STUDIES OF MATTER AND LIFE.

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THE discoveries of recent science have greatly affected the notions we are able to form concerning the relations of force and matter, and likewise of the connection between physical agencies and manifestations of life. In studies of this description we are struck with the amount of force that lies potentially in extremely minute quantities of matter ready for vigorous action the moment the right stimulus is applied, and by the way in which quickness of motion makes up for smallness of weight. The physical inquirer is not obliged to tarry for the curious and important investigations of the metaphysician; he need not attempt to settle the fundamental questions—what is matter? and what is force?—in the ultimate constitution of either. To the experimentalist, matter is known by what it does; and whether the problem before him relate to mechanics, chemistry, electricity, light, heat, or gravitation, it is with matter in motion and exhibiting force, because in motion, that he has to deal. The same may be said of all the physical processes and manifestations of life, though we seem no nearer than the ancient Greeks were when we try to understand the connection between motions of particles and the phenomena of feeling and thought.

Light, heat, electricity in its various forms, chemical force and nerve force, are not only now classified as "modes of motion," but the motion in each manifestation of these forces appears to be wave motion; and it is probable that gravitation, the correlation of which with other forces is not yet established, may at last be found to be a wave motion also. In wave motion each particle moves, pendulum-wise, backwards and forwards in a small curve, transmitting the motion to the particles before it in more or less rapid succession, the motion becoming weaker as the original impulse is divided amongst more and more particles, until at last it is so enfeebled that it cannot be observed. The common illustration of throwing a stone in a still pond and watching how, as the outward circling wavelets spread, they grow weaker and weaker, and if the space is large enough, at last seem lost in the calm beyond—this affords a good notion to begin with of wave forms and wave force; but suppose, instead of a stone striking the surface of water, a sudden explosion took place of a particle of dynamite at some depth below. Here we should have waves in all directions, ascending, descending, and spreading on every side. Such waves would bear somewhat the relation to the pond-waves that a well-known toy composed of balls within balls would do to a mere section of the whole concern. Wave beyond wave in consecutive series, spreading in all directions from a point, must be conceived as spherical shells one outside the other like the coats of an onion, each expanding and contracting within narrower limits, and sending the wave force and the wave form onwards to an indefinite extent.

The quantities of matter acted upon by these wave forces may be very small, and yet the power exerted very great. Thus "Faraday found the quantity of electricity disengaged by the decomposition of a single grain of water in a voltaic cell to be equal to that liberated in 800,000 discharges of the great Leyden battery of the Royal Institution. This, if concentrated in a single discharge, would be equal to a flash of lightning. He also estimated the quantity of electricity liberated by the chemical action of a single grain of water on four grains of zinc to be equal in quantity to that of a powerful thunderstorm." * Tyndall himself also beautifully illustrates this subject in his remark: "I have seen snow-flakes descending so softly as not to hurt the fragile spangles of which they were composed; yet to produce from aqueous vapour a quantity which a child could carry of that tender material, demands an exertion of energy competent to gather up the shattered blocks of the largest stone avalanche I have ever seen, and pitch them twice the height from which they fell."†

When galvanic electricity is employed to decompose water, the constituent elements, oxygen and hydrogen, are not merely *allowed* to separate, but they are pulled apart with great force, and Gassiot showed that if the water were confined in iron bottles an inch thick, a small battery gave force enough to split them asunder. The directive force which the particles of water obey in the act of freezing, and which leads to its expansion, has similar power; and, as is well known, a very small quantity of water will burst a strong shell or split a great rock.

Although heat sets the molecules of all sorts of matter in

* Tyndall, "Notes on Electricity," p. 15.

