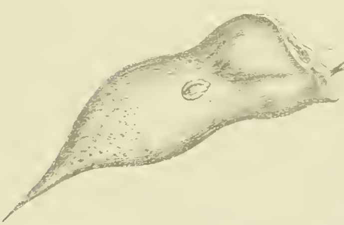

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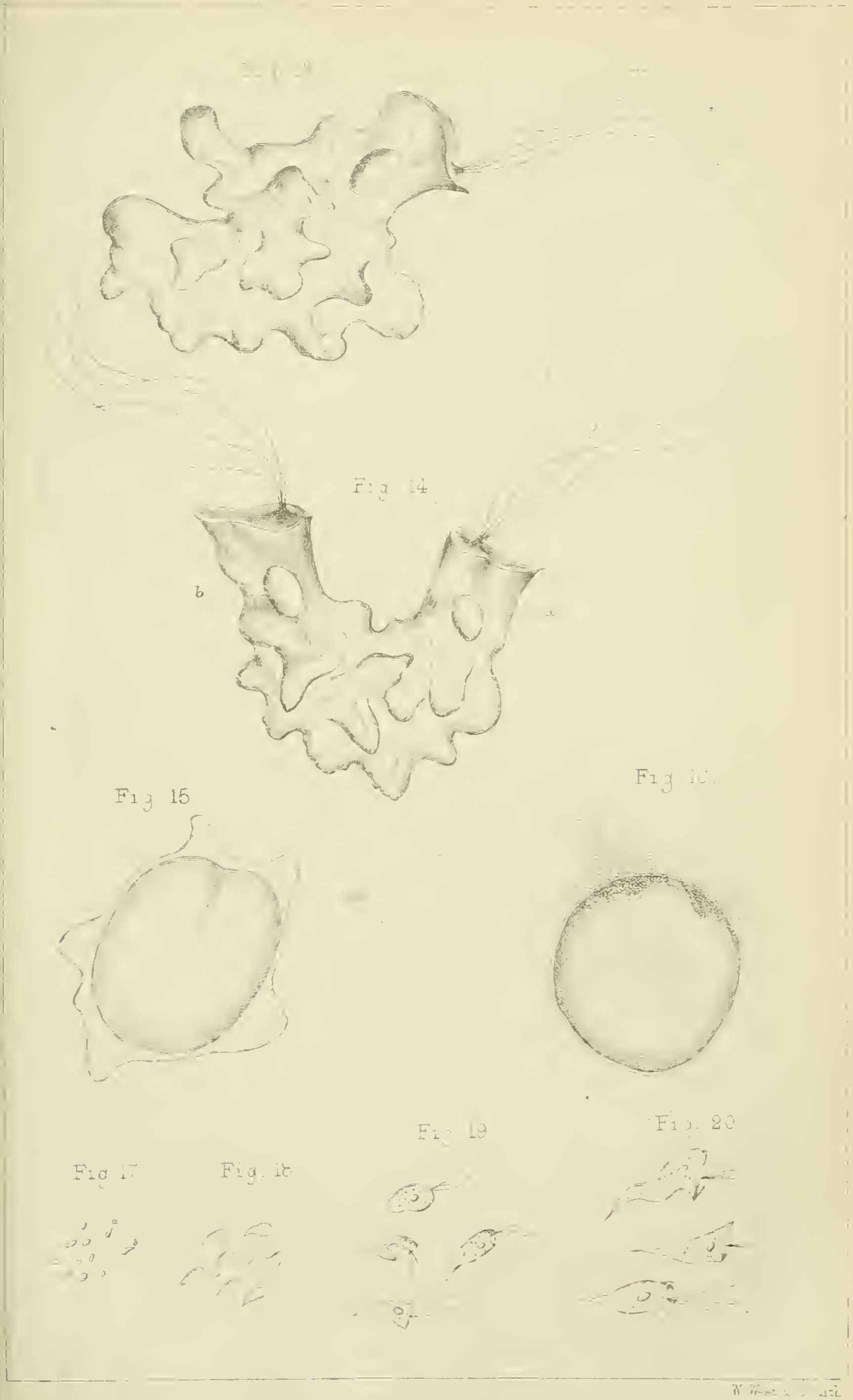

