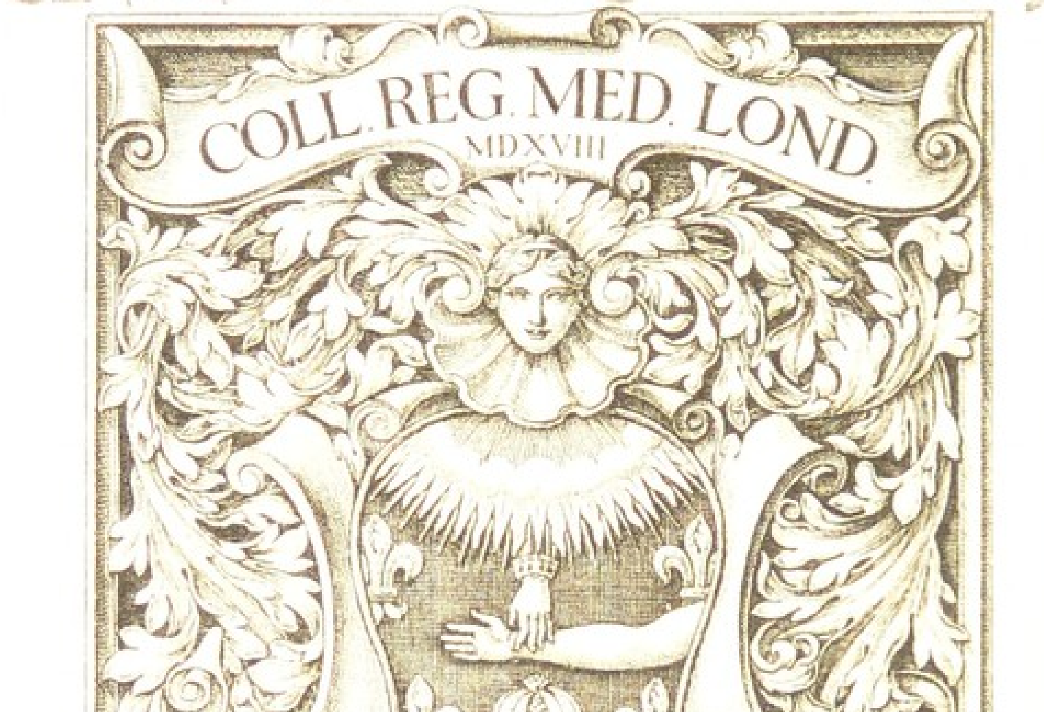
THE DYNAMICS OF LIFE

GOWERS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THE

DYNAMICS OF LIFE

AN ADDRESS

Delivered before the Medical Society of Manchester
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BY

W. R. GOWERS, M.D., F.R.S.

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PREFACE.

THE following Address, delivered in a condensed form, is reprinted from the pages of the *Lancet*, with minor alterations and additions. The only other word of preface needed is a statement of the fact mentioned in the early part of the Address, that no novelty is assumed for the conceptions here presented. Their form seemed, to those to whom the Address was given, to possess some freshness, and thus they may be of use to others. The fundamental conception may be open to question, but, even so, it may promote a clearer perception of the truth.

W. R. GOWERS.

LONDON; *November*, 1894.

THE DYNAMICS OF LIFE.

Gentlemen,—At Manchester—second in England only to the metropolis as a medical centre and source of knowledge—it is, I conceive, superfluous for me to apologise for taking a theoretical subject for such an address as that which I have the honour to give to-night. I need hardly remind you that between what we term "theory" and "fact" the transition is gradual; that much of that which we regard as fact is only fact to our thought. Observation alone is certain—observation pure and simple. The interpretation of observation introduces uncertainty in proportion to the extent to which inference is involved; to this we are often blind—blind sometimes to its existence, generally to its amount. But there is a region in which we must recognise hypothesis as absolute. It is the region below the surface whence no reflected light can pass, but whence all observed phenomena proceed. Here we must either accept indirect perception, or we must be content with no perception of the causes of that which we observe.

