PROFESSOR TYNDALL'S EXPERIMENTS ON SPONTANEOUS GENERATION, AND DR. BASTIAN'S POSITION.[1]

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THE largest difficulty surrounding the question of the mode of origin of septic organisms is that of discovering their life-cycle. By dealing with them in aggregations we run told and untold risks. The conflict of results by this means, in the most accomplished hands, employing the most refined methods during the past eighteen years, is a sufficient witness. Repetitions of experiments, and conflicting results, and explanations of the reason why, and so the cycle rolls. Of course important lessons in biology are learned, but not *the* lesson. And yet by the teachings of this complex and doubtful method *alone* Dr. Bastian is content to accept "abiogenesis" as a great fact in nature.

To those who are best acquainted with the experimental history of the subject for the last twenty — but certainly for the six — years this is the more remarkable. For the weight of evidence is certainly not only *not* in favor of "abiogenesis," but is in the strongest sense adverse to it. The most refined, delicate, and continuous researches all point to the existence of what are at present ultra-microscopic germs. This, indeed, is directly affirmed by the authors. A single and recent instance will suffice. After a remarkable series of experiments detailed before the Royal Society, Dr. W. Roberts says: "The issue of the foregoing inquiry has been to confirm in the fullest manner the main propositions of the panspermic theory, and to establish the conclusion that *bacteria* and *torulæ*, when they do not proceed from visible parents like themselves, originate from invisible germs floating in the surrounding aërial and aqueous media."

But further, this has been remarkably sustained by analogical evidence. There are putrefactive organisms that closely approximate to the bacteria in form, structure, and size. These are the "*monads*," or, as Professor Huxley doubtless more fitly names them, the *Heteromita*. They live side by side with the bacteria in the same putrescent mass, and certainly in the later stages of the disintegration of dead organic matter are the most active and powerful agents. From their greater size they present a more promising field for microscopical research than the bacteria themselves; and the life-history of some of these could be fully mastered. I long since felt that valuable aid might thus

[1] Extracts from an article in Popular Science Review, London, April, 1876.

be rendered to the discovery of the nature of the bacteria. Armed with the best and most powerful appliances which the modern optician could supply, Dr. J. Drysdale and myself ventured on the work. The results are fully detailed elsewhere. It need only be remarked here that the only hope of success was in *continuous* observation of the same form, in the same drop of fluid under the highest powers. The secret, therefore, was to find a means of keeping the same drop under examination without evaporation. This we did. The result was that patient work enabled us to completely unravel the life-history of six of these organisms. These life-cycles cannot be here recounted. Suffice it now to say that each of them multiplied enormously by self-division (fission), but that the life-cycle in *each case* began and ended in *a distinct genetic product* — call them what we choose, spores, germs, or ova.

We have here, then, important indications of fact concerning the nearest allies of the bacteria: they develop from germs.

We have, besides, the weight of the best experimental evidence pointing clearly to the existence of germs in the bacteria themselves. But the microscope has failed to *demonstrate* the latter. Its finest powers and finest methods failed to reach them.

Happily at this juncture Professor Tyndall has stepped in, and with his accustomed brilliance and precision has opened up the path we need. *He has presented us with a physical demonstration of the existence of immeasurably minute molecules of matter — utterly beyond the reach of the most powerful combination of lenses yet constructed — which are the indispensable precursors of bacteria in sterilized infusions.*[1] In short, he has opened up a new and exact method, which must lead to a scientific determination of the existence and nature of the bacteria-germs. His beautiful experiments on the decomposition of vapors, and the formation of actinic clouds by light, led him to experiment on the floating matter of the air, and with what results is widely known. Confined and undisturbed air, however heavily charged with motes, becomes at length, by their deposition, absolutely clear, so that the path of the electric beam is invisible across it. From this, and associated indications, he acutely inferred "that the power of developing life by the air, and its power of scattering light would be found to go hand in hand;" so that a beam of light sent across the air into which infusions might be placed and examined by the eye, rendered sensitive by darkness, might

[1] Nature, January 27, 1876, page 252, and February 3, page 268.

be utilized with the best results in determining the existence of bacteria-germs. To bring the idea to a practical result a number of chambers were constructed with glass fronts. At two opposite sides facing each other a couple of panes of glass were placed to serve as windows, through which the electric beam might pass. A small door was placed behind, and an ingenious device was arranged to enable a germ-tight pipette to have free lateral, as well as vertical, motion. Connection with the outer air was preserved by means of two narrow tubes inserted air-tight into the top of the chamber. The tubes were bent several times up and down, "so as to intercept and retain the particles carried by such feeble currents as changes of temperature might cause to set in between the outer and the inner air."