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Life history of a monad.

other. Indeed, from the fact of their being all in the same fluid, and developing in the same field at one time, it appeared perfectly natural—if it had been permissible—to *assume* from the then known facts that the springing form was a younger condition of the biflagellate, and the calycine a higher development of the latter. So strongly did we at one time believe the facts to point in this direction, that when we had followed a calycine form to the state of encystment, to be presently described, we did not hesitate to express the conviction in our diary that in a few hours the field would be full of the young of the springing monad!—a prophecy which the event completely falsified, administering by that means a salutary caution, and opening up one of the many pathways made known to us by our failures, and leading to the truth. Indeed, it became perfectly clear after continued work that we could never conclude that the contents of our continuously moist field, at any given time, were necessarily sprung from the most conspicuous forms predominant some little time before; and therefore until the complete life cycle of any given group of forms is known, nothing can be certainly affirmed concerning them.

It may be interesting to allude to the peculiar phenomena presented by the monads when they had been for some hours in our moist cell. We take an example when our maceration was most prolific in the variety of forms present; some hours after the "dip" had been put into the chamber and under examination, the monads ranged themselves in *zones;* and these zones were persistent, however many days this drop might be preserved in unevaporated condition. The illustration is taken from our diaries in 1873; it is seen in Fig. 1, which is a portion of the field after it had remained under examination in the moist chamber four days. B C represents the margin of the cover-glass—the field being seen with a comparatively low power—*d d* is an outermost zone, in this instance, of the "springing monad"; these were in intense activity, constantly changing places with a rapid spring, but always preserving the zone in its integrity. At a distance from this zone about equal to its own width came another, composed largely of the "biflagellate" form, and an immense number of the young of this, and probably of other forms also, intensely active, shown at *e e*; and finally within this, a zone of what with comparatively low powers would be taken merely for bacteria, but which under the scrutiny of the highest powers proves itself to be composed by no means in the larger proportion of these, but to consist of still and active germ-like bodies, the development of which with care and persistence may be followed. This is drawn at *f f*. Swimming about freely between and within the zones were stragglers from all of them, with many other forms in no way connected with them. This was, with variations merely as to which monad or group occupied the several positions, almost the universal condition of the field. Sometimes the zones were not complete, and sometimes there were two, or even one, instead of three: but this largely depended upon the abundance, variety, and condition of the forms which might be taken up in any given "dip."

Now it would be an extremely difficult matter to prove that any arrangement approximate to this existed in a large macerating mass; but we have nevertheless repeatedly observed that required forms were found in incomparably greater abundance in one part of the fluid than another. Be this, however, as it may, this zonal arrangement was a remarkable feature. What aggregated them together in this way it would be impossible to say satisfactorily; probably the desire for oxygen may have drawn them towards the edge of the cover-glass; but this will not account for their *sifting out* as it were into separate groups; and it leaves unexplained how it was that creatures of higher organization, as ordinary paramœcia and forms of kerona, could live to the very end, in the greatest activity and apparent health, in the centre of the field, that is at A, Fig. 1, and its immediate neighbourhood. This at least we learned from it, that the earlier stages of many different forms were present, the adults of which *may not at all be represented in the field at the time.* There are also, doubtless, myriads of other forms not recognizable, and we have given reason to believe * others still which to our best appliances are invisible. It is further in harmony with biological facts, and the evidence afforded by our inquiries, that many of these must await some change of circumstances before they could develop and come to maturity. The flagellate monads, for example, as a whole did not appear for some weeks after the various forms of bacteria; and the calycine form did not in any case appear for some months after the "springing," "hooked," and "biflagellate" monads. We do not attempt to explain this; but we do not hesitate to believe that the reason is discoverable; and it will in all probability be found to depend on very simple causes, such as the season and temperature, which is without question a real cause, the preparation of the pabulum by the bacteria and successive monads, and the chance addition of germs to the macerating mass, either through the air or otherwise. The two first reasons apply on the supposition that the fluid does contain the germs in a dormant condition until the circumstances become favourable. The third is a fact; for as we have already pointed out, the "biflagellate" monad was wholly absent one year, although its follower the "calycine" came in spite of its absence. In the same way we have observed the absence of the *Spirillum volutans* and other forms. It is true that this never

* 'M. M. J.,' vol. ix., 1874, p. 71.

applies to *Bacterium termo* and *Penicillium glaucum;* but in the present state of our knowledge we may be allowed to infer that the sporules of these are simply ubiquitous.