† "Heat as a Mode of Motion," 4th edit. p. 147.

motion, not purely wave motion, it comes to us in a wave motion from the sun, conveyed like light by a material so attenuated as almost to reach the supposed condition of spiritual existence. This ether of space, which we can neither see nor feel, approximates to the conception, if such can be formed, of an immaterial substance. It must be so thin, and so light, that an inconceivable quantity would be required to weigh a pound, and yet when in motion the marvellous speed of its oscillations enables it to exert gigantic force. It can act so mildly that we are utterly unconscious that any substance strikes our eye when we see, or have a sensation of, violet light, in consequence of 700 million millions of its minute waves dashing against it in a second. But light can also cause chlorine and hydrogen to rush together with enormous force, and it can instantly tear to pieces chemical compounds held together by forces equivalent to prodigious mechanical powers.

Professor Josiah Cooke reckons that if this ether (of whose existence he is not quite satisfied) were as dense as common air, it would resist pressure on each square inch of seventeen million million pounds, just as air balances one of about 15 lbs. without suffering compression. He also tells us that if we could confine ether in a cylindrical vessel of sufficient strength to bear the pressure, and put upon it "a cubic mile of granite rock, it would only condense the ether to about the same density as that of the atmosphere at the surface of the earth." *

In consequence of its wonderful elasticity, ether can convey light waves about a million times quicker than air can convey sound waves, and some of the pulsations that reach us from the sun, and which lie beyond the violet end of the visible spectrum, must make their extremely short wave oscillations much quicker than the 700 millions of millions of violet light. Should, contrary to probabilities, the theory that space is filled with ether, and that ether has the properties mentioned, be ultimately found untenable, the measures of wave lengths and wave velocities must still refer to something positively existing. Light comes to us from the sun at the rate of about 190† millions of miles in a second, whatever it is; and when physicists say a wave of red light is about $\frac{1}{39,000}$ of an inch long, and a violet one about $\frac{1}{57,500}$ long, no doubter of the existence of ether, like Professor Cooke, hesitates to assume that they are quantities of

* "The New Chemistry," p. 23.

† The exact distance can never be known, as some residual error is unavoidable. When all the Transit of Venus calculations are finished and compared with the experimental methods adopted in Paris, the average result will probably be not far from 190 millions.

something. The probabilities are, however, enormously in favour of the theory that ascribes certain properties to ether, and that light and heat consist in its undulations. All known facts coincide absolutely with this theory, and it has been the means of leading physicists and mathematicians to fresh discoveries.

What is this ether, that it possesses properties so extraordinary, and that, to speak in common language, a mere nothing of it in point of quantity can be the source or the vehicle of enormous powers? Professor Tyndall says it must be a material substance, but perhaps not a form of ordinary matter. If it is composed like common matter, its particles or molecules do not touch; and in that case it will be difficult to avoid the belief that there is a still more subtle kind of matter filling up the interspaces. If it be matter not divided into atoms or molecules, but continuous, we may expect to find that it will exhibit many properties and peculiarities not yet discovered, differentiating it from matter in ordinary forms.

Faraday followed Newton in feeling an invincible objection to the notion that matter could act through empty spaces, and, as we find in his life by Dr. Bence Jones, he was fond of quoting the following passage from a letter of Newton to Bentley:—"That gravity should be innate, inherent, and essential to matter, so that one body may act upon another at a distance through a *vacuum*, and without the mediation of anything else, by and through which this action and force may be conveyed from one to another is to me so great an absurdity, that I believe no man who has, in philosophical matters, a competent faculty of thinking, can ever fall into it. Gravity must be caused by an agent acting constantly according to certain laws; but whether this agent be material or immaterial, I have left to the consideration of my readers."

Faraday's own views on this subject were never very clear to other people. He recognised "lines of force," and spoke of "atoms" as centres of force, and not as so many little bodies surrounded by forces. The force was the atom extending indefinitely in all directions. According to these conceptions, "water is not two particles of oxygen (and hydrogen) side by side, but two spheres of power mutually penetrated, the centres even coinciding."* In the same place he said, "The force or forces constitute matter; there is no space between the particles distinct from the particles of matter."

