THE NATURE AND ORIGIN OF LIVING MATTER (PROTOPLASM).

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[*Read before the Royal Society of Queensland, 13th May, 1899.*]

Mr. Byram's exceedingly interesting paper on the "Beginnings of Life" touched at its close on topics which belong, as he remarked, rather to the realm of philosophy than of science, strictly so called. He described to us the simplest known living beings, illustrated in a very able way their marvellous variety of form and activity, and at the same time pointed out their apparent simplicity of structure; how that they all were but modifications of a single cell, that is, a naked mass of jelly-like protoplasm, containing a central portion of greater density known as the nucleus. We were shown how cells of the closest similarity of form and activity to these existed in the higher animals and plants, how the tissues of all animals and plants were composed of collections of such cells, modified more or less from their primitive simplicity to perform special functions, yet never departing very far from it; and how, in fact, every animal and plant, every one of us, originated from a cell of very simple form, the ovum, closely comparable to an amœba, or other unicellular organism. So far our lecturer kept to the firm ground of science. All that he told us is easily demonstrable, and very much of it can be actually seen by anyone who will devote a little pains to the investigation. But anyone so doing, if of a thoughtful disposition, can hardly fail to ask himself certain questions, which, as Mr. Byram remarked, are probably to be regarded as insoluble. What is the nature of this glairy, transparent, mobile substance we call protoplasm, which forms the body of this shifting speck of life? How does it differ from other substances know to us as lifeless and inorganic, and is this

difference merely one of degree, or is there a deep and unfathomable gulf between them? Finally, how did living matter first arise and come to exist?

You will not, I hope, suspect me of thinking I have any new solution to offer of these well-discussed problems. Scientifically they are insoluble. They take us into regions where observation and experiment, the methods of science, are unavailing, and where the human mind is ever in danger of mistaking its self-evolved imaginations as equivalent to demonstrated truths, or worse still, of mistaking merely verbal solutions for real. For the latter error there is one sufficient remedy, and that is to substitute mentally the meaning of the word, or, in logical terms, the definition, for the word itself, and unless one is continually prepared to do this the discussion of any philosophical problem becomes futile.

When, for instance, we are told that all matter is living, that there is no such thing as dead inorganic matter, we are, I submit, in danger of deriving comfort from a mere verbal assertion. For if we apply the term living to all matter, what meaning do we attach to it? That there are great and real differences between living and non-living matter is a fact of science, which we cannot explain by denying it to be. If, however, the assertion be explained to mean, in more accurate language, that the protentiality of life exists in all matter, that the properties of living matter exist in an attenuated degree, or in a dormant condition, in simpler chemical combinations, we have an admissible hypothesis, which deserves discussion. But the facts must be recognised in the first place.

Let us for a moment contemplate the amœba, and consider the properties of its living substance. I cannot do better than quote one of the earliest observers, who sixty years ago described this substance, not by the term protoplasm, by which we know it, but by the term sarcode. "I propose," said Dujardin, "to name sarcode that which other observers have termed a living jelly, a substance glutinous, diaphanous, homogeneous, refracting light a little more than water, but much less than oil, extensible and ropy like mucus, elastic and contractile, susceptible of spontaneously forming within itself spherical cavities or vacuoles which become occupied by the surrounding liquid. The most simple animals, such as amœbae and monads, are entirely

composed, at least to all appearances, of this living jelly. Sarcode is without visible organs, and has no appearance of cellularity; but it is nevertheless organised, for it emits various prolongations along which granules pass, and which are alternately extended and retracted; in one word, it possesses life." In this old description, to which the most recent science has but little to add, you will note the stress laid upon the movements of protoplasm as indicative of life. And, indeed, these movements are sufficiently remarkable. It is true that of recent years Bütschli has shown that if oil be rubbed up with certain alkaline salts in a moist condition, and a minute fragment of the paste be examined in water, the latter diffuses into the paste and converts it into a froth, in which streaming movements occur and changes of external form not unlike those shown by living protoplasm. These movements are due to diffusion currents set up by the chemical changes taking place between the water and the soapy oil. How far they can be regarded as explaining the movements of protoplasm is, I think, very doubtful. Similarity may be apparent as well as real, and it is very doubtful whether protoplasm really consists of a vacuolated mass as Bütschli contends, and further, even more doubtful whether these simple diffusion currents, which cease after a time, really explain in any way true amœboid movements.