These simple reasons may quite sufficiently account for the successive appearance of different forms of infusoria in organic infusions, without having recourse to the startling hypothesis of heterogenesis. The reported observations of Dr. Bastian, Dr. Gros, and some few others, alleging the origination of one known form from parents of an entirely different nature, such as the development of nematoids from spores of vaucheria,* of diatoms, pediastrieæ and other algæ from euglenæ,† and so forth, are instances which we presume could only be accepted scientifically by tracing the whole process step by step, repeatedly, until every stage in the process of mutation was actually discovered and described. The possibility of misinterpretation is great. Indeed, we distrust all observations founded on successive "dips" in a quickly changing organic infusion, and in fact put no faith in observations of this sort not conducted on the plan of keeping the same drop under continuous observation during all alleged transformations. As far as our observations upon these lowly forms go, we are bound to say that not the slightest countenance is given to this doctrine of heterogenesis. On the contrary, the life cycle of a monad is as rigidly circumscribed within defined limits as that of a mollusc or a bird. There is no indication of any unusual or more intense methods of specific mutation than those resulting from the secular processes involved in the Darwinian law, which is held to furnish the only legitimate theory of the origin of species.

In the facts pointed out in the previous pages we also see an explanation of the *sameness* which Billroth attributes to the organisms of the septic processes: he remarks frequently on the recurrence of so small a number or variety of generic forms in all putrefactive processes. He says, for example: "The notion is widely prevalent that the minute organisms generally met with in the putrefaction of the juices of the human body form an impassable labyrinth, and belong partly to the animal and partly to the vegetable kingdom; and also that in infusions of various organic tissues a countless multitude of so-called infusoria are found, with endless variety of form and species. But if anyone sets about looking into the wonders of the creation he is very soon undeceived; instead of the expected variety, he finds a monotony of forms which soon extinguishes all interest of a merely superficial nature, for he may search various putrefying fluids for *weeks* without finding anything but what he was already familiar with in the first days of his microscopical studies, as vibriones, bacteria, and

* 'Beginnings of Life,' p. 531. † Ibid., p. 447.

micrococci."* This is undoubtedly true of the *earlier stages* of the septic processes, but certainly not of the later. The first stages of a maceration are all that Billroth describes, without question; but if the animal matter exist in sufficient quantity, and the process be allowed to continue—not for the "weeks" of which this observer speaks, but for *months*—then an immense variety of flagellate forms arise, often wholly extinguishing almost every trace of the bacteria and their congeners, and still the putrefactive process is carried on with great vigour. Hence we are wholly disinclined to believe that the bacteria are the only, or even (in the end) the chief organic agents of putrefaction; for most certainly in the later stages of the disintegration of dead organic matter the most active agents are a large variety of flagellate monads.

We do not profess to decide what is the true nature of the monads we have studied; that is, to decide whether they be vegetable or animal. We nevertheless strongly believe in their animal nature. But if this be so, they afford another illustration of the inefficiency of the distinction between the animal and vegetable kingdom, which assumes that animals can only assimilate organic compounds; while vegetables can elaborate their protoplasm from those which are inorganic. We made a series of experiments on the transplantation of known forms to Cohn's "nutritive fluid,"† which contains no albuminous matter, but only mineral salts and tartarate of ammonia. The result was that we found that not only the bacteria, but the flagellate monads lived, throve, and multiplied in it, although supplied with no other pabulum. If it be affirmed that this is a proof of their vegetable nature, we can only say that the same must be said of the *kerona* of Ehrenberg and Dujardin, which flourished side by side with the monads, with this nutritive fluid as the sole source of pabulum. And both alike lived and multiplied in the dark.

