altogether failed to fulfil the expectations which the originators of the College of Chemistry entertained when they placed the new institution under my direction, it is due to the powerful influence which the friendship of Sir James exercised upon my career at that most important period of my life.

POSTSCRIPT. Having in the preceding sketch pointed out the early exertions which Sir James Clark made to procure a Government grant for the College of Chemistry, it is certainly not without interest to contemplate that at present a Royal Commission is sitting in London charged to inquire in what manner science can be best promoted in England by the grant of Government subvention, and that the author of this sketch, whilst writing it, has received from that Commission an invitation to proceed to England for the purpose of giving evidence on the mode in which scientific institutions are supported by Government in Germany.

II. THE THEORY OF ATMOSPHERIC GERMS.

By ARTHUR ERNEST SANSOM, M.D.,
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ONE of the most celebrated of the Deputies lately commenced a speech before the Austrian Reichsrath with the words :—"The great question before us is,—Is Charles Darwin right or wrong?" Probably this sounded strangely, for the world is not accustomed to be told suddenly that the solution of a scientific problem is material to its position or its progress. There is another great question which has been recently debated with a considerable amount of warmth, and has seemed to evoke a very considerable interest. Mighty issues are involved in it, and yet its problems are interwoven with the most ordinary processes of domestic life. It has to do with the most abstruse speculations as to the origin of living things in the kingdom of nature. It concerns the art of the brewer and the maker of wine. It is linked with the processes which preserve food from decomposition and sewage matters from being hurtful to mankind; with the treatment of wounds and with the arrest and prevention of pestilence. Complex in its relations, the question can nevertheless be curtly stated—Do living things of necessity spring from pre-existing living things or no?

Those who debate this question range themselves in two classes, with defined lines of demarcation between them. The ones say: living things do *not* necessarily arise from pre-existing bodies, which possess or did possess attributes of vitality; but they may originate from non-living matter in connection with the ordinary forces of nature. The others say that living things invariably are the progeny of living things; that in nature only vital material is capable of endowing non-vital matter with the special properties which itself possesses. After a protracted debate in the learned societies of France, the upholders of each side of the question appear to have arrived at that stage at which each prefers to remain unconvinced. More recently in this country the ardour of debate has been displayed, and yet there are strong forces in either camp.

The following is a brief outline of the debateable ground. It is well known that it is the tendency of moist organic matter, under certain physical influences, to undergo certain processes known as decay or decomposition. Either it disintegrates, evolving nauseous odours, and giving rise in the course of the disintegration to a multiplicity of chemical products organic or inorganic. Such is known by the term putrefaction. Or, the organic material being less complex in the beginning, the process runs a more definite course and the products are less varied. Such is fermentation.

In both instances there is observed intimately connected with the process, the occurrence, growth, and multiplication of living organisms, either amid the particles of the moist decomposing substance or upon the surface, where these frequently make their appearance as ordinary mildew. How are these results explained by the two theories? According to the one, the molecules of a putrefying or a fermenting body are in a state of motion, tending to the disruption of their elements. The living particles observed are the results of the communion of certain non-living elements with the physical forces with which they are in relation. Thus there is a strict analogy between crystallisation and creation. As in the one case certain molecules under certain conditions assume definite crystalline forms, so certain molecules under other certain conditions assume the appearances and the attributes of vitality.

According to the other theory, there is a single cause for all the phenomena. This cause is the presence of living matter. The organic elements of a putrescible or fermentescible compound undergo disruption by no inherent tendency of their particles to motion, but by the influence upon them of living, growing, and multiplying organisms, which, by their very acts of life and struggle for existence, superinduce this disruption. The living beings which are acknowledged to be present are the intimate causes and not the adventitious signs, nor yet merely intermediate agents of the decomposition of the material.

If we investigate the question from the stand-point of the second theory, we shall have to inquire concerning the living organisms declared to be the *prima moventia*, how they are brought into relation with the decomposable matters. The close relation between the presence of atmospheric air and the occurrence of the phenomena of putrefaction has been constantly admitted. It is a matter of common knowledge and common practice that to expel the air from a putrescible substance is a powerful means of preserving it from putrefaction. The presence of air is one of the conditions insisted upon by the supporters of the theory of spontaneous generation as essential to the production of living forms. No other gas can be substituted for atmospheric air except oxygen.