Where we can have no certainty we must be content with probability, or relinquish all attempts to know. We cannot limit knowledge to the certainty of actual observation. The help that even pure hypothesis can give is too great to be despised. If it enables us better to discern that which is in sight, to discover more of its details, to see its relations more clearly, to grasp its character more firmly, the result is surely worth an effort. These considerations prevent me hesitating to ask your attention this evening to some considerations which are hypothetical. I fear I must add that I shall be compelled to ask for your close attention. I regret that it should be so—I should prefer to discuss some simple practical subject. But there is sometimes a compulsion in the selection of a subject against which it is not wise to strive. That which I now submit to your consideration has, for some time, pressed on my thought too persistently to permit me to use this opportunity in any other way.

In thus availing myself of the occasion, however, I shall be a trespasser. I shall have to pass into regions where I have no strict right to be, but into which I go because from them come the streams that water our own province. I wish to tell you how they appear to a stranger and sojourner in the land, and to tell you not in the language of the country, but in our own simple tongue. But the account may be useful because it will, I hope, make us think more of that which underlies many of our practical problems. Disease belongs to life as health does. We pass from one to the other in knowledge as in experience. But in our thoughts of abnormal action we are often thrown back upon our conception of normal action; we are thus made to endeavour, more earnestly, to perceive that which underlies both, because in the one, we have more need than in the other. Hence the general subject—the process by which energy is manifested in the animal body—we may usefully connect with the most obtrusive manifestation of energy we encounter, either in health or disease—an epileptic fit. But I ask you to do this especially because the attempt will bring before us, in an effective way, the limitation of our efforts in the presence of life, and also the way in which disease, as such, in its essential nature, is distinct from the process of its manifestation. Many phenomena of disease take us directly to the mysterious relations of energy to life which underlie all we observe, and are in their nature beyond our direct scrutiny. They raise at once the problem of their nature. We cannot contemplate such disorders as epilepsy without being compelled to wonder what is their actual nature, and how their manifestations are produced. And we cannot do so apart from the consideration of similar processes in health. Their reflected light makes some features of normal life more conspicuously important and compels their closer study. They often make us ask more questions with greater persistence. Disease puts before us the processes of life in more startling aspect, and therefore often with more effect, than do the normal phenomena with which we are so familiar that it needs more effort to wonder and to ask. The features of an epileptic fit make us ask, more than even the swift motion of the race-horse, Whence and how is the intense manifestation of energy which by its violence makes the result so impressive and so alarming? But the wonder makes us ask a like question regarding analogous manifestations of energy in health equally marvellous in the humming-bird and the elephant. Whence and how is motion produced by the muscles, and whence is the mysterious nerve force derived that excites the muscles to contraction? What is the source of the manifested energy? That is the first question.

The answer may be familiar to you in its form, and yet it gives us only the first step on which to place our feet. As far as can be discerned all energy released is the result of chemical combination. Oxygen is everywhere brought to the complex compounds of the tissues. Simpler compounds are formed by its union with them; even, and indeed especially, carbonic acid, which may be regarded as one of the simplest combinations, is released in conspicuous amount in muscular contraction, just as it is by a like process in the combustion of coal. The energy of the latter is released as light and heat,—that is, minute motion,—in the former as obvious motion. This fact, that the source of the energy that is manifested in the animal body and in the processes of human life—from a sigh to a convulsion—is "latent chemical energy," makes the first question to be considered the actual nature of this.

Latent Chemical Energy.