But there are other and more subtle differences between living and non-living matter. A proper mental grasp of these is essential to the understanding of our problem. They consist in chemical changes which are characteristic. All living matter has this in common, that it continually absorbs oxygen and gives off carbonic acid. If you will consider this for a moment, you will see that it involves the recognition of the fact that living protoplasm is always in a state of wasting or decomposition. Its constituent molecules, which consist partly of carbon, are continually becoming oxidised and breaking up into much simpler non-living chemical compounds. As a necessary condition to its existence, it possesses the opposite power of taking up non-living matter and transforming it into protoplasm. Its chemical equilibrium can only be maintained by a continual succession of chemical changes, opposite in character, for its substance is in a continual state of flux. On the one hand is an in-stream of molecules containing carbon, nitrogen, &c.; on the other, an outflow of the same elements in other, usually much simpler,

combinations. By these chemical changes a continuous formation of energy takes place, which energy is given off as heat, or sometimes also partly as mechanical motion, or in other ways. Living matter is continually in a state of unstable chemical equilibrium.

By a preponderance of assimilation over waste the living cell grows in size. A consideration of the statements just enunciated will convince you how fundamentally different such growth is from that, for example, of a crystal. The latter growth is wonderful to contemplate, but it is a growth by accretion; each increment once formed is stable. The growth of the cell usually ends in division, which, in the case of the amœba, leads to the formation of two individuals each resembling the parent cell. But in the higher animals, the process of cell division leads to more complex developments. A brief glance at these is necessary for our purpose.

The human ovum, not very different in structure from an amœba in the encysted stage, consists of a nucleated cell about fifteen of a millimetere in diameter, forming a speck just visible to the naked eye. The first stages of development consist, as in much humbler forms of life, in the division of this cell into two, four, sixteen, and more cells, forming a cluster, somewhat resembling the form of a mulberry. As the cells multiply fluid accumulates between them, and they form a minute vesicle, round which the cells are grouped at first in two, then in three layers. From these three layers of cells are developed by successive steps all the marvellous complexity of the adult human frame. The process by which this change occurs has to a great extent been observed and mapped out. It is a wonderful history, and the process by which each cell assumes its right place, and each group of cells differentiates itself into the right tissue in exactly the right situation, is entirely baffling to the imagination. Let me very briefly glance at the developmental history of one portion of the human frame. It is at first surprising to learn that the whole nervous system is developed from ancestral cells, which formed part of the external surface, or skin, of the embryo. As the development of the individual is but a recapitulation, with some modifications, of the development of the race, this fact seems to take us back into a very remote past, when the cells specially devoted to sense-perception, which would naturally be situated near the surface, were not yet differen-

tiated into peripheral sense organs and central cells, receiving nervous impressions from these sense organs. However this may be, you will observe in a very early stage of the embryo of a hen's egg, or of any other vertebrate, the appearance of a superficial groove, bounded by two ridges of thickened cells. These ridges increase in height, meet above, and coalesce, forming a tube lined by cells which originated from those covering the surface of the embryo, but have become distinct from them. The forepart of this primitive nervous tube undergoes very complicated changes, into which I will not enter, to form the brain. The hinder portion retains to the end very much of its primitive form, and constitutes the spinal cord of the adult. The first step towards the connection of the embryonic spinal cord with the other organs and tissues is a budding out of groups of cells along its dorsal surface on each side. The cell-buds become detached as little cell-islands, which develop into the spinal ganglia. In the next place the cells of these embryonic ganglia grow out into processes at each end, the two processes of each cell travelling in opposite directions. The centrally growing processes return to the spinal cord, and so resume connection with the central nervous system. The remaining processes have a peripheral direction, and form the sensory nerve fibres. They are joined by outgrowths from the anterior cells of the spinal cord, which grow out to form the motor nerve fibres. At each vertebral segment a nerve is formed by the union of one of the motor and sensory roots. I wish you to try and picture to yourselves the peripheral growth of these nerve fibres, how they insinuate themselves among the other tissues, as the roots of a plant insinuate themselves between the particles of the earth on which it grows. But the process is not an aimless one; each nerve cord, each branch, each filament takes its determined course, and no part of the body is free from their invasion. The sensory filaments form a network all over the body, but of especial fineness on its surface. The motor filaments seek out the developing muscles, and each one attaches itself to its appropriate muscular fibre. If you try to realise this you will gain a faint conception of the method by which one strand is woven in the wonderful fabric of flesh common to all of us.