In reference to the mode of locomotion among the monads, it may be remembered that what appeared like an *organ* of locomotion—an arrangement by which the action of the flagella appeared to be originated and controlled—was seen in the "biflagellate" form.‡ In every instance where there was only one flagellum, or where the two arise and move from the same point, their insertion in the body-sarcode was always in front; so that the flagellum or flagella had a pulling motion like that of the paddle of an ancient coracle; never the pushing motion from the stern like the sculling or rowing of a modern boat. This evidently

* 'Untersuchungen über die vegetation-formen von Coccobacteria Septica,' &c. Von Theodore Billroth. Page 3. Berlin. 1874.

† This fluid is composed of the following ingredients, viz. phosphate of potash, sulphate of magnesia, triple basic phosphate of lime, tartarate of ammonia, and distilled water.

‡ 'M. M. J.,' vol. xii., p. 264.

arises from the complete flexibility of the flagella, by which a propelling motion plainly could not be applied.

We now proceed to the description of the form immediately before us. For working purposes we have called it the "calycine." Its general appearance is accurately shown in Fig. 2. Its length varies from the $\frac{1}{900}$th to the $\frac{1}{1000}$th of an inch, its breadth in the broad part being a little more than a third of this; but it is compressed from side to side, and its width edgewise is not more than an eighth of its length. The form as shown in the drawing is very regularly preserved. The front of the body-sarcode is obliquely flattened, and at its lower part this gives rise to four flagella. They take their origin in a stalk which is short and almost at the point of contact with the body-sarcode divides into four pyramidal parts, out of which the flagella come. Just under the place where the flagella originate, at the flattened end of the sarcode, a spout-like projection occurs, as at *a*, Fig. 2. A long furrow goes obliquely down from this spout towards the pointed tail at the opposite end; and another depression occurs in the middle of the form, also lengthwise, giving the hourglass shape to the flattened extremity *b*. The sarcode is at times loose in texture, and the monad takes as a consequence unusual shapes, one of them being remarkably like a Brazil nut, and others still more distorted. The flagella are extremely fine, and are so rapid in their movement that their number was only certainly made out after nearly a week of watching; but as the forms became more inert we were enabled to discover their number accurately. A large nuclear body was always present in about the same position—*c*, Fig. 2—and two large "eye spots," with the strange rhythmical opening and shutting to which we have referred in other monads.* The position and relative size of these are shown at *e*; the diametrical line in each disk is the line of juncture, and from this both halves opened and then closed again with a snap. Its mode of locomotion was a graceful gliding through the water, the flagella moving so often and so rapidly as to render their detection impossible when the monad is at its swiftest. They could roll over on their long axis, and change the direction of their motion with lightning-like rapidity, and however crowded the field, not the slightest approximation to collision occurred.

A number of vacuoles are sometimes scattered over the sarcode, and at times the body becomes distinctly granular, the sarcode being slightly distended; and we have seen this granular matter quickly discharged, the body being left transparent and retracted. From the analogy of the "biflagellate" we were led to presume that this was one of the developmental phases, but the presumption was not confirmed by observation, and we simply record the fact.

The first process in the life history of this monad is, as usual,

* 'M. M. J.,' vol. x., p. 248; also vols. xi. and xii.

fission, and the more carefully this process is studied, the more remarkable it appears; for we have here not a uniform homogeneous rod of sarcode like the bacterium which we can easily imagine by mere growth to elongate and divide by transverse fission, as it is said to do, but we have a creature of distinctly marked shape, a certain amount of structure and differentiation of parts, of which each part appears to generate a counterpart of itself. How long *this* process may be going on we cannot exactly say, but the time taken in *visible* separation is from five to sixty minutes; but several times one-half of a fission has been followed, and whatever internal processes may have been at work must have been completed in from twenty to thirty minutes, for after that time fission has again ensued. But in every case the division results in two individuals equal to each other in shape and apparent size; a little less in bulk than the original monad, but in every sense as perfect.