Whence comes the force released by chemical union? We speak of it as "latent chemical energy," "chemical tension," and sometimes as "potential energy." For reasons to be mentioned later, it is here spoken of as "latent" and not as "potential." What conception can we form of this force? It is of fundamental importance because, first, it is as such that all energy is introduced into the body—in food and in air; secondly, it is from this that it is manifested by vital action. In this form it is received and stored, and from this it is produced. I should perhaps ask,—not "what conception can be formed," but "what conception is held" regarding it. I have, indeed, already asked this, but I have had somewhat peculiar difficulty in obtaining a perception. Into this I need not go, but I may say that the answers constitute one of those mental equations the result of which is zero. I have searched in books without success for any definite statement of the conception I desire to put before you; I cannot doubt, however, that it has been expressed, because many writers have so implied it that it is not easy to understand how they can have escaped its definite statement. I know that it is held by some distinguished biologists; but, on the other hand, I have been told by one of the most celebrated chemists that it is inconceivable. Hence I am left with at least the advantage of compulsory self-reliance. I am compelled to start from that which appears to me the only conception that is possible, and to state it as it appears to me; but I would disclaim once for all any suggestion of actual novelty. Moreover I should also explain that I purposely avoid the use of the special precise terms which those familiar with the subject will miss, and the absence of which they may lament. But, at the outskirts of physical science, it is wiser for us, outsiders, to use only the words we know, than those to which we must attach a precise meaning that we should have to learn. If I used them at all, you would be alarmed at the number and apparent complexity of the terms I should have to introduce. I avoid them, therefore, because I think they would hinder rather than assist us.

No energy can be manifested which does not exist before in some other form. The energy that is made manifest, alike in the combustion of coal or in muscular action, must exist before as a definite form of energy—inconspicuous it may be, but not less real. The only form which our present knowledge enables us to conceive is inter-atomic motion, oscillatory motion of the atoms of the substances that combine. It may be, indeed, also between the molecules in which the atoms are grouped. Since we cannot, I think, conceive it except as between atoms and between molecules, it seems convenient to term it simply "minute" motion. The motion of an aggregation of molecules as a whole —that is, the motion of a mass—we may term "massive." In spite of the added conception of size which has been connected with the word "massive," it seems more convenient than that which has been used in the same sense, "molar."

I fear I must ask you to approach the subject by degrees. Slow steps may make our footing less insecure on ground that is unfamiliar to us. Moreover you must pardon me if, partly to help myself by increased consciousness of security, I illustrate that which to many of you does not need this aid. It may seem difficult to conceive that the light and heat which are liberated when a piece of coal burns exist before combustion—exist as motion in the oxygen and coal. The heat and light are forms of energy, and can be changed into any other form by adequate contrivance. They can be changed into motion not only massive in the restricted sense, but conspicuously massive in the common sense. To many the conception is familiar that minute motion is universal. To others it may be unfamiliar, in spite of the attractive writings of Tyndall, Ball, and others. Yet, to those accustomed to the idea, it may be difficult to conceive that latent chemical energy exists as motion in every substance capable of chemical combination. That this energy, sufficient to move a railway train, should exist before combustion as minute motion among the atoms of carbon and the atoms of oxygen is not easy to conceive. It may seem that it cannot be conceived. Of course I use the word "conception" in its widest sense, and not in that of forming in the mind an exact picture of the process. Yet we know facts which show how great an amount of energy may exist as atomic motion, and yet may be absolutely imperceptible to us.