The purpose of this brief sketch has been to bring home to your minds the real and great difference between the phenomena

exhibited by living matter, that is to say, protoplasm, and other varieties of matter. As to this difference there is no dispute, and the more one grasps it mentally the less inclined one is to minimise it in any way. But when we come to the explanation of this difference, we find two possible alternatives. We may regard protoplasm as ordinary matter acted upon by ordinary chemical and physical forces, but of exceedingly complex constitution. Or we may regard it as ordinary matter plus an immaterial something to which is commonly applied the terms "life," "vitality," "vital principle." On the former alternative the differences between protoplasm and ordinary matter are differences of great extent, it is true, but only of degree. On the latter hypothesis there is a gap between the two which no thought nor reasoning can bridge over.

I have lately been reading a quaint old book written some two hundreds years back by one of our old English naturalists, John Ray. It so happens that in this work two opposing views as to the nature of living matter are both stated. In treating of this very development of the animal body, Ray remarks—"It seems impossible that Matter, divided into as many minute and subtle Parts as you will, or can imagine, and those moved according to what Catholick Laws soever can be devised, should without the Presidency and Direction of some intelligent Agent, by the meer Agitation of a gentle Heat, run itself into such a curious Machine as the the Body of Man is." The difficulty, which must have occurred to everyone who has considered the problem, could not be stated with more definiteness. When Ray is treating of another subject, the contractions of the heart, he states his views again. The cardiac contractions were, he supposed, due to an influx of spirits (by which he did not mean anything immaterial, the word meaning simply gases or vapours) into the heart during systole. "What," he asks, "directs and moderates the Motions of the Spirits? They being but stupid and senseless Matter, cannot of themselves continue any regular and constant Motion without the Guidance and Regulation of some intelligent Being. You will say, What Agent is it which you would have to effect this? The sensitive Soul it cannot be, because that is indivisible, but the Heart when separated wholly from the Body in some Animals continues still to pulse for a considerable time; nay, when it hath quite ceased it may be brought to beat again by the application of warm

Spittle, or by pricking it gently with a Pin or Needle. I answer, it may be in these Instances, the scattering Spirits remaining in the Heart, may for a time, being agitated by Heat, cause these faint pulsations, tho' I should rather attribute them to a plastick Nature or Vital Principle." This "plastick Nature" was a great comfort to John Ray, by its means he releases himself from every difficulty. It answers, I apprehend, exactly to the term "vitality" or "vital force," which, till quite recent years, could always be invoked to cut the knots of physiological puzzles. But on the very next page to the quotation given is an extract from a contemporary work by Mr. Boyle (whether the same as the physicist who enunciated Boyle's law of the volume of gases I have not ascertained), in which a very different order of ideas is introduced. "I think it probable," writes Boyle, "that the great and wise Author of Things did, when he first formed the Universe and undistinguished Matter into the World, put its Parts into various Motions, whereby they were necessarily divided into numberless Portions of differing Bulks, Figures and Situations in Respect of each other; and that by his infinite Wisdom and Power he did so guide and overule the Motions of these Parts at the Beginning of Things, as that (whether in a shorter or longer Time Reason cannot determine) they were finally disposed into that beautiful and orderly Frame that we call the World; among whose Parts some were so curiously contrived as to be fit to become the Seeds or seminal Principles of Plants and Animals. And I further conceive that he settled such Laws or Rules of local Motion among the Parts of the Universal Matter, that by his ordinary and preserving Concourse the several Parts of the Universe thus once completed, should be able to maintain the great Construction or System and Economy of the Mundane Bodies and propagate the Species of living Creatures." Ray's reply to this hypothesis is so curious that I must quote it:—"This Hypothesis, I say, I cannot fully acquisce in, because an intelligent Being seems to me requisite to execute the Laws of Motion; for first Motion being a fluent Thing, and one Part of its Duration being absolutely independent upon another, it doth not follow that because anything moves this Moment it must necessarily continue to do so for the next, unless it were actually possessed of its future Motion, which is a contradiction; but it stands in as much Need of an Efficient to preserve and continue its Motion as it did at first to produce it.