Upon what element of the air does its influence upon putrefaction and upon the appearance of living forms depend? The nitrogen may be at once dismissed, as direct experiment shows that it prevents putrefaction and is fatal to living things. The influence might appear with greater show of probability to be due to the oxygen. This was the hypothesis of Gay-Lussac, but experience soon showed that in many instances putrefaction was prevented when oxygen had free access to putrescible solutions; and when the progress of chemistry allowed Gay-Lussac's experiments to be conducted with greater precision, it was found that in cases wherein putrefaction was arrested by the attempted expulsion of air, oxygen, instead of being invariably absent from the gaseous residuum, was very generally present. Furthermore, according to Dr. Bastian's late experiments, the development of living forms may take place though all air may have been excluded as rigidly as possible.

Schwann concluded from his experiments that it is not oxygen, at least the oxygen of the air, which occasions putrefaction, but *a principle* contained in ordinary air which heat can destroy. This same principle could also, according to Schroeder and Dusch, be arrested by the meshes of cotton-wool. And it could be arrested by flexures made in a fine glass tube which admitted the air to a putrescible fluid, according to observations made by Pasteur and more lately repeated by Lister. Now, it may be urged that these results are not the *invariable* teachings of experiments. In case of certain putrescible fluids, and in certain conditions, putrescence has not been prevented by the means employed; but it must be recollected that, in all the instances quoted, parallel experiments were carefully made. In the one case, wherein the air was uncalcined or unfiltered, putrescence took place and organisms appeared; in the other, wherein the air was calcined or filtered, there were no putrescence and no organisation. The first step in the inquiry is the determination of the substances besides the gaseous constituents which are present in atmospheric air. The suspended matters are proved to be—(1) A number of fine particles of inorganic matter; chloride of sodium derived from the sea is proved by spectrum analysis to be present almost constantly; fine particles of the metals are present, especially in localities where are prosecuted trades, wherein they are manipulated. (2) A quantity of organic *débris*; starch cells and fragments of vegetable tissue are common; cotton and wool fibres are found in certain localities besides many kindred dry organic substances. (3) Organic *débris* derived from the animal body is also abundantly found. Epithelium cells have been frequently observed in ill-ventilated rooms; Eiselt found pus cells in the air of an ophthalmic hospital; organic matter, moreover, is given off from the lungs, for sulphuric acid is darkened, permanganate solution is decolourised and pure water rendered offensive by it. (4) Lastly, organised bodies, spores of fungi, have been seen by a host of observers. The appearance of organised bodies in ordinary atmospheric air was first satisfactorily established by Pasteur (see fig. 1). Since his observation the microscopic examination of air has been made in many ways by different observers, and all have agreed as to the presence in it of sporules of cryptogams, and of bodies possessed of vitality.

Fig. 1.

Corpuscles obtained from atmospheric air, treated by (*a*) solution of potash, (*b*) aqueous solution of iodine. (After Pasteur.)

The fact of the presence of organised bodies in the air being to all intents and purposes uncontested, we have to consider their possible relations in the causation of the development of vital forms in putrescible solutions. On this point there is wide difference of opinion. M. Pasteur, with the Panspermatists, holds that they are the sources of all the organisation; M. Pouchet and the heterogenists, that they are far too infrequent and insufficient to account for the phenomena.

The question, "Are the organisms which have been observed and described sufficient to account for the multitudes of living forms which are met with in the course of putrefaction?" is of the first importance. If so, they ought to be observed upon or within the putrescible solution, and their mode of multiplication should be distinctly made out. It is, however, certain that this cannot be established. When an organic solution is examined, prior to the commencement of putrefaction, the highest powers of the microscope fail to detect the ova or spores of the future minute organisms. There remains, therefore, this dilemma: either the germs are invisible or else the primigenetic molecules are self-formed in the fluid. We should then inquire if there is anything in analogical evidence which could tend to the conclusion that the germs of living things are so minute that the microscope cannot detect them. Dr. Beale, using the highest powers, figures extremely minute masses of germinal matter which develop into perfect fungi, yet which might elude very close investigation; and it is far from certain that these are not the indices of still more minute particles of living matter. It is surely unfair to stay further investigation by asserting at once that, because the germs cannot be demonstrated, therefore the inquiry is at an end, and the question is judged. The heterogenists have constantly urged this: they say "Show me a specimen of these creatures and I will admit them; otherwise I shall declare that they do not exist." The eye alone is not the test absolute of the cause of phenomena. Would a philosopher assert that a man could safely enter a poisonous atmosphere because he could see nothing wrong even with the highest aid to his visual powers? Would it be fair to conclude after the inoculation of vaccine virus into an animal that no virus exists in its blood because none can be detected? Would it be fair to infer that the weeds which appear in such abundance in our gardens spring up spontaneously because we cannot trace their seeds as they are wafted by the air? The method which Professor Tyndall has popularised has shown that the apparently homogeneous atmosphere which we breathe is dense with floating particles; the minuteness of these particles is extreme. It has been asserted that though many filters fail to intercept them, a stratum of cotton-wool is a perfectly efficient filter; but we must not entirely accept this dictum, for Pasteur long ago found that if strata of cotton-wool were arranged in series and air were drawn through them, fine particles were absorbed by many of the successive layers. As far, then, as the direct examination of the air, microscopic or otherwise, is concerned, we may conclude that there is at least as much evidence in favour of the germ theory as of the spontaneous generation theory.