Let me ask you to conceive an instance sufficiently simple. Supposing there is a mass of iron, a foot square, in this room at its present temperature. The mass would seem absolutely still, in mass and molecules. No energy can be discerned in it. Expose it for a short time to a temperature 100° higher, and bring it into the room again. Its aspect is the same, but we can find abundant evidence of energy in it. A touch reveals the change. Its atoms are in vigorous and obvious motion; from it the wave motion of heat passes off in all directions, and if properly secured this could be changed into other conspicuous forms of energy. We should find, moreover, that there is a slight increase in size in the mass, and that this holds good of the smallest particle we can measure. This would compel the belief that the increased minute motion of the mass is accompanied by an increased distance between the atoms, with, therefore, a greater range of atomic movement. Presently, having lost the increased motion it had acquired, it would seem as inert as before. But conceive the piece of iron moved from this room, the temperature of which it shares, into surroundings 100° lower in temperature. At once we should have all the manifestations of energy and atomic motion which we have just conceived as presented in this room after exposure to a temperature 100° higher. We are thus compelled to believe that in every substance about us there is the minute motion of heat corresponding to its temperature. However imperceptible, it is not less energetic. Other forms of motion in the iron there may also be, but the facts just mentioned show that we must not think that vast energy may not exist as minute motion where none is conspicuous, or is even perceptible by our unaided senses. Nor can we venture to fix any narrow limit to the energy that may thus exist, and may co-exist in different forms. We know, at least as far as we can know anything of the subject, that not only may a piece of iron, such as I have asked you to picture in your mind, be the seat of the atomic motion we recognise as heat; it may, perhaps must, be the seat of the atomic motion of electricity; it can be made the seat of the atomic motion of sound. These forms of motion—for we believe that all three are forms of atomic motion—may co-exist among the same atoms—distinct, precise. If you think of a piece of glass instead of iron, the co-existence becomes still more complex; and if you think of the glass as tinted, the necessary definiteness of the co-existence makes the effort to grasp the phenomena distinctly useful. We may note in passing that if this conception be true it brings this form of latent energy into harmony with all our conceptions of other forms—we think of each, from light to electricity and sound, as some form of motion, massive or minute. Indeed, we may say that it would be accurate to discard the old term, the "transformation of energy," and substitute that of the "transition of motion." Is it not curious, by the way, to note that, long ago, the search after perpetual motion occupied ingenious minds, but, was at last relinquished, and that now the object appears before us unsought? In the energy of the universe we see nothing but perpetual motion.

I ask you to allow me to proceed on the assumption that I have indicated. We assume that latent chemical energy is a form of minute motion. One advantage of the term "minute" is that it includes both inter-atomic and inter-molecular motion, and there is reason to believe that it is both. We know that it must be atomic because, *e. g.* in combustion, atoms of carbon pass off, and, recombining in a simpler form as carbonic acid, release the latent energy. The carbonic acid must be the result of the escape of atoms; but there are also phenomena in organic substances which teach us that molecules may pass off. Consider the well-known fact that a particle of musk may give off, in a still room, molecules sufficient in number to act on the olfactory nerves of any person entering the room, and yet the amount may be so minute that, after years, no loss of weight can be found. That which thus acts on the nerve in a special, constant way must be molecules of definite composition, and can scarcely be more than molecules. This shows that undivided molecules may pass away. But does not even this simple instance show much more than that? Why do they pass away? They pass off into still air; they move; what is the source of their motion? The only conceivable explanation is that their dissemination is due to a propulsive energy, and that this must be an inter-molecular force, which we can best conceive as motion—motion in such excess of the inter-molecular attraction as to expel from the musk the molecules that are upon the surface. It may be urged that there may be repulsion and expulsion of the molecules without inter-molecular motion; but in all the cases in which we can discern the character of the energy that causes molecular release, such as the effect of heat, in every state of matter, we find evidence of motion. The relation of heat to the emanation of odours, moreover, strengthens the belief that inter-molecular motion is the form in which the energy exists that expels the molecules from the mass and propels them through the air.