Secondly, let Matter be divided into the subtilest Parts imaginable, and these be moved as swiftly as you will, it is but a senseless and stupid being still, and makes no nearer Approach to Sense, Perception, or vital Energy than it had before. . . And as for any external Laws or establish'd Rules of Motion, the stupid Matter is not capable of observing or taking any Notice of them, but it would be as sullen as the Mountain was that Mahomet commanded to come down to him; neither can those Laws execute themselves. Therefore there must, besides Matter and Law, be some Efficient, and that either a Quality or Power inherent in the Matter itself, which is hard to conceive, or some external intelligent Agent, either God himself immediately or some Plastic Nature."

It is my opinion that, judged even by the standard of his own day, Ray was a better naturalist than philosopher. My object in reading these extracts is to point out some errors that may not yet be entirely dead. Firstly, we have the highly figurative and wholly false conception of the "laws" of nature as something which poor, stupid matter has to understand and obey. Secondly, we have assertions regarding motion which are purely verbal, and embody no real conception of what actually occcurs. Here, of course, science has advanced greatly since Ray's time, and we know motion to be both universal and indestructible, and to exist in forms which were then unsuspected. Thirdly, I would ask is there not something purely subjective also in Ray's ideas of matter? Have we any right to speak of "stupid and senseless matter"? Are not these question-begging epithets?

Whatever view we may take of the nature of protoplasm, there is no doubt it is composed of the same elements as the rest of the universe. As long as life continues there is a continual procession of atoms of carbon, nitrogen, hydrogen, oxygen and other elements, variously combined, into the living substance, and an equally unbroken procession of carbon, nitrogen, hydrogen, and oxygen out of the living substance. It is not only after death that the animal body is resolved into inorganic combinations of these elements. We may compare a living organism to the little columns of dust which are sometimes seen spinning down the streets of our western townships. The sleeping dust is for one instant aroused, whirled round in complex

and unaccustomed motions, and then returns to rest again, to be ever replaced with fresh particles as long as the air-vortex continues its brief career. So during life dissolution is an unceasing process, and the living organism is but a temporary resting place of migratory atoms from the non-living world. Furthermore, it is also certain that there is no creation or destruction of force in the living organism. Here, as elsewhere, the rule of the conservation of energy holds good. The greater part of the vegetable world derives its energy direct from the sun's rays, and stores it up in the form of chemical combinations. The animal world, destitute of this power, appropriates the energy stored up by plant life by devouring these complex chemical substances, albumen, fat, starch, sugar, &c. Its energy is derived from the chemical changes which result in the combination of the contained carbon, hydrogen, &c., with the oxygen of the air. This energy is given off mostly in the form of heat, a smaller fraction in the form of mechanical work, which for the most part is also soon converted into heat. So that all life derives its energy from the sun, and sooner or later gives it back in the form of heat. In the process there is change, transmutation of force, but neither loss nor gain; one form of vibration is replaced by another, but the chain is never broken. As a late distinguished physicist wrote, in lines which, though half jocular in form, contain serious thought:—

"When earth and sun are frozen clods,
"And, all its energy degraded,
"Matter to Ether shall have faced,
"We, that is all the work we've done,
"As waves in ether shall for even run
"In swift expanding spheres through heavens beyond the sun."

Having grasped this conception of the living organism as a temporary halting place of atoms derived from the inorganic world as a temporary focus of energy derived from without and passing without again, must we add to matter and force a hypothetical something called "vitality?" Admitting to the full the vast difference between the phenomena of living and non-living matter, and the impossibility of picturing to oneself any mechanical arrangement of atoms and molecules, which will explain the former, I ask do we make the problem any clearer by such an assumption? Indeed has the word vitality any meaning that we can figure before our minds. Is it any more than a verbal expression, a word that merely covers

ignorance, the negation of knowledge? I cannot see that it is. Even if we call it vital force I cannot see that we gain anything. For force is some form of movement, of molecular or atomic vibration. It is conceivable that molecular vibrations may occur in protoplasm which have no analogies elsewhere, but if so we know nothing of them. Further, they are derived if present from forms of vibration, chemical or heat vibrations, which exist without the living cell, and are speedily resolved into these again. Once more I think we gain nothing by the assumption. I may be pardoned for using an illustration which has done good service in much abler hands than mine. In this glass you have the familiar substance water, of well known and comparatively simple chemical constitution. You might not suspect it of being the seat of molecular forces of most intricate and mysterious complexity. Yet, if guided by scientific knowledge, you follow it with the imagination, you will see that it is so endowed. Let this glass stand on the table sufficiently long and its contents will disappear; they have become converted into aqueous vapour diffused in the atmosphere. Let the air containing this vapour be transported by a favourable atmospheric disturbance to the Alps of New Zealand. The gaseous particles will become transformed into solid crystals of snow, and on microscopical examination the constituent molecules of our humble fluid will be seen to have arranged themselves in wonderful and intricate patterns of geometrical regularity, which for marvellous beauty cannot be surpassed even by the organic world. Do we render this mysterious power of water to assume intricate geometrical forms any easier to understand by attributing it to a hypothetical something called *aquosity*. You will reply doubtless that to do so is merely to invent a word, not to explain a phenomenon. And granting that the phenomena of life are much more complex than those of crystallisation, does this invalidate our applying the same reasoning to the word vitality.