We need not for present purposes pursue these speculations further. The wave forces mentioned communicate immense velocities to the molecules of matter, and these velocities are, in

* "Life of Faraday," vol. ii. p. 178.

fact, their powers. A gas—or common air, which is a mixture of gases—resists pressure and exerts pressure, because its particles are in vigorous, rapid, and ceaseless motion. Substances that are translucent, or transcalorescent, are so composed that ether waves go through them as water goes through a sieve. Bodies that do not allow light or heat to pass in this way, have their molecules set in motion by the impulse of the ether waves, and thus new forms of force are generated.

Tyndall's beautiful experiments on the powers of various substances to absorb heat and stop its radiation offer most instructive instances of the power exerted by small quantities of matter. Taking the absorption of one atmosphere of common air to be unity (1), it was found that this power was augmented thirty-fold when the same quantity of air was permeated by a little vapour of patchouli; lavender vapour raised it to 60 times, camomiles to 87, cassia to 109, and aniseed to 372. Upon these results Tyndall remarks "that the number of atoms in the tube (experimented with) must be regarded as almost infinite in comparison with those of the odours. . . . it would be idle to speculate on the quantities of matter implicated in these results. Probably they would have to be multiplied by millions to bring them up to the pressure of ordinary air. Thus—

> The sweet South
> That breathes upon a bank of violets,
> Stealing and giving odour,

owes its sweetness to an agent which, though almost infinitely attenuated, may be more potent as an intercepter of terrestrial radiation than the entire atmosphere from bank to sky." *

Wherever we find power exhibited, matter is in motion, and if the quantity of matter is infinitely small, and yet the power great, it is because the motion is infinitely quick. The waves of chemical force streaming from the sun are very short, and the quantity of matter acting in each oscillation, and tapping at the molecules on which it acts is inconceivably minute, but the taps are as inconceivably numerous and rapid. They are also rhythmical, and we know how the stone walls of a large building may be set in vibrating motion when an organ tone of the right pitch impels air waves to go on tap, tap, tapping till the whole fabric shakes.

We learn from these and similar facts that the wave forces can give great powers to infinitesimally small portions of matter, and that, as we are not able to place any limit that we can comprehend to the possible velocities of atoms and molecules,

* Tyndall, "Heat as a Mode of Motion."

so we are not able to assign any limit to the minuteness which would be incompatible with the exercise of effective force.

Becquerel has shown that when a membrane is moistened on each side by a different liquid, an electric wave force is set up, able to effect chemical decomposition. Thus the minutest part of the minutest gland, or of the smallest organism that is capable of assimilating external matter, is enabled to change the chemical condition, and pull asunder molecules or atoms that would resist the mechanical force of a steam-engine or a hydraulic press.

Unfortunately, we have no chance of seeing the ultimate atoms or molecules of matter. Chemists use the term molecule to denote the smallest quantity of any substance capable of existing alone; but the definition is not quite satisfactory, because they have reason to believe there are many compound molecules that only exist in parts of more complicated combinations. Could we, by help of any apparatus, see ultimate molecules, the sight would be an astounding one; for an extremely minute portion of any substance, however solid and quiet it might appear to ordinary vision, would be exhibited to us as composed of infinitely more particles than all the stars we can perceive in a clear sky, and all in motions as harmonious as those of the celestial bodies. When either compositions or decompositions are going on we should see hosts, by the myriad, rushing together, or springing apart, as the case might be. Eternal motion is the condition of life, whether of the smallest unit or of the entire universe. Nature, as Humboldt said, is ever arranging herself in new forms, and absolute stillness would be cessation of being.

The limits of visibility was one of the topics brought before the Royal Microscopical Society in February by the President, Mr. H. C. Sorby, in a remarkably able, and admirable, Annual Address.* Omitting the estimation of unavoidable errors in the construction of microscopical apparatus, and referring to researches by Pigott, Helmholtz, and Woodward, it seems that it is possible to distinguish the most favourable objects—alternate dark and bright lines such as in Nobert's test-plates—when they are as near each other as to be only $\frac{1}{112,000}$ of an inch apart, provided that several circumstances, which need not now be explained, are favourable. Minute spherules of about $\frac{1}{80,000}$ to $\frac{1}{100,000}$ of an inch may also be seen if their refractive power differs sufficiently from the fluid, or other medium in which they are immersed. It may, however, be affirmed that few objects less than $\frac{1}{80,000}$ of an inch in diameter can be seen;