It is at least as easy to conceive the existence of germs so minute that vision, however aided, fails to detect them, as it is to conceive the undemonstrable union of ordinary matter and ordinary forces to produce a living thing which, when produced, overrides the laws of both. Two objections, however, are urged against the germ theory which are of high importance. The first difficulty may be stated thus: the spores or germs of definite fungi are themselves definite: they are not of infinite minuteness; these fungi nevertheless spring up when it is absolutely certain that their ordinary spores cannot be discovered. The second difficulty is this: the organisms found in putrescible solutions are of many varieties and species; there must be definite and distinct germs for each of these. You must, therefore, concede that the air contains multitudes of them, that every square inch of it is a magazine of innumerable varieties. The air would be then encumbered with germs. These questions may be styled those of the specificity and the plurality of germs.

According to the germ theory the essential cause of each variety of fermentation is a cellular fungoid organism. The objective phenomena of fermentation are but the results of the development, growth, and acts of life of the organisms. How, then, does this theory explain the apparently spontaneous fermentations, *i.e.*, when no determining cellule has been added to the organic solution? It is proved that a yeast cell can form in a saccharine fluid precisely as other varieties of organisms arise in other putrescible fluids. The fluid in which yeast cells float, and which contains no formed cells whatever, is exceedingly efficient in inducing saccharine fermentations. It follows either that those cells arise from molecules infinitely more minute than the cells themselves, or else the germ theory cannot stand. The careful researches of Dr. Beale have shown that molecules capable of development into perfect yeast cells are of extreme minuteness, many of them being much less than 1-100,000th of an inch in diameter. Such germs as these are readily capable of being wafted by the air and could defy the closest means of detection.

It was long ago ascertained that other fungoid spores than those peculiar to yeast could, in a manner precisely similar to the latter, induce fermentation.

Penicillium cultivated upon lemon gave rise to alcoholic fermentation, with the production of yeast globules, and, conversely, yeast globules were found to produce *Penicillium* as well as *Mycoderma*. It is obvious that this observation of the mutability of species in fungoid organisms is of the highest importance. The apparent structural characters of the spores and the subsequent developments and fructification of *Mycoderma cerevisiæ* differ widely from those of *Penicillium*. If they are thus mutually convertible, it would annihilate the argument advanced against the existence of atmospheric germs on the score that, to explain the different varieties of forms produced, one must concede the existence of an immense number of germs in the air of different kinds. This would tend to show, on the contrary, that the same germ under different conditions could assume the appearances and the functions of a different organism.

The most elaborate investigation of recent date bearing upon this subject has been made by Professor Hallier, of Jena.

According to Hallier, the same germinal molecules develop according to the nature of the fermentescible substances in which they are deposited into the fungoid forms peculiar to each fermentation. The forms inducing putrefaction, fermentation, and mildew are all varieties of one another. As they develop within fluids they are cellular formations. When they grow upon the surface only do they present fructification (*Schimmel*). Hallier endorses Pasteur's view that the germs of all are carried by the air. The most abundant source of germs appears to be *Penicillium crustaceum* (see fig. 2), whose spores are universally

FIG. 2.

Fructification of *Penicillium crustaceum*. (Hallier.)

FIG. 3.