Into the bottom of the boxes were fitted air-tight large test-tubes, intended to contain the liquid to be exposed to the action of the moteless air.

"On September 10th the first case of this kind was closed. The passage of a concentrated beam across it showed the air within it to be laden with floating matter. On the 13th it was again examined. Before the beam entered, and after it quitted the case, its track was vivid in the air, but within the case it vanished. Three days quite sufficed to cause all the floating matter to be deposited on the sides and bottom, where it was retained by a coating of glycerine, with which the interior surface of the case had been purposely varnished. The test-tubes were then filled through the pipette, boiled for five minutes in a bath of brine or oil, and abandoned to the action of the moteless air."

In this way the air in its normal condition was freely supplied to the infusions, but of mechanically suspended matter it could be demonstrated that there was none. And it was proved, with a clearness that admits of no quibble, that infusions of every kind, animal or vegetable, were absolutely free from putrefactive organisms. "In no single instance . . . . did the air which had been proved moteless by the searching beam show itself to possess the least power of producing bacterial life or the associated phenomena of putrefaction." But portions of the same infusions exposed to the common air of the Royal Institution Laboratory at a continuous temperature of from 60° to 70° Fahr. fell invariably into putrefaction; and when the tubes containing them amounted to 600 in number not one of them escaped infection — they were all "infallibly smitten." Here is irresistible evidence

that there is a direct relation between a mote-laden atmosphere and bacterial development. The whole series of Dr. Tyndall's exquisite experiments is simply an irrefragable affirmation of this truth. The presence of the physically demonstrated motes is as essential to the production, in a sterilized infusion of septic organisms, as light is to actinic action. They cannot be made to appear without the precursive motes; they cannot be prevented from appearing if the motes be there. That these are the germs of bacteria by themselves, or associated with minute specks of matter, approximates to certainty in the proportion of hundreds of millions to one.

A beautiful illustration of the minuteness and multitude of the particles is given. Let clean gum mastic be dissolved in alcohol, and drop it into water; the mastic is precipitated and milkiness is produced. Gradually dilute the alcoholic solution, and a point is reached where the milkiness disappears, and by reflected light the liquid is of a bright cerulean hue. "It is in point of fact the color of the sky, and is due to a similar cause — namely, the scattering of light by particles small in comparison to the size of the waves of light."

Examine this liquid with the highest microscopical power, and it appears as optically clear as distilled water. The mastic particles are almost infinite in number, and must crowd the entire field of the microscope; but they are as absolutely ultra-microscopic as though they had no existence. I have tested this with an exquisite $\frac{1}{50}$ of Powell and Lealand's, employed with a new and delicate mode of illumination for high powers,[1] and worked up to 15,000 diameters; but not the ghostliest semblance of such particles was seen. But at right angles to a luminous beam passing among these particles in the fluid "they discharge perfectly polarized light." "The optical deportment of the floating matter of the air proves it to be composed, in part, of particles of this excessively minute character," and it is among the finest of these ultra-microscopical particles that Professor Tyndall finds the sources of bacterial life. It is almost impossible to conceive a nearer approach to certainty concerning the nature of these minute particles than this. Their minuteness, their capability of being physically demonstrated, the absolute necessity of their presence to the origination of bacteria in sterilized infusions of any and every kind, taken in connection with what we *know* concerning the germs of the *Heteromita* whose life-histories have

[1] Monthly Microscopical Journal, April, 1876.