This brings before us a second well-known fact, which we should keep clearly before our minds. Wherever there is motion as the constituent of energy there is also attraction, limiting and determining the motion. We can only conceive wave motion—such wave motion, for instance, as that which we believe most forms of energy consist of—as motion limited by attraction. I need not trouble you with instances. It is important to note that it must be the attraction between the atoms that is the chief influence in determining the range of their movement, its cessation, and its renewal. In considering these problems others present themselves that are not strictly relevant, and yet should not be passed by unmentioned, since they aid the conception. The wave motion, ever lessening or being renewed, is like that of a pendulum, or like that of a bullet shot upwards. The movement of the bullet gradually lessens, for a moment is *nil*, and then is renewed in the descent. As it lessens, it becomes potential under the influence of gravitation;

as it increases, it ceases to be potential. So also with wave motion. The motion is for ever becoming or ceasing to be potential under the influence of attraction. In the bullet shot upwards, at the moment of stillness which intervenes between its ascent and descent, its motion is wholly potential. It might be so maintained by an obstruction to its descent, as in all bodies around us that are restrained from falling. In all there is potential motion, which must have existed to raise them to their place. I allude to this because that is my reason for using the term "latent energy," rather than that which is current in this connection—"potential energy." Great as is the weight of the authority with which the latter term, "potential energy," is associated, it is only accurate when "energy" is used in the sense of manifested energy, or, as it is often termed, "kinetic energy." The word "potential" now means that which has the power of producing, and by transfer to the object, that which *may be*. That which only "may be" is not. We cannot speak of energy as non-existent, as merely that which may be. Therefore I think it is better not to speak of energy, without qualification, as "potential." It is not quite the same thing to speak of potential motion; but it is needless to pursue the point, which is beyond my subject.

All are familiar with that which is called "chemical affinity"—the mysterious influence which causes elements to unite closely. We might compare it with gravitation, but that it is, or seems to be, special, not general. Gravitation is a force of attraction related only to mass; chemical affinity is a force of attraction related to some special feature of the different elements. It connects atoms closely, and, as it seems, with little room for movement. When there is much movement—that is, much latent chemical energy—the atoms are associated and kept together by some force of attraction, of which we know nothing, save that it seems to be opposed to the influence of chemical affinity. This attraction seems indistinguishable from that which, when atoms are combined into masses, we call "gravitation," which has furnished us with the illustration of the pendulum and the bullet.* Of course there is much which we cannot in any way understand, whatever hypothesis may be formed of these conditions. I should perhaps say that the little we seem to understand only shows us how imperfect is that limited comprehension. But, as I have hinted, we should not let the difficulties that are seen, stand in the way of our attempt. If we are wrong, we may be a step towards the right path; if we hastily reject that of which much is at first sight unintelligible, we are thrown on this alternative—we must be content to make no attempt to perceive the nature of the facts. Thus latent chemical energy is,

* My excuse for such mention of familiar facts is not only the fact that the address was delivered to those who are physicists only in so far as they are physicians, but also a recent statement by Mr. Huxley. He said that he had had reason to regret that his consciousness of the learned character of his audience at the Romanes Lecture he gave at Oxford, made him depart from the rule he had often enjoined on others —viz. never to assume that the hearers have the detailed knowledge necessary to clearly understand the statements made.

we conceive, minute motion. It is restrained, and therefore maintained in its form, by an attraction which binds the atoms together in molecules—perhaps first in sub-molecules, the minor groups that are called "radicals," which are more closely connected together than the molecules, but less closely than the atoms that compose them. The minute motion thus restrained is greatest in the simple elements, as pure carbon and oxygen; great in complex compounds, apparently in proportion to their complexity; and least in the simpler and close compounds, such as carbonic acid. When chemical union takes place under the influence of chemical affinity, closer compounds are formed, with less minute motion in their molecules, and the energy which is released in the process of union is the difference in the amount of this minute motion in the substances before and after the closer union. The readiness with which the union takes place seems to depend upon the relation borne by the amount of minute motion to the attraction which limits it; the motion tends to repel the atoms from each other, and to drive off those at the surface and permit them to join adjacent atoms but for the force that holds them together.