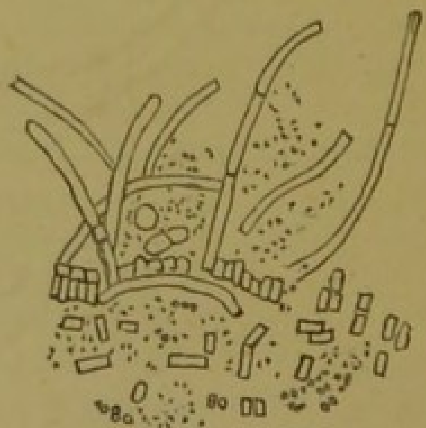
Spores of *Penicillium crustaceum* bursting in water and setting free their contained particles, which unite in rows or chains. (Hallier.)

spread because it is more hardy, more fertile, develops at lower temperatures, and grows and fructifies more rapidly than others of its kind. It will accomplish its growth and will bear fruit in forty-eight hours. A socalled spore of *Penicillium* falling into watery fluid bursts into a multitude of particles, each of which may be the radicle of a living fungus; the minute particles approximate and unite in twos, forming a double cell; moreover, they subdivide excessively rapidly, "so that the number produced can scarcely be expressed" (see fig. 3). The minute particles then unite in chains, constituting *Leptothrix*, which is not a species but a form of vegetation common to many species. In pure water development can go no farther, nor after a few hours do the organisms continue to be formed; for further development the presence of a nitrogenous substance is necessary. The minute spherules (*micrococci*) are the special ferments of putrefaction; in the presence of sugar the spherule enlarges and becomes a nucleated cell (*cryptococcus*) identical with the yeast-cell (see fig. 4).

Fig. 4.

Cryptococcus in various grades of development from *Penicillium*. (Hallier.)

Fig. 5.



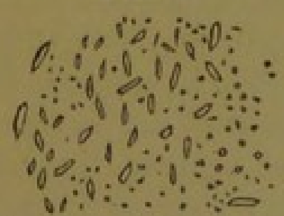
Milk ferment.

A very similar change takes place in oil fermentation. In milk the *micrococcus* elongates and forms parallelopipeds or staff-like cells (see fig. 5); in acetic fermentation the cells assume a lancet shape (see figs. 6 and 7). These ferments increase by division, and are classed by Hallier under the term *arthrococcus*. If we can accept the teaching of the foregoing evidences, fermentation and putrefaction are both due to the influence of a single agent —vitalised matter—which is transported from place to place by the air. We must believe that ordinary air contains minute masses of living matter—call these particles germs, germinal matter, protoplasm, bioplasm, or what we will—that they are derived from the fructification of fungi which can spring up wherever nitrogenous organic matter is in contact with air; that from such fructification it is not the visible spores but minute fragments of these which are the first causes of the subsequent decompositions; that these living molecules grow wherever they find a soil meet for them, and in different soils develop into different forms, and produce by their vital acts different effects.

It now appears that none of the objections hitherto urged are fatal to the germ theory. Chief, however, amongst the arguments adduced against it has been that deduced from the results of destructive agencies.

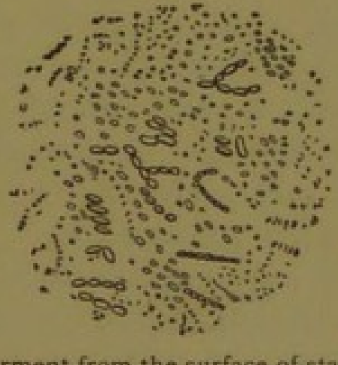
At a very early period in the history of the controversy concerning the origin of life, investigations were made with the intention of determining this question. Can vital organisms be found to develop under physical influences which are, under ordinary circumstances, fatal to any living thing? If so, there is a great difficulty in the way of accepting the germ theory. The heterogenists have argued that living bodies *are* discovered after processes

Fig. 6.



Acetic ferment in course of development. (Hallier.)

Fig. 7.



Acetic ferment from the surface of stale beer.

of physical destruction which it is *impossible* for life-possessing matter to withstand; therefore, by exclusion, spontaneous generation must occur.

The necessary conditions for experiments of this nature are—(1) the subjection of fermentescible matter to such destructive agencies that vitality in it is impossible; (2) the prevention of any subsequent contact with it of an agent which may be a possible vehicle of vitality.