been studied, render it simply inevitable that we have at length reached, what we are justified in believing to be, a genetic product of the bacteria through which their continuation as organisms is preserved. When first I saw the simplicity and beauty of this method, it struck me that its applicability as a test in reference to germs — *known to be such* — would have considerable collateral weight; and a method of employing it was suggested by a fact in past experience.[1] I had in my possession a maceration of cod's head, which I had kept in use for eleven months. It had become a pulpy mass, and in the middle of January last it was comparatively free from bacteria, but swarmed with two monads — the fourth and sixth of the series described by my colleague and myself. To ascertain their exact condition, I watched them on the "continuous stage" for three consecutive days, and found that both forms were to be seen plentifully emitting spore. The maceration had become very short of moisture, which served my purpose. I subjected it to a dryer air with a higher temperature, and it was not very long in becoming a moist pulpy mass, with sufficient cohesiveness to be removed from the vessel; and in this condition it was placed in a heating chamber, which was slowly raised to a temperature of 150° Fahr., and kept at this for an hour. This was 10° Fahr. higher than Dr. Drysdale and myself had proved necessary to destroy absolutely every adult form. The baked mass now appeared cracked, porous, and flaky. In parts it was extremely friable, and with little pressure crumbled into almost impalpable powder; while by friction a very large proportion was reduced to the finest dust. To avoid all possibility of error this powder was again exposed in the heating chamber, spread over a plate of glass, to a temperature of 140° Fahr. for ten minutes — thus rendering the plea of mere desiccation impossible.

A chamber or box was now prepared precisely like Professor Tyndall's, except that there were no tubes to communicate with the outer air.

In the Researches on the Life-History of Monads we had proved that they could live, thrive, and multiply almost as well in Cohn's "nutritive fluid" as in the normal animal infusion. This fluid is composed of phosphate of potash, sulphate of magnesia, triple basic phosphate of lime, tartrate of ammonia, and distilled water. If these ingredients are all mingled the fluid becomes speedily charged with bacteria, unless hermetically

[1] Monthly Microscopical Journal, xii. 262, 263.

sealed, and sometimes even then. We therefore keep the ammonia in a separate solution, mixing them when required.

A portion of the fine dust of the maceration was now taken and thoroughly scattered through the air of the prepared chamber. The condensed beam from an oxyhydrogen lime-light [1] was then sent through it. Its line of passage was far more brilliantly marked inside the chamber than in the outer air. It was deemed inexpedient to insert the fluids while such brilliant points were visible in the air, and four hours were suffered to elapse. The lime-light beam was still visible with perfect distinctness, but its path within the chamber was much less brilliant and more homogeneous than it was without. The fluids were then carefully mixed, and five small glass basins of the mixture were inserted. The whole was undisturbed for five days. At the expiration of that time the beam of the lime-light sent through the chamber was absolutely invisible, although perfectly clear in the open air on both sides of it.

The fluids were now withdrawn. Ten "dips" were taken out of each basin for microscopical examination. *In every "dip"* — that is, fifty in all — *one or other of the monads appeared, and were in a state of active fission;* and in twenty-seven of the "dips" both monads were found. Bacteria swarmed the field, which of course I fully expected.

I now took five *other* glass vessels, and inserted them with great care into the now moteless air of the chamber, and poured in, as before, fresh Cohn's fluid. They were exposed for another five days. On careful microscopical examination of seventy-five "dips" *not a single monad of either form appeared;* bacteria were feebly present, but of course no steps were taken to guard against these, and, as before, they were anticipated.

The air of the chamber was again impregnated with dust, as before, suffered for a time to settle, and *these same vessels of fluid*, which had yielded negative results, were again placed in the chamber. At the expiration of five days they were again examined, *and one or other of the monads was found in every successive "dip."*

Now let it be observed that there can be no possible error as to the forms. They were the identical species of the maceration, with which I am as familiar as with a barn-door fowl. What, then, is the logic of these facts? Dr. Tyndall proves that bac-

[1] This was of course very much less capable of "searching" than the electric beam; but it served for the rougher end I had in view.