To this reasoning it may be objected that our protoplasm, a mere speck of structureless jelly, exhibits none of the machinery which might be reasonably expected in a substance capable of such complex evolutions as I have endeavoured to briefly indicate in the early part of this discourse. But this objection can be hardly pressed, unless we are prepared to limit the possibilities of organisation by what we can actually see.

Protoplasm may well be, and no doubt is of infinite molecular complexity. Recent research has revealed a very complicated structure in one portion of the cell, the nucleus, which by the extraordinary changes which it undergoes during cell-division, must be regarded as playing an important if not the chief part in this process. It would be interesting to describe these changes at length, but would not advance us in our argument. For these nuclear changes explain nothing of the process in which they occur, they merely indicate what we might have otherwise inferred that the process is a very complex one.

If we contemplate living matter from the point of view of chemistry, we have sufficient evidence that it must be exceedingly complex. At no very distant date it was believed to be a peculiarity of all chemical substances derived from the products of vital activity (always excepting the ultimate products of its oxidation, such as water, carbonic acid, &c.), that they were incapable of formation by artificial synthesis from inorganic materials. The rapid progress of organic chemistry has since then resulted in the synthesis of great numbers of these substances, and has at the same time thrown much light on their molecular constitution. Compared with that of the substances treated of in inorganic chemistry this constitution is much more complex. But chemistry falls very far short of revealing the constitution of even dead protoplasm, far less of living. It has indeed been said that chemical analysis can never give us any idea of the structure of living matter, because in the act of analysis it has become no longer living. If life be regarded as a metaphysical principle resident in protoplasm, of course it cannot be considered susceptible of analysis. But if not so regarded there is nothing in this objection, for all analysis necessarily involves destruction, the resolution of one form of matter into others which do not possess the same properties. We cannot even analyse water without resolving it into oxygen and hydrogen. A more serious if not fatal obstacle to chemical analysis lies in the impossibility of obtaining living matter in a pure condition. Leaving the nucleus out of consideration we are in the habit of speaking of protoplasm as something homogeneous. But if we consider, it cannot be so. As living substance is continually undergoing decomposition, it may be inferred that the products of this decomposition are

constantly to be found in what we call protoplasm. We have reason to believe that the ultimate products formed arise not suddenly, but by gradual stages of chemical degradation from the living matter. These transitional products will naturally be present to a variable extent in conjunction with the actually living substance itself. Again, the cell-protoplasm contains nutrient material, and probably (though here we have no clear knowledge) intermediate products between this nutrient material and living matter. How much of this apparent homogeneous protoplasm actually possesses the properties of living matter we do not know, and have no present methods of ascertaining. If, however, we take masses of what is usually termed protoplasm and subject it to chemical examination we can always obtain from it three kinds of matter, fats, carbohydrates, and proteids. Of these the proteids (of which albumin is one) have a molecular constitution of peculiar complexity. A chemical formula, which can only be regarded as a rough approximation, C_{72} H_{112} SN_{18} O_{22} has been assigned to them as the result of analysis. Even if approximately correct, this formula only indicates their minimal complexity. Their real structure might be more correctly indicated by any multiple of this. But the composition of proteids has no relation to that of cell-protoplasm except this, that the latter must be more complex, and may be exceedingly more complex. Furthermore, living protoplasm differs fundamentally from dead proteid in one respect, that it must be regarded as in a peculiar state of unstable chemical equilibrium, while the latter is a comparatively stable substance. To this point I shall return presently.