* See "Monthly Microscopical Journal," for March 1876.

and of that size those only that are favourably placed. Mr. Sorby proceeded to inquire what sort of relation this power of microscopically assisted vision bears to the probable size of molecules of matter. He cited the results obtained by Stoney, Thompson, and Clerk-Maxwell, in attempts to calculate from different data the number of ultimate atoms in a given volume of any permanent and perfect gas at 0° C. and a pressure of one atmosphere. Thompson assigns as the greatest possible limit 98,320,000,000,000 in one-thousandth of an inch cube, which is $\frac{1}{1,000,000,000}$ of one cubic inch. Clerk-Maxwell, estimating the true number indicated by the phenomena of the interdiffusion of gases, made it 311,000,000; and Stoney, from his point of view, 1,901,000,000,000. The mean of these numbers is 50,260,000,000,000. In a letter received by the writer from Mr. Sorby, since the publication of his address in the "Monthly Microscopical Journal" for March, he assigns double weight to Clerk-Maxwell's calculations, for reasons that we need not stop to explain, and considers the number of atoms in a cubic $\frac{1}{1,000}$ of an inch of gas to be about 6,000,000,000,000, and that in the same space of liquid water the number of water atoms would be 3,700,000,000,000,000.

Water is essential to organic life: if an organism is thoroughly deprived of it, death ensues, though some creatures may be dried so as not to exhibit the least appearance of moisture, then pass into a dormant state, and become active again when more water and an appropriate temperature are supplied. The common rotifer and the *Anguillula tritici* have this property, and it is exhibited to some extent by that curious vertebrate, the Mud Fish, which survives an amount of drying that would be fatal to most animals as highly organised, though the baked mud in which it passes the hot dry season appears to prevent the desiccation from being carried too far for continuance of quiescent life.

If we say water is so valuable to organic creatures on account of its dissolving so many substances they need to be supplied with in a fluid state, we may be asked why water has such power, and it seems probable that they depend upon the immense number of its molecules, as well as upon their mode of aggregation. Each atom or molecule in motion tends to set adjacent atoms or molecules in similar motion; and a great number of small impulses, rhythmically repeated, easily set considerable masses of such bodies in fresh motions, differing more or less from those which belong to their own constitution. A child with a little hammer, tapping at a great log of wood, will in time set all the particles vibrating, and though each particle may move only through a small fraction of an inch, when the whole log vibrates, the total quantity of motion is enormous, because the small motion of each particle is multiplied by millions and millions—that is, by all the particles the log contains.

Among the complex substances which chemists are acquainted with, no one could be named more important to organic life than albumen, which we all know in the condition of white of egg; and its remarkable powers of utility in the growth and development of plants and animals depends upon its extremely complicated structure. It contains a multitude of atoms of carbon, hydrogen, nitrogen, oxygen, and sulphur. It is usually found slightly alkaline; and some chemists, like Gerhardt, consider white of egg as a definite compound of an albumen acid with sodic hydrate, and believe other sorts of albumen have an analagous composition. Omitting, however, the alkali, Mr. Sorby takes as a probable composition of albumen C_{72}, H_{112}, N_{18}, SO_{22}; the letters representing the substance above named, and the figures the number of atoms which they contribute to the structure. With this view of albumen he finds that in a cubic $\frac{1}{1,000}$th of inch of horn there are about 71,000,000,000,000 molecules of albumen. A molecule of this substance, though much larger than one of water, is far removed by its minuteness from any possibility of human vision; and as Mr. Sorby explains in his paper, light is too coarse a medium to enable them to be seen, even if we could add sufficiently to the powers of our microscopes.