The process is as follows. An actively swimming form becomes soft and plastic; the posterior end loses its sharpness, and becomes blunt and rounded. At the same time a semi-amœboid state ensues all over the sarcode, causing singular projections in every part of the body. In this state the nucleus-like body becomes very developed, and often is surrounded by what appears like something flowing from its substance. The "calycine" in this condition is drawn at Fig. 3. This may be repeated several times, after which a comparatively pear-shaped form is taken, the flagella being at the broad end: during the whole of this time the sarcode is in vivid internal motion—a kind of self-acting kneading process. At this time the root of the flagella is seen distinctly to split, dividing them into two separate pairs; and at the same moment a motion is set up which pulls the divided pairs of flagella asunder, making the interval of sarcode to grow constantly greater between them. This is seen in Fig. 4, where *a*, *b* show the complete division of the thick quadruple base of the flagella, and the arrows show the direction in which each pair is pulled. At the same time the nucleus shows marked symptoms of constriction, as is shown at *c*. From this time there is a tendency to take a rounder form, while the separate pairs of flagella rapidly diverge, as shown in Fig. 5; the flagella still moving in the direction of the arrows, and the nucleus-like body still more completely divided. The opening between the two pairs of flagella now rapidly increases, and the mass of sarcode becomes bean-shaped, as in Fig. 6, the nuclear disk having completely divided into two; at the same time an internal indication of constriction is given at *a*; and very shortly the two pairs of flagella have reached a position exactly opposite each other; the constriction has become very decided, as seen in *a*, Fig. 7, and the parts now evidently separating pull *against* each other, as seen by the arrows in the same figure. From this time the constriction rapidly deepens, the two halves become more normal in shape, until the moment when they are about to divide; they are drawn at Fig. 8, the nucleus-like bodies taking their normal place in each, and often the "eye-spot" making its appearance. Still pulling in the direction of the arrows, complete fission is effected, and each half is provided with a sharp "tail." Much of this, it is needless to say, was only made out after weeks, and in some instances months, of continuous labour, and only then with the highest powers. The general method of fission, indeed, was made out with the $\frac{1}{16}$th, with eye-piece giving 1200 diameters; but the complete *detail* was only successfully compassed by the $\frac{1}{25}$th and $\frac{1}{50}$th of Powell and Lealand, with diameters ranging from 2500 to 5000.

But even now the whole difficulty of fission in this monad was not overcome, for, as we have seen, it is normally provided with *four* flagella; but at fission these divide into two *pairs*, so that each half of the original monad, although complete in all other respects, has only *two* instead of *four* flagella. Yet in a very few minutes the free halves were seen to have acquired the full complement. At first, and for a long time, an inquiry into their mode of acquisition seemed hopeless; but we were at length rewarded by seeing the manner in which it happened. The newly fission-formed "calycine," after darting about rapidly but irregularly for some few seconds, attaches itself to the floor, or to some comparatively fixed object, by the free ends of the flagella, and remaining almost motionless itself, a rapid vibratory action is set up for nearly the whole length of the flagella, as seen in *d*, *e*, Fig. 9. Very speedily the ends *split*, as seen at *b* and *c*. This splitting is carried further and further towards the base, as seen in *b*, Fig. 10, where *c*, *d* have opened out nearly to the end until at length it opens completely, as seen in the same figure at *a*, *e*. The whole of this process was complete in 130 seconds after the pair of flagella became fixed and vibratory, and was seen perfectly with the supplementary stage and small condenser made by Powell and Lealand for developing the markings on *Amphipleura pellucida*. But it was also seen with the usual condenser and the $\frac{1}{50}$th.

The semi-amœboid condition preceding fission appears common to all these monad forms before any remarkable vital change. In the instance before us it was impossible to predicate whether this condition in any "calycine" in the field would issue in fission, or another vital process in its life history, to which we must now refer. Certainly the more frequent phenomenon was mere self-division; but long-continued observation showed in this case, as in others, that, although most frequent, it was far from being most important.