The agency usually employed for the destruction of all possible life in fermentescible fluids has been heat; the precautions against the admission of possible germs or germ-laden air have been various. The most simple of these processes has been the subjection of the fermentescible fluid to heat, varying in intensity in different experiments, and its preservation in sealed flasks whence air was as rigidly as possible excluded. The originator of this method of investigation was Needham. Since his time it has been put in practice with varying methods for the exclusion of possible germs after the heating of the fluid. The temperatures employed have varied in different experiments from boiling for periods ranging from a few minutes to six hours (Pouchet, Mantegazza, Child, Bastian) to 153° C., or 307·4° F. (Bastian). The means of excluding possible vitality subsequently have been passing the air through a tube raised to a red or white heat (Pouchet, Wyman, and others), or through a tube containing strong sulphuric acid (Pouchet, Joly, Musset), or supplying only oxygen (Pouchet, Child, Mantegazza), or artificial air (Pouchet, Child), or by preserving the boiled putrescible fluid *in vacuo* (Pouchet, Bastian). In all these cases organisms have been described as resulting. In these experiments it would appear that the conditions would be fulfilled with the least liability to objection in the cases wherein the solutions were exposed to very high temperatures *in vacuo*. M. Pouchet filled a flask with a decoction of malt which had boiled for six hours, and hermetically sealed it. After six days a deposit, apparently of yeast, took place in the flask; on the seventh day the external temperature having been suddenly raised the flask burst with a loud report. There had been fermentation, and the microscope disclosed that yeast corpuscles had been formed. Dr. Bastian has also performed analogous experiments with great care. In his first series, the fluids were boiled in small flasks for ten to twenty minutes, and then by means of the blowpipe hermetically sealed; after periods varying in the different experiments from five to thirty-nine days, the flasks were opened, and the contents were examined with the result of the discovery of many lowly-endowed organisms. Living bodies were also found when solutions of tartrate and phosphate of soda and some other saline solutions were in like manner made the subject of experiment. It has been supposed that these observations are very antagonistic to the germ theory, and lend colour to the views of heterogenists. In briefly considering this conclusion we may divide the arguments into two classes, the first being derived from the evidence of the supposed destructive influence of high temperatures on living matter, the second from the supposed impossibility of the pre-existence of germs in the fluid employed. It must be recollected that by the argumentation in favour of heterogeny the method of exclusion is employed, and this requires the most prolonged and patient employment before its conclusions can be said to approach finality. Furthermore, its upholders must be prepared to substitute for the explanation of phenomena which may be derived from any other theory another which shall be more satisfactory.

Let us, in the first place, accept as proved, by the results of the experiments, that living forms have been discovered after the subjection of the fluid containing them to a temperature of 307·4° F.

The affirmative proposition necessary to establish the heterogeneous evolution of these organisms is that no living thing can in any state and under any conditions withstand a temperature of 307·4° F., without annihilation of its vitality.

It is probable that this would, according to their preconceived notions of the properties of living bodies, be at first sight adopted by most people.

It is difficult, *à priori*, to believe that living matter could resist such a seemingly powerful cause of destruction; but it behoves us to consider the subject, not solely according to our preconceived ideas, but to inquire as to the properties and the behaviour of living matter from observation below the surface of ordinarily visible nature. And here we find many seeming paradoxes: we find that it possesses powers of persistence and of resistance, which would certainly, *à priori*, appear impossible.

First, as to persistence. We know that vitality may lie dormant for a period which is almost inconceivable. Stramonium seeds, according to Duhamel, can develop after remaining twenty-five years under ground. Friewald observed the germination of melon seeds after they had been kept more than forty years. Pliny asserted that corn grew after it had been kept 100 years. Desmoulins obtained plants from seeds found in a Roman tomb of the third or fourth century. Finally, it is well known that corn found in some of the tombs of ancient Egypt has germinated and grown to perfection, and that a squill-bulb, found in the hands of a mummy has, when planted in this age, and in this country, grown and blossomed. In these cases it can scarcely be questioned that, remarkable as it may seem, the vitality (or term it what we will) of the various germs has slumbered during the protracted periods indicated.

The proposition that there have been in these cases actual death and subsequent reviviscence cannot be seriously sustained, least of all by those who uphold the heterogeneous evolution of living things according to definite and progressive stages by which the identical original form could only by a miracle be obtained. Concerning lowly-endowed organisms, Claude Bernard taught that "infusoria carefully dried lose all vital property, at least in appearance, and can remain thus for whole years; but when water is restored to them they re-commence their life in the same manner as formerly, provided a certain degree has not been overpassed in the desiccation."

These facts alone are sufficient to show that we must rely on no *primâ facie* or surface ideas for our conception of the nature and properties of those bodies which possess vitality.

Then, as regards resistance on the part of living organisms, especially with regard to temperature.