When so many atoms of various substances are built up together to form a new substance, there is reason to believe that they are arranged in groups, each group having a definite constitution, and being a distinct entity, at the same time that it has an appointed place and a definite relation to the whole. Each group may be regarded as a system in which the atoms composing it are in ceaseless motion, exerting force upon their neighbours, and keeping within certain bounds, just as the planets do that circle round the sun. Each group acts as a whole upon other groups, and thus there are motions of groups as well as motions of atoms, subject to the same conditions of keeping within bounds.

Now, it is evident that the wave forces of which we have spoken have great opportunities of effecting changes in such complex structures. One form or mode of wave motion may strike with its myriad pulsations at a group of atoms, another may strike at certain atoms in the group, and by such means some atoms or groups may be thrown out of their courses, and then the rest may form a new pattern, or, if suitable atoms of another sort are at hand, may take them in to what may be called their social system, and modify it accordingly.

The phenomena of the nourishment and growth of plants and animals depend upon actions of this sort brought about by the wave motions of heat, light, electricity, and so forth. Reproduction is, as Claude Bernard explains, intimately connected with nutrition. A particle capable of germination or growth receives an impulse from a particle of an opposite sex, that is, of one in a different molecular condition, and development is stimulated and caused to take place so as to repeat with minor variations the parent forms. The well-known facts of inheritance show that, although the female germ and the stimulating male element—the ovule and pollen grain of a plant, for example—are very minute, they are big enough to contain, in some form, or way, forces which cause all fresh matter that is assimilated to arrange itself so as to reproduce a series of parts repeating for generations with marvellous fidelity the parental types.

The same thing is noticed with animals in which the same species or the same race is reproduced from one generation to another with remarkable accuracy, extending to minute and often unexpected detail. For information on this subject the reader must be referred to the works of Darwin and other writers. What we have now to consider is whether the germ particles and sperm particles can possibly be conceived to contain enough molecules built up in definite patterns, so that, as Darwin in his theory of Pangenesis supposes, they can supply *parents* enough to enable us to regard each portion of a complex organism, plant or animal, as composed of their lineal descendants. "If," says Darwin, "one of the simplest Protozoa be formed, as appears under the microscope, of a small mass of homogeneous gelatinous matter, a minute atom thrown off from any part, and nourished under favourable circumstances, would naturally reproduce the whole; but if the upper and lower surfaces were to differ in texture from the central portion, then all three parts would have to throw off atoms, or gemmules, which, when aggregated by mutual affinity, would form either buds or the sexual elements. Precisely the same view may be extended to one of the higher animals, although in this case many thousands of gemmules must be thrown off from the various parts of the body." *

To compose a plant under this theory, the seed must contain gemmules which attract suitable matter to form root-fibres; other gemmules that in like way cause cells to grow and aggregate to make a fibrous stem, others to supply the sap, others to cause the growth and development of the leaves, flowers, and finally to supply the ovule and the pollen with a complete set of gemmules to carry on the process from one generation to

* "Animals and Plants under Domestication," vol. ii. chap. xxvii.

another; and as certain peculiarities of distant ancestors sometimes suddenly appear in their descendants, the ancestral gemmules must be sufficient in number to last for many generations, or they must act as parent cells and produce other cells.

Mr. Sorby applied himself to this problem, and sought to find what quantity of molecules existed in the quantities of matter that acts as germs and sperms. Supposing each gemmule contained a million molecules of the albuminous compound that is the physical basis of life, Mr. Sorby finds that "one thousand such gemmules massed together would form a sphere just distinctly visible with our highest and best magnifying powers." "If," he adds, "the gemmules were of much greater or much less magnitude, it appears to me very probable that Darwin's theory would break down from two opposite causes, or would need very considerable modification, because, if much greater, their number would be too few to transmit sufficiently varied characters, and if much less, they would scarcely contain enough of the ultimate atoms of matter to have a sufficiently varied individual character to transmit, since, of the assumed million ultimate molecules, only eighteen thousand would be of a true protoplasmic nature, the rest being water in molecular combination." Taking the $\frac{1}{6,000}$ of an inch as the mean diameter of a single mammalian spermatozoon, Mr. Sorby calculates it might contain 2½ millions of such gemmules, and, "if one of them were lost, destroyed, or fully developed at the rate of one in each second, this number would be exhausted in about one month; but since a number of spermatozoa appears to be necessary to produce perfect fertilization, it is quite easy to understand that the number of gemmules introduced into the ovum may be so great that the influence of the male parent may be very marked, even after having been, as regards particular characters, apparently dormant for many years."