Although we are unable to follow the complex physico-chemical changes which we believe to occur in living cells, we are able in one special instance to obtain indirect evidence that such changes do occur. The association of chemical and electrical changes are very obscurely understood in the inorganic world. But it is well known that such an association is real. We have no means of detecting any electric phenomena in the amœba, but in two highly specialised living tissues, muscle and nerve, of the higher animals we can detect them. If a muscle removed from the body be stimulated by an electric shock (which for present purposes may be regarded as instantaneous) the contraction which follows does not occur instantaneously. There is an appreciable interval, called the latent period, which

intervenes between the stimulus and the contraction. Accurately measured, this interval occupies about 1/100th of a second. During this brief interval the electrical reaction of different parts of the muscle undergoes a change. This change arises at the point of stimulus, and travels as a wave along the whole length of muscle, which, be it remembered, is still in an apparently quiescent condition. Immediately or very soon after this electrical wave has exhausted itself, the muscular contraction begins. The conclusion can hardly be resisted that muscular contraction is preceded as well as accompanied by physico-chemical changes. The rate at which the electrical wave travels has been measured; in the frog it is about three metres (10ft.) per second. In warm-blooded animals it is probably somewhat faster. Its wave-length in the frog is about 3 millimetres (one-eighth of an inch). Surely these results point to the existence of some very complex mechanism. But muscular contraction is a vital act, performed by a living tissue. When we find that similar electrical changes have been observed to accompany the contractions of the leaves of the plant called Venus' Fly-trap, the structure of which is as far removed as possible from muscular tissue, we are, I think, justified in generalising, to the effect that all movements of living matter, including those of the amœba, are due to physico-chemical changes, and depend on an exceedingly complex mechanism.

If we apply our electric shock, not to a muscle, but to a nerve, no obvious result ensues, unless the nerve is attached to a muscle. In that case the muscle contracts, showing that a stimulus has been propagated along the nerve fibres. But whether a muscle be attached to the nerve or not, examination by suitable apparatus will show that this propagation has been accompanied by an electrical change precisely similar to that which occurs in a muscle during the latent period, with the exception that it has a greater wave-length, 18 millimetres (three-quarters of an inch), and a considerably greater velocity. This velocity in the frog is about 28 metres (92 feet) per second, in man about 33 metres (107 feet) per second (compared to the velocity of light, or electricity, or even of sound, this is extremely slow). It can hardly be doubted that these electrical changes in nerve fibres are due to some physico-chemical mechanism, and that their velocity is fixed by this

mechanism. Yet it will hardly be denied that nerve fibres are living tissue, and that the conduction of impulses is a vital act.

Some light seems to be thrown on the unstable chemical equilibrium of living matter by its great susceptibility to the action of a large number of substances, which we call poisons. Many of these are fatal to protoplasm, converting it into dead matter, even when they come into contact with it in infinitesimal dilution. On the physico-chemical theory of living matter this action presents no special difficulty to the understanding. The molecule of strychnine for example can be regarded as a complicated piece of mechanism, which when brought into contact with the still more complex mechanism of the cells of the spinal cord at first excites its molecular or other vibrations and disturbances to greater activity, but carrying its action further it deranges this mechanism altogether, in other words the cells are killed. Another poison will diminish the activity of the cells of the spinal cord from the first, and then kill them. On the physico-chemical theory the conflict is not wholly unintelligible. We can to a certain extent picture to ourselves two mechanisms which interfere with one another. But if we suppose living matter to be inhabited by a metaphysical something, "vitality," how can we imagine the struggle between it and our strychnine molecule? The vitalists may, to borrow an old witticism, conjure up their "metaphysical grenadier," but how will they make him fight?

To all this reasoning I can imagine the objection raised: "You may, perhaps, in a few instances, and to a small extent, discover physico-chemical analogies in the behaviour of living matter. All this is beside the point. No mechanism, however complicated, no possible combination of atoms and molecules can be conceived to explain all the activities of protoplasm." Here, I think, we come upon the "stupid, senseless matter" of our old author. If we arbitrarily conceive of our atoms and molecules as so many hard, round particles, like small shot, only much smaller, such an objection is natural. But this conception is a purely arbitrary one. We cannot at present form any clear idea of the structure of non-living matter which will explain all the phenomena which it presents. For instance, who of us has any clear conception of what takes place in and around a metallic wire when a current of electricity is passed through it? Or, to ask another question, how can we explain the attraction that

every particle of matter throughout the universe has for every other particle, which attraction we know as gravitation? Or, again, why is it that an atom of oxygen will combine with two atoms of hydrogen? We say that the oxygen has an "affinity" for the hydrogen; but this is merely to re-state the fact in a figurative way. On what mechanism does this "affinity" depend? It would be easy to multiply unanswerable questions of this kind. We need to remember that the simplest form of matter is something mysterious, as to the nature of which we know very little.