First of all, we have *direct* evidence as to the influence of temperatures on low organisms. We have abundant evidence that they can support very low temperatures, very high temperatures, and very rapid alternations of temperature. Bacteria and monads survive a cold of 23° F. for an hour, and often 5° F. for a few minutes. The lowest organisms "possess for the most part," says an ardent supporter of heterogeny, "a resistance often surprising to heat and cold." An experiment of M. Pouchet shows even that certain of them can easily support sudden changes of temperature, even a rapid transition of 100° C. In the hot Geyser springs which reach nearly to the boiling temperature, unicellular plants have been found growing. Practically, however, the extreme limit of heat which it is found that *developed* organisms can bear in the presence of water has been fixed at 100° C., *i.e.*, the temperature of boiling water, and this by the upholders of either side. In dry air, organisms are capable of withstanding a considerably higher temperature than when they are contained in fluids.

In the ovum and spore condition, life-possessing matter, according to all the evidence, possesses a higher power of resistance than obtains in case of the developed organism. The zoosperms of the frog can retain their vitality in a cold not exceeding 24° below freezing. M. Payen determined that the sporules of the *oidium aurantiacum* resisted a moist heat of 248° F., and only lost their faculty of germination at a heat of 284° F. Pasteur asserted that spores of mildew *in vacuo* or dry air were fertile after exposure for twenty minutes to half an hour to a temperature of from 248° F. to 257° F., but he concluded that exposure for more than twenty minutes to 260° F. to 266° F. completely destroyed their vitality. It is thus seen that organised material in the embryonic condition is capable of resisting temperatures which seem at first sight almost impossible. An argument to the contrary has, however, been urged from the behaviour of known and recognised spores under such conditions. Pouchet observed that the spores of *Ascophora*, *Penicillium*, and *Aspergillus* were completely *disorganised* by being boiled for a short time in water. So, also, Bastian showed that a fungus and spores heated in a sealed flask for four hours to 153° C.; that is to say, treated in precisely the same manner as the solutions which yielded him, in the case of infusions, evidence of life and organisation, were completely disorganised. "Not a single entire spore could be found; they were all broken up into small, more or less irregular, particles." But it behoves us to inquire further as to the signification of this disruption. We can quite agree that by the influence of the heat the spore is torn asunder and dissipated into fragments, but it is another thing to assert that such fragments are bereft of all vital property. Observations have all tended greatly to show that our notions concerning a "spore" must be modified. It is not, like the seed of a phanerogamous plant, the nucleus of a single organism, but a collection of extremely minute individual particles, each of which may become a definite organism. Though, therefore, we may agree that there is an apparent disintegration of the visible spores, we need not subscribe to the view that every one of the individual particles succumbed to the destructive influence. Disruption need in no way connote destruction. The divided polyp is not destroyed, but its fragments grow into fresh organisms, and a dismembered portion of a plant can become an individual tree. We may agree that the spores have lost the power of reproducing the plant whence they were originally derived, but we know also that the surroundings and the conditions of pabulum are greatly changed by the influence of the heat, and this may be a sufficient explanation. One observes when mildew grows upon organic matter, that though a certain species (say *Aspergillus*, for instance) may be shedding its spores in all directions, these do not spring up as successive crops of *Aspergillus*—a species totally distinct in form succeeds it, and so on through the generations following. We are not bound to believe, therefore, from the apparent evidences of physical destruction, that every particle is rendered lifeless; certainly we cannot conclude this from *à priori* grounds. To say that because higher forms would have lost vitality, therefore lower or embryonic forms must lose it likewise, would be equivalent to estimating the power of resistance to physical influences of a spermatozoon from the power of resistance of a developed animal.

Dr. Bastian asserts that the vitality of vibrios and bacteria is destroyed by the boiling temperature: when infusions containing active bacteria and vibrios are boiled, the result is the disruption of the vibrios and the disappearance of all signs of life in the bacteria. "All their peculiarly vital acts have at once ceased, and they have henceforth displayed nothing but mere Brownian movements." It must, however, be remembered that such diagnosis of vitality is purely arbitrary. In the course of putrescence, no one can tell when movements cease to be Brownian and commence to be vital; conversely, when the special bacterian movements have been caused by heat to cease, no one could assert that the movements of the *débris* were purely mechanical; or, if all movements had ceased, it could not be positively stated whether vitality had been annihilated or only paralysed.