In most substances the attraction that unites is in excess of the motion that tends to separate, or the substance could not exist as such.* It is necessary

* I have avoided special reference to the states of matter, which merely involve a difference in relative degree, but would compel considerations that could not but add to the complexity of the statements, already sufficient.

for the motion to be increased in order to set the atoms free, so that they can yield to their affinity with adjacent atoms and combine with them. If we take simple elements (in which the atoms are grouped in molecules) the amount of motion which has to be added is great in the case of some, little in the case of others. It varies likewise in the case of the complex compounds of these elements. In proportion to the amount needed to overcome the attraction, we have what is commonly called stability—that is, a stable substance needs much motion to be added. Conversely, we have instability when little additional motion is needed. In the case of coal (which, although not pure carbon, we may regard as such for our purpose), the attraction so far preponderates over the amount of minute motion that the motion has to be considerably increased in order to release the atoms. We increase, at one part of the coal, the motion of latent energy by adding that of heat, and so set these atoms free, and they instantly form compounds with less intrinsic motion, and most of that before existing among them is released as light and heat. That is what is done when we light a fire. In the case of another element, however, the minute motion may be already in such excess of the attraction that the atoms at once fly off and combine with adjacent oxygen, without any need for an increase in the atomic motion. Yellow phosphorus cannot be in contact with air without "burning"—that is, without the atoms at the surface joining those of oxygen to form a close compound with little minute motion, the previous atomic motion being released as light. Is it not significant that, in the case of coal, simple heat, which we know to be motion, has the effect of releasing the atoms? Does not this confirm the hypothesis that the energy which it increases is also motion? We shall meet with so many other facts which present the same harmony with the theory, that I can hardly venture in each case to draw your attention to it. But I would point out the significance of the well-known fact that when phosphorus undergoes the change from yellow into the allotropic red form, and with the change loses its instability (that is, according to this theory, loses much of its minute inter-atomic motion, so that the attraction becomes preponderant), this change is accompanied by the liberation of heat —that is, of minute motion. Time does not permit me to trace other instructive instances of the addition of motion as the cause of the liberation of the atoms and energy, and instances are so familiar, abounding on every side, that it would be needless for me to do this. Yet the fact is of fundamental importance for our ultimate conceptions. I must also ask you to note another equally important and equally familiar fact, that when this liberation of atoms, and consequent release of their motion, has begun, it progresses from molecule to molecule through the mass; progresses slowly or rapidly, according to the conditions under which the atoms are combined, and to the character and the degree of motion that releases them. Some of the escaping motion increases that in its neighbourhood, and thus it is only needful to add motion to a few molecules. I may leave for your own consideration and comparison the phenomena of the combustion of coal, spreading slowly through the mass; those of the explosion of coal gas and air, in which the released motion acts with such rapidity, or the effect on gunpowder of a spark, or, perhaps still more instructively, the effect on a quantity of nitro-glycerine of the simple added motion of concussion. All these are examples of the disturbance by motion of chemical equilibrium—that is, of the balance between the attraction which tends to keep together, and the minute motion that tends to separate. That which makes these facts so important to us may have dawned on you already, if it has not been before familiar to your thought. The added motion—a spark in the case of gas or gunpowder, heat in the case of coal, a concussion in that of nitro-glycerine—is essentially the same process as that which in physiology we call the action of a stimulus. We can, I think, perceive all stimuli to be forms of motion.* In the case of many physiological stimuli the fact is too obvious to need consideration, and I believe that, where it is not obvious, the conception will be found to be one from which there is no escape. If that which is added is motion, it is probable that the energy which this increases is also motion.

* See, however, the appended Note, the significance of which may not be clear until after perusal of the latter part of the address.

The Dynamics of Muscle.