The fact that the semi-amœboid condition is common to both great transformations in this monad, and the one we are about to describe is very much the least frequent, enhances the difficulty of finding instances of the phenomenon. But if the amœboid forms be patiently watched here and there over two or three days of watching, some of those which we have described as in a self-kneading process internally will be seen to retain the form of the flagellate end more perfectly than others, while the opposite end of the sarcode will become much more truly amœboid. Now if this be carefully watched, the "ventral disk" (as we have called it for working purposes), or nuclear body, will be seen to grow unusually large and prominent. The "eye spots" will be seen to be in rapid rhythmical action, and soon—in the course of two or three hours—the posterior end of the sarcode will be strongly amœba-like, pseudopodia being protruded with a more constant and rapid motion than is usually seen in the amœba. A "calycine" in this condition is drawn at Fig. 11, and another very near the same field at the same time is seen at Fig. 12. It will be seen that the flagellate end of both is only slightly changed, and the large size of the nucleus-like body will be observed. Now in this condition they swim more and more slowly for some hours, until in some cases they cease to swim entirely, moving exactly as the amœba does, by the extrusion of pseudopodia. Indeed it could not be distinguished from an amœba but for the persistence of the shape of the flagellate end of the body and the slow waving of the flagella. Its aspect in this condition is drawn at Fig. 13. And one remarkable peculiarity of this condition is the great voracity of the creature. The "field" in its neighbourhood is rapidly cleared of dead and living bacteria, simply devoured by it. It is probable that this capacity for absorbing nutriment, which must give large advantage in the struggle for existence, explains the amœboid condition so common at what will be seen to be such an important period in the development of the monads.

In some instances it does not become so utterly amœba-like as this, but swims very slowly; but in either case, whether by swimming or creeping, if it meet another in a similar state the *amœboid parts touch*, and instantly blend into each other. This is shown in Fig. 14. In this condition the blended creatures may swim again with great freedom and ease, both sets of flagella acting apparently in concert. But now blending of the entire mass goes on, and in the course of thirteen hours the two "eye-spots" blend and cease to act; the two sets of flagella unite and fuse into mere sarcode, and the two nucleus-like masses, *a*, *b*, flow into one, until in about eighteen hours all trace of form is gone, and a somewhat irregular, distended sac is all that remains. This is drawn at Fig. 15; and in the course of another six hours this sac becomes round, and will be seen, if carefully watched, to pour out in all directions, without any violent splitting or breaking up, innumerable masses of little bodies, just visible to a magnifying power of 1800 diameters, and well defined as exquisitely minute oval bodies, highly refractive, with a power of 2500 diameters ($\frac{1}{50}$). This is drawn at Fig. 16.

The future of these minute bodies was carefully followed with the $\frac{1}{50}$th, and large numbers developed under examination, the development being distinctly traced in all its stages. First the minute and just perceptible specks appeared to swell—to grow larger in all directions, but they were perfectly inactive. This continued for from two to three hours, when some of them began to have a beaked appearance, as shown at *a*, *b*, Fig. 17. Growth was now very much more rapid, and at the end of two hours more they had assumed the shapes shown at Fig. 18. Between this time and the end of the next hour, in some way which we entirely failed to elucidate, flagella were acquired; in some cases two, but in the majority three, were made out, but never more at this stage. They now became rapidly motile, and of course the difficulties of noticing minute development increased; but their appearance thirty-five minutes after the acquisition of the flagella is drawn at Fig. 19, the nucleus-like body having definitely appeared. From this time they grew rapidly, and in many the four flagella could be seen; and at the end of the ninth hour after emission they had taken the parent form, and in all save size were the well-known "calycine," which had so long occupied our attention. Their aspect in this stage is drawn in Fig. 20.

The complete life history of this monad is therefore,—development from a germ or sporule of extreme minuteness, and on the attainment of maturity multiplication by fission, constantly and for an indefinite time; but the vital power is at intervals renewed by the blending of the genetic elements, effected by the union of two, when both are in an amœboid condition, from which a still sac results, in which germs or sporules are formed, which eventually escape, and again originate the life cycle.