In face of all the facts it cannot be said that the heterogenists have proved their case, that subjection to a heat of 153° C. is an absolute test of the absence of vitality. When we see the extraordinary powers of persistence and of resistance of life-possessing matter, any single test which we may impose, unaccompanied by collateral evidence, cannot satisfactorily prove the absence of vitality. The very experiments themselves, which are supposed to prove the impossibility of vitality by the stringency of the adverse influences employed, demonstrate how vital matter defies such adverse influences. Could one predict that, even if low forms could originate, complete fungi could grow and fructify in the conditions of vacuum and of pabulum which would be profoundly altered by the exceedingly high temperature? But not only so; in some of Dr. Bastian's experiments the growth of organisms seems to have been *favoured* by the conditions. As, therefore, with phanerogamous plants there is a wide range of temperature-conditions most befitting the perfection of different species, so there is no reason for denying to lower forms a wider range than our *à priori* views would have led us to imagine.

We will now turn to the second part of the argument advanced in favour of the heterogeneous evolution of the organisms found in these conditions, viz., the impossibility of the pre-existence of living matter in the materials employed in the experiments. The chief evidence in this direction is adduced by Dr. Bastian from his experiments with saline substances. In examining crystals of the neutral tartrate of ammonia, Dr. Bastian found in their interior positive evidences of fungoid germs. Far from this being an argument in favour of the transformation of crystalline into living matter, many will consider that it lends weight to the germ theory. Upholders of the latter assert the universal presence of germinal molecules. Dr. Bastian shows them to exist in crystals by physical demonstration. That once in a saline solution such vital organisms can grow and propagate is no matter of doubt—it is admitted by either side. Pasteur showed that a salt of ammonia and the phosphates could become a perfect pabulum for torula cells. The oxalates and phosphates have been shown by Hallier to be excellent media for the development of fungoid fibres, oidium forms, mycoderms, and fructifying organisms. The whole difficulty rests, therefore, with the earliest phenomena.

It behoves us to inquire into the teaching of the negative as well as the positive results. That the proliferation of forms of life under restrictive influences such as have been mentioned is exceptional is taught by the results of every labourer in the field. Privation of air is admitted to be a most potent cause in prevention of the appearance of organisms: or to put it in another way, "experiments in closed vessels are quite unfavourable to the demonstration of heterogeny, because the natural and regular progress of the phenomena is paralysed." Increment of heat is another adverse influence, "because the destructive agent impairs without destroying that organising force which is an essential property of organic matter." These are the modes of expressing the facts adopted by the heterogenists; and MM. Joly and Musset, by actual experiment, prove that the organisms in a putrescible solution submitted to ebullition "are more simple and less numerous accordingly as the ebullition is prolonged." In fact, we must conclude with M. Pennetier "that the phenomena of spontaneous heterogenic generation, intense while their regular course is respected, are nevertheless manifest, though in successively lessening degrees, as causes of difficulty are increased, to finally cease when the phenomena of fermentation and putrefaction are themselves prevented." This as an *explanation* of the position to which science has arrived in this question it is scarcely needful to say is feeble in the extreme; it is merely a categorical expression of results which can be explained at least as well by the one theory as by the other.

From the foregoing data it appears that none of the arguments adduced are sufficient to invalidate the germ theory. There is a mode of putting the question which must appear to many to be unfair. It is alleged that the onus of proof rests entirely with the Panspermatists. It is not for the heterogenists to prove that germs do not exist, but for the Panspermatists to prove that they do exist. "The charge of proof in science rests with those who allege a fact." Surely the facts support precisely the contrary view.

The positive proposition '*omne vivum e vivo*' is asserted by all the evidence of visible nature, and by microscopic research, to those confines beyond which human powers cannot reach. That there is an exception to the seemingly universal law in the case of those organisms which are invisible it must be the duty of those who embrace the theory of spontaneous generation to prove, or else to tolerate becomingly the scepticism of others. It behoves us seriously to weigh the only real objection to the reception of the germ theory—the resistance to the destructive agency of heat, and to inquire as to the effects of other physical agencies which may contribute to a solution of the question. It is not by the results of a single method of investigation that this question is to be judged, but rather by the collective evidence of many methods.