To cease the argument here would be easy, but it would be to shirk the real difficulty of the problem of life, a difficulty which is no doubt present in your minds. Life in ourselves is indissolubly connected with consciousness. Furthermore, when we come to the bottom of things, it is the nature of our own consciousness which really interests us most. That this consciousness is intimately connected with certain living animal cells, which, with their processes and ramifications, constitute that highly complex organ known as the brain, cannot be disputed. A slight external pressure on this organ, a small clot of blood washed into one of its blood-vessels, cause instantaneous loss of consciousness. A febrile condition, or the presence of a minute proportion of various poisons in the blood profoundly affects our consciousness. A long, lowering illness will sometime reduce a powerful intellect to a condition of utter childishness, to be followed after recovery by a complete return to mental power. These facts are familiar, but what explanation can be given of this association of matter and consciousness?

Let me say at once that science has no explanation to offer. I would go further, and say that, to the best of my belief, no conceivable extension of scientific knowledge would bring us any nearer to a solution. By way of illustration, let me remind you of an instance in which science is able to offer explanations. Few things are more complicated than the infinite variety of sounds produced by the human voice. Yet these can to a large extent be analysed and resolved into their component parts, and the method of their production is also susceptible of scientific investigation. By a simple arrangement of mirrors it is possible for a singer to watch the motions of his own larynx, and to observe the movements of the vibrating vocal cords as the various

notes are sounded. Let us now, by an effort of the imagination suppose that it were possible, by some extension of scientific knowledge, for a man to directly inspect the workings of his own cerebrum. There is nothing inconceivable in such a supposition. Let us imagine further that it were possible for any one of us not only to observe the intricate interweaving of the processes of his own brain cells, but to be cognisant of every molecular tremor which passed down those processes, and to be able even to follow the vibrations of molecules and intricate dance of atoms as one micro-chemical change leads to another in the mysterious laboratory of the protoplasm of the nerve cell. Extend the imagination as far as you please, and then ask yourselves whether the nature of consciousness, of the thoughts that accompany these molecular storms, becomes any clearer. If you will allow me to anticipate your reply, it will be—"Not by the least infinitesimal fraction."

Granted that direct observation and experiment can here avail us nothing, and that the nature of consciousness is inconceivable, it might still be contended that the intimate connection between matter and consciousness is not confined to the solitary instance of the human cerebrum, that it is in some sort common to all living matter. The argument would run somewhat on these lines: Consciousness is known directly only to the individual. By analogy and inference he naturally, indeed inevitably, attributes a similar consciousness to his fellow men. But the lower animals most nearly allied to ourselves also exhibit, in an inferior degree, phenomena which in our own species we should consider to be indicative of the possession of consciousness, and by irresistible analogy we are led to attribute consciousness to them also. This once granted, we have a series of animal forms of gradually decreasing complexity, in no part of which can we draw a line and say, here consciousness ends. A similar line of reasoning may be applied to the development of the individual. By insensible gradations, therefore, we are led to attribute a consciousness of some sort to the amœba. If to the amœba, then also to the white blood-corpuscle, and to every animal or vegetable cell.

It seems to me that if this line of argument be admitted we could not stop here. If we attribute consciousness to every speck of protoplasm, it would be equally easy, or equally difficult, to

attribute it to a drop of water, or a grain of sand, in fact to all matter. What we should mean by the word consciousness used in such connections it is impossible to say. We seem to have come back to something like the old "vitality," but with extensions to inanimate nature, like the "plastic nature" of John Ray; execept that we do not invoke this "plastic nature" to explain physical phenomena. Furthermore, these speculations offer no explanation whatever of the nature of consciousness; they merely extend the problem. And it might with great force be urged that the chain of analogy has been strained to breaking-point. Starting with the human consciousness, the nature of which is quite inconceivable to us, we have imagined the existence of an infinite series of "consciousnesses" equally inconceivable, but certainly different to the first. We have landed ourselves into a region where assertion and denial are both little more than verbal, and therefore, to my mind, alike illegitimate.