teria only develop in sterilized infusions when the air around them is laden with motes of incalculable multitude and exquisite minuteness. Given the presence of these, and the development of bacteria is inevitable. The inference is that the motes are *germs*. The above experiments show, that in closely allied septic organisms, the germs of which have been demonstrated and their developments watched, if the dry *débris* of a maceration in which these forms are found be scattered in the air around a prepared fluid, and demonstrated by similar optical means, that the said organisms develop; but if the minute dust from the *débris* be optically proved to be *absent*, none of the monad forms appear. Here we do not hypothecate a germ, but we *know* that it exists; and its deportment in similar conditions is identical with that of the assumed bacterial germ. Do we need more irresistible evidence that the bacteria develop, not *de novo*, but from genetic products?

Now, until Dr. Bastian's promised "new results"[1] have appeared, I believe I am justified in affirming that the strongest cases on which even he relies for "spontaneous generation" are recorded on pages 175, 180, of his Evolution and the Origin of Life. They are thus introduced: "After this I may, perhaps, be deemed fully justified in quoting two *very typical* experiments for the further consideration of those who stave off the belief in spontaneous generation — either by relying on the insufficient reasons for doubting the influence of boiling water, or because of their following Pasteur, Cohn, and others in supposing that certain peculiar bacteria germs are not killed except by a brief exposure to a heat of 227° or 230° F. For even if we could grant them these limits, of what avail would the concession be . . . . in the face of the following experiments?" The details of the experiments follow. They are alike in method, and we will concern ourselves only with the second. A strong infusion of common cress, with a few of the leaves and stalks of the plants, were inclosed in a flask, which was hermetically sealed while the fluid within was boiling. It was then introduced into a digester and gradually heated, and afterwards kept at a temperature of 270–275° F. for twenty minutes, and was retained at a temperature, if the time of heating and cooling be considered, over 230° F. for one hour. This flask was opened after nine weeks. The reaction was acid; the odor was not striking. On microscopical examination with a $\frac{1}{12}$ inch objective "*there appeared more than a dozen very active monads.*"

[1] Times, January 29, 1876.

Now, fortunately, Dr. Bastian has not only carefully measured and described these organisms, but he has drawn them, and they are reproduced on the frontispiece of the book. He describes them as the $\frac{1}{4000}$ of an inch in diameter; they were provided with a long, rapidly moving lash (flagellum), by which granules were freely moved about. But, besides this, "*there were many smaller, motionless, tailless spherules, of different sizes, whose body-substances presented a similar appearance to that of the monads*, and of which they were in all probability earlier developmental forms." [1]

Now, by careful comparison, I find that this monad is no other than the "uniflagellate monad," which is the fourth in the series whose life-histories were studied by Dr. Drysdale and myself.[2]

(1.) Dr. Tyndall has proved, in connection with a host of others, but in a more definite and precise manner, that in *filtered infusions* five minutes' boiling does kill every form of bacteria.

(2.) He has further shown that they are propagated by demonstrable germs *only*, in such infusions; and

(3.) This fact removes the probability of their spontaneous generation to an almost infinite distance.

As to the development of bacteria in infusions charged with solid matter, precise experiment of a sufficiently comprehensive character has yet to be made on them, in relation to the demonstrated germs. Meantime, shall we accept "spontaneous generation" on such ground as its strongest advocate has now to offer, and ignore the vast chain of facts copiously attested and controlled, which are in perfect harmony with the known laws of the entire organic world? This, and nothing less than this, is what Dr. Bastian inculcates and demands.

RECENT LITERATURE.

PICKERING'S ELEMENTS OF PHYSICAL MANIPULATION.[3] — The first volume of this useful manual we noticed at the time it was published; the second, now before us, is more extended in its range than originally intended by the author, and will be still more valuable for students. This volume treats of electricity, heat, mechanical engineering, meteorology, practical astronomy, and lantern projections. The author suggests

[1] Evolution, page 178.

[2] Monthly Microscopical Journal, xi. 69, *et seq.*

[3] *Elements of Physical Manipulation.* By PROF. E. C. PICKERING. Part II. New York: Hurd and Houghton; Boston: H. O. Houghton & Co. 1876. 8vo, pp. 316. $4.00.