We now proceeded to make the usual experiments on temperature, and its effect on the adult and the sporule. Our method has already been minutely described,* and in this case, as in all the others, was strictly followed. The result showed that the sporules of the "calycine" can resist a temperature of 250° Fahr. (121° C.), but no higher. We may quote one example in illustration. Six slides were taken, the contents of which were fully ascertained to be what was needed. They were heated in the usual way up to 250° Fahr., and allowed gently to cool. The contents were then examined with our best powers, first dry and then moist, but no trace of motion—even Brownian—was visible in any one instance. But in twenty-two hours from the time of heating three of the slides had a number of "calycine" forms in a very advanced stage, which had been watched from their origin in still gelatinous points,

* 'M. M. J.,' vol. x., p. 57.

as seen on former occasions, to the earliest stage of motion, and on to the acquisition of flagella. One other slide contained only a very few, which did not fully develop, and the other two, so far as this form was concerned, were barren.

This may be taken as a typical example. But we had ascertained on this and many former occasions that a temperature of 150° Fahr. (65°·5 C.), destroys utterly all the adult forms, as well as those which had reached any stage of development which might clearly be distinguished from the sporule.

In reviewing the whole series, then, it is plain that rapidity of increase and multiplication is the prominent feature in the vital phenomena of the monads. Everything subserves this end; but it also appears that the methods by which this prolificness is secured are dependent upon the recurrent blending of the genetic elements from which each species arises.

It may be well to compare the results of the whole.

In the cercomonad division by fission was the constant phenomenon. But this was the division simply of one into two. The result of the blending of the sexual elements was the production of spores in inconceivable quantities and immeasurably minute.* These survived exposure to a temperature of 260° Fahr. (178° C.).

In the "springing monad" the methods of increase were in a general sense the same.† In the "hooked monad" the increase by fission resembled broadly all the preceding; but it differed remarkably in the fact that the product of the genetic blending was not sporules, but minute *living* forms resembling the parents.‡

But the "uniflagellate" monad multiplied with enormous rapidity; not by mere bi-fissipartition, but by *multiple fission*, as many as from thirty to sixty being the product of *each* fission.§ And this form, after the union of the sexual elements, poured out innumerable myriads of sporules, so minute that at first they could not be seen by our highest powers, but it was merely perceived that a mass of something glairy was flowing out of the broken sac, and these were afterwards watched unceasingly, and seen in their early stages of development.

Now of these three forms, the two which poured out sporules were enabled *by* their sporules to survive a temperature of 148°·88 C. (300° Fahr.), but the form which developed *living* young only feebly survived a temperature of 82°·22 C. (180° Fahr.).

The "biflagellate" monad is characterized by multiple fission, and in addition a kind of parthenogenetic budding, aiding immensely in the rapidity of increase, and also the emission of minute sporules genetically produced; and these germs can survive a temperature of 121° C. (250° Fahr.), which is exactly the tem-

* 'M. M. J.,' vol. x., p. 53. † Ibid., p. 245.
‡ Ibid., vol. xi., p. 7. § Ibid., p. 69.

perature resisted, with no injury to the developmental power, by the sporules of the monad now described.

Thus it will be seen that in no instance was the continuance of the species maintained without the introduction of a sexual process, a blending of what are shown in the sequel to be genetic elements, and thus going farther to suggest caution as to the supposition that *any* organism can be perpetuated by the mere self-division of single individuals.

Our heating experiments have uniformly proved the fact that the spores resulting from sexual generation have a power of resistance to heat over the adult which is greater in the proportion of 11 to 6 on the average, and this appears to us to be the very essence of the question of Biogenesis *versus* Abiogenesis. In some, at least, of the septic organisms spores are demonstrably produced, and these spores can resist a temperature nearly double that of the adults on the average; and that which some can resist is 88° Fahr. above the boiling point of water. All this is in general harmony with the admirable experiments of Dr. W. Roberts,* as well as with the later ones of Huitzinga,† who could not destroy the bacteria or their germs by boiling under a heat of 230° Fahr. continued for half an hour.

* 'Phil. Trans.,' 1874.

† 'Academy,' March 13, 1875.