Again, taking the germinal vesicle of the mammalian ovum as $\frac{1}{1,000}$ of an inch in diameter, "it might contain 500 millions of gemmules," and "if these were lost or fully developed at the rate of one in each second, this number would not be exhausted until after a period of seventeen years." If the whole ovum, about $\frac{1}{150}$ in diameter, were all gemmules, the number would be sufficient to last, at this rate of one per second, for 5,600 years! This is, however, not probable; but Mr. Sorby's remarks have completely removed all doubts as to its physical possibility from the Darwinian theory, and they prompt us to a wonderful conception of the powers residing in minute quantities of matter.

The student of nature stands surrounded on all sides by infinities. He can imagine no bounds to space or time; see no traces of a beginning, discover no symptoms of an end. There is an eternal flow and motion throughout the universe, a ceaseless change from power in the potential to power in the active form, and back again from the active to the potential—nothing added, nothing stationary, and nothing lost. Such is the aspect of the physical world, but what of the world of thought and will? Here we pause before a door of difficulty, and have no key to open. Let Du Bois-Reymond point it out:—

"Suppose we had arrived at an astronomical knowledge of the human brain, or even of an analogous organ in an inferior creature whose intellectual activity was limited to the sensations of well-being and discomfort. So far as regards the material phenomena of the brain our comprehension would be perfect, and our intellectual need to seek for causes would be satisfied in the same degree as it would be in regard to contraction and secretion, if we possessed astronomical knowledge of a muscle and a gland. The involuntary acts which emanate from nervous centres, without being necessarily connected with sensations, such as reflex and associated movements, respiration, tonicity, and lastly, the nutrition of the brain and spinal marrow, would be entirely known to us. It would be the same with the material changes that always coincide with intellectual phenomena, and which probably are conditions indispensable to them. And surely it would be a great triumph of science if we could affirm that such intellectual phenomenon was accompanied with certain movements of atoms in certain ganglionic cells and certain nerve tubes. What could be more interesting than to direct our intellectual vision inwards, and see the cerebral mechanism in motion corresponding with an operation of arithmetic, as we can watch that of a calculating machine; or to perceive what rhythmical movement of the atoms of carbon, hydrogen, nitrogen, oxygen, phosphorus, &c., corresponds with the pleasure we feel from musical harmony; what eddying currents of the like atoms attend the acme of delight, and what molecular tempests accompany the horrible suffering that ensues from irritation of the trigerminal nerve . . . ; but as regards the mental phenomena themselves, it is easy to see that, after acquiring an astronomical knowledge of the brain, they would remain just as incomprehensible as they are now. In spite of such knowledge, we should be arrested by those phenomena as things that are incommensurable. The most intimate knowledge of the brain to which we can aspire would only reveal to us matter in movement; but no arrangement, and no movement of material particles, can form a bridge to conduct us into the domain of intelligence. Motion can produce nothing but motion, or enter into the condition of potential energy. Potential energy in its turn can produce nothing besides motion, the maintenance of an equilibrium, the exertion of pressure on traction. The total quantity of energy remains always the same. In the material world nothing can go beyond this law, and nothing can do less than it requires. The mechanical effect is precisely equal to the mechanical cause that exhausts itself in producing it. Thus the intellectual phenomena which flow from the brain beside of, but in addition to, the material changes that occur in it, are, to our intelligence, wanting in a sufficient reason. These phenomena remain outside the physical law of causality, and that is sufficient to render them incomprehensible." *

* Du Bois-Reymond, "Revue Scientifique," Oct. 10, 1874, p. 342.