It is no help to the understanding of consciousness, as we know it, to attribute it to the combination of the separate "consciousnesses" of some thousand nerve-cells. To speak of the human mind as built up of such particles, as a wall is composed of bricks, or as water is composed of oxygen and hydrogen, is to use materialistic propositions of something which is not matter; to misuse language, not to express mental conceptions, but to conceal their absence. The synthesis is unthinkable. We have no right to forget that all our knowledge of matter depends on sensations represented in consciousness. Our molecules, atoms, ether, vortices, are all only extensions of sensation. They are what, if our inductions are trustworthy, we should see and feel if our sense-organs had their range sufficiently extended. Of what lies behind the sensations we do and can know nothing. The real nature of the external universe is as much beyond the possibility of knowledge as the nature of consciousness itself. There is nothing in science to contradict the familiar lines of the poet:—

"The cloud-capped towers, the gorgeous palaces,
"The solemn temples, the great globe itself,
"Yea, all which it inherit, shall dissolve
"And, like this insubstantial pageant faded,
"Leave not a rack behind. We are such stuff
"As dreams are made of, and our little life
"Is rounded with a sleep."

Leaving the nature of consciousness on one side, as a problem altogether outside the range of science, we may, I think, regard all the other properties of protoplasm as susceptible of physical and chemical explanations. I do not see that this is a conclusion which ought to give offence to anyone. It is the natural and inevitable result of the application of scientific method to the study of living matter. So long as in the non-living world motion was regarded as a property of matter, which needed some immaterial agent to keep it from ceasing at any moment, a science of physics was not possible. In the same way the continuance of the supposition of an arbitrary principle of vitality which made the phenomena of protoplasm something quite different in kind from other chemical and physical changes would have deprived the science of biology of any stable foundation. It is true that with our present knowledge we have scarcely approached the ultimate problems of physiology. Yet all that has been learnt, and it is no small total, has been acquired on the assumption that living matter is subject to ordinary physical and chemical laws. In this sense science is materialistic. I use the word with some misgivings, as there is, I know, a vague popular horror of a something called "Materialism," which is supposed to explain away all mystery from the universe. Why, the very air we breathe is full of mystery! Such fears are irrational, mere chimaeras raised by ignorance and want of thought, and therefore beyond the reach of argument.

To fulfil the promise of my title I ought to add a few words regarding the origin of life. This is a problem to be approached with diffidence. In speaking of the nature of living matter we were treating of something that we can actually see and examine, but its origin is far removed. We must recognise that our present state of knowledge shows a great gap between non-living and living matter, and we know nothing of any development of the former into the latter. We no longer believe, as some used to believe, that frogs arise from a mixture of dust and rain-water, that maggots are bred from decaying flesh, that bacteria arise *de novo* in turnip infusion. At the same time we have very strong reasons for thinking that at a distant epoch this globe was in a molten condition, at a temperature which would render the existence of any living beings impossible. Life must be

concluded to have arisen since this epoch. Sir William Thompson has suggested that living matter in a dormant or spore condition may have been conveyed to the earth by some falling meteorite. If we admit this possibility our difficulty is but pushed further back. There is but one method, that I know of, of meeting the difficulty, and that is by invoking the principle of the "continuity of nature." By an induction, supported by numberless instances, we have come to believe that natural changes come about, not by sudden and violent means, but by the summation of long series of gradual transitions. We can, for instance, trace in thought much of the gradual alteration sustained by our cooling globe as it passed from its primitive molten condition into one suitable for sustaining life. We can trace the gradual transitions between living beings. Under their infinite diversity we can trace a fundamental similarity. The nuclear changes during cell-division, for example, to which I have already alluded, appear to be of a similar character (with some variations in detail) in all animal and vegetable cells, from the most highly organised animals and plants to the lowest. Where we meet with gaps in our classifications, we are accustomed to suppose that these imply the former existence of intermediate forms, which have now become extinct. In this way we may become inclined to believe that the present gap between non-living and living may at one time have been filled by steps of which we are at present ignorant. An attitude of scepticism on this point is reasonable, but if forced to choose between the hypotheses of continuity and discontinuity I should incline to the former.

This brings me to the end of my task, which has expanded much beyond my original intentions. My object has been not to attempt impossible solutions, but merely to state these problems, as they present themselves to my own mind, as clearly as I could. How far I have succeeded in making myself intelligible is for you to judge.