Heat is not the only destructive agency which may be employed in the inquiry: others, fraught with much valuable teaching, may be put in force, though these have been apparently in the recent controversies entirely ignored. Such are the evidences derived from the destructive influences of chemical and of poisonous agents. It has been known from time immemorial that the addition of certain compounds prevents both putrefaction and fermentation. The belief being that these processes were essentially chemical, it was naturally probable that the agents which suppressed them should be susceptible of a chemical classification: but the infinite variety and opposite properties of the various agents precluded this classification. If the processes were, as asserted, those of oxidation, it would surely be not unreasonable to expect that the agents which arrest them should also arrest oxidation; but common experience taught an absolutely contrary lesson—that *oxidising* agents were the most efficient in arresting the processes. Again, on the chemical theory there ought to be some quantitative relation between the amount of a chemical agent employed and the degree of its influence; but the fact is that an agent present in such feeble quantity as to be capable of no appreciable chemical effect on a mass of putrescible material is yet capable of stopping all putrefaction. Furthermore, agents, such as carbolic acid, which are proved to exert no influence whatever on processes purely chemical, are among the most efficient of all means for preventing putrefaction and fermentation.

A large series of observations shows, on the other hand, that the agents arresting these processes exert their influence precisely in so far as they are *poisonous* agents to low organisms. If at any stage of the process these microscopic organisms are rendered lifeless, the process, with all its attendant phenomena, ceases: on the other hand, the overt signs grow with their growth, strengthen with their strength, subside when they languish, and cease when they die.

Hitherto experiments have usually been made with the view of ascertaining the effects of antiseptic agents when mixed with putrescible material; but the author has attempted to ascertain the results which occur when the air alone is influenced by certain agents, the materials being left intact. In this way the evidence of the results obtained from experiments with *heat* may be tested by the evidence of other agents of vital destruction.*

The results obtained may be thus briefly summarised:—

1. Putrefaction, mildew-formation, and the appearance of organisms can be checked or absolutely prevented by the existence of certain agents in the air supplied to a putrescible body.

2. The power of such agents can in no sense be measured by their chemical constitution or characters. From many experiments the following expresses their order of efficiency from weakest to strongest:—(1) chloride of lime; (2) sulphurous acid, ammonia, sulphuric ether; (3) chloroform; (4) camphor; (5) iodine, phosphorus, creosote, carbolic acid.

3. The agents which stop fermentation are vegetable, not animal, poisons. Fungi will grow in the presence of hydrocyanic acid and of strychnia.

4. Comparative experiments show that a given volatile agent is far more efficient when it is contained in the air supplied to a putrescible solution than when an equal quantity is mixed with the solution itself.

(5) All fungoid organisms can be prevented by the presence of a minute proportion of creosote, carbolic acid, ammonia, hydrochloric acid, or sulphurous acid in the air, though beneath the surface of the fluid are found numerous bacteria and vibrios.

There seems to be no escape from the conclusion that the germs of fungi exist in the air and are destroyed by the volatile poisonous agent.

* See paper by the Author in the "Chemical News" (vol. xxii, pp. 241, 254), "Evidence concerning the Germ Theory of Fermentation afforded by the Action of certain substances when Suspended in the Air."

III. MOLECULES, ULTIMATES, ATOMS, AND WAVES.

By MUNGO PONTON, F.R.S.E.

PART I.

CHEMISTS have, for a considerable number of years, recognised the convenience of distinguishing the particles of chemical compounds by the term "molecules," reserving the term "atoms" for those of the chemical elements; but the time seems now to have arrived when it has become needful to make a further discrimination. This need has been rendered manifest by the results of spectrum analysis. The word "atom" conveys the idea of a particle incapable of being analysed; but the spectrum has shown the particles of the chemical elements to be otherwise constituted. Had they been simple homogeneous masses of definite size and weight, each element, when thrown into vapour and rendered incandescent, would have exhibited in the spectrum only a single bright line; because every particle of the element being precisely alike would, when in the vapourous state, and freed from all extraneous influences, have vibrated in exactly the same periods of time, and so have originated luminous waves of only one definite length and period. The discoveries of Messrs. Bunsen and Kirchhoff, however, and of other labourers in the same field of research, have shown that the chemical elements, when in the state of glowing vapour or gas, exhibit more than one bright spectral line—some of them, indeed, a large number of distinct lines of various degrees of brightness, in widely different regions of the spectrum. Even hydrogen, the element which is at once the lowest in specific gravity, and the lightest in the scale of chemical equivalents, exhibits four bright spectral lines, while iron presents a large number.

The law of chemical combination by equivalent weights appears to exclude the supposition that the ultimate particles of any element differ in size and weight—the equivalent being merely an average. For the smallest quantity of the vapour of any chemical element shows the same number and kind of lines as any greater quantity; while there is an extreme improbability that this should be the case, did the ultimate particles differ in size and weight, and were the combining proportion merely a general average of those diverse weights. The only alternative conclusion appears to be, that each ultimate particle of the element consists o