We pass from the inorganic processes to those that occur when energy is released from the organic substances of the animal body. We may conveniently begin with the process of life which causes the most conspicuous release of energy—muscular contraction. By this the higher organisms change their relation to their surroundings; by this alone, indeed, they manifest energy in its obtrusive form—motion. Thus the first question that presents itself in vital dynamics is, What is the source of the energy which muscular contraction releases, or, in common language, "produces"? It is one of the most familiar facts of physiology that all muscular action is accompanied by chemical changes—by the formation of simpler chemical compounds than those which constitute muscular tissue, and especially by the formation of carbonic acid, as in combustion. The continuous escape of this by the lungs is a fact of much and deep significance. It is a proof of the continuous process of such chemical union as we know releases energy, and its increase when muscles act is alone reason for associating the two as cause and effect. The directness of the relation has been abundantly proved. We have long been accustomed to ascribe the manifestation of energy by muscles to chemical combination. The carbonic acid is, of course, due to the union of the atoms of carbon of the muscular substance with the oxygen, brought from the lungs by the blood-corpuscles, and passing from them, dissolved in the lymph, to the muscular fibres. You know that the contraction is also attended by the formation of compounds less simple than carbonic acid, but more simple than the constituents of the muscle. We must regard the energy manifested as the difference between that which was previously latent in the complex compounds of the muscle, and that in the simpler compounds that are formed.

Whence comes the energy thus liberated ? Whence comes the atomic motion which, as we conceive, constitutes the latent energy ? The source of the energy, and therefore the source of the motion that constitutes it, is familiar. It is conveyed into the body by food on the one hand, and oxygen on the other ; the food comes directly from vegetable and animal sources, but all is ultimately traceable to the former. In growing plants, simple compounds, especially carbonic acid and water, are broken up under the influence of light and heat. The light and heat are essential, and the evidence is conclusive that they disappear in the process,—that is, the minute motion tears asunder the carbon, oxygen, and hydrogen, and to do this it has to pass into the molecules of their elements and it remains in them. As in elements, so in the complex compounds of carbon and hydrogen, the "carbo-hydrates," the motion remains in hidden form. This process in the plant is reversed when chemical union occurs in the animal body. The original simple compounds are reproduced, and the energy that was hidden is revealed and released.* Thus, according to this conception the motion of the light and heat passes between and remains between the atoms of the elements that are separated, and much remains even when they are united in a complex compound. It remains in the molecules until new conditions permit its liberation. It is the sunshine, near or distant, recent or long ago, which constitutes the source of the energy—which, in fact, *is* the energy—manifested in animal life. It is the motion of the sunshine that is the motion of the latent energy. These facts are, in general, familiar to you.† I mention their features because we seem to be compelled to conceive that the energy which becomes latent or hidden was originally motion, and as motion it again becomes manifest in muscular action. Our present knowledge does not enable us to conceive it as anything but motion during its latent stage. If it is not motion, we must at once abandon the attempt to conceive it. We must invoke the inconceivable in general to escape from the inconceivable in particular, a course which may indeed be more consistent than it at first appears to be, but can scarcely be a step in useful thought.

Accepting the conception, how does it affect the aspect of the process of muscular contraction? Muscular contraction is a shortening of the muscular

* I do not allude to the relations of nitrogen; all-important as they are, their consideration would make the subject needlessly complex, and the omission makes no difference to the argument.

† Their particulars will be found in full technical description, though without verbal recognition of the special theory here mentioned, in Vines' Lectures on Vegetable Physiology.

fibres and increase in their width. The two are one process. Increase in width is manifestly the result of a movement of the atoms, so that they come to occupy, in considerable proportion, a transverse instead of a longitudinal relation. But in this change of shape and change of relation, there is an escape of atoms from the muscle—of the atoms that unite with oxygen and pass away,—and there is also the escape of what we call "sub-molecules," which pass away as the more complex products of muscular action. It seems impossible to dissociate the two—change of shape and escape of atoms. The atoms can only pass away at the surface, by a lateral movement such as is involved in the increased width. It seems reasonable to associate this transverse lateral movement with the peculiar structure of the fibres which we recognise, in their general aspect, as "transverse striation." The released atoms escape laterally, and the fibre widens. The widening is attended with a bulging corresponding to the transverse striation.* This change follows the reception of an additional amount of energy, which we call the "stimulus" that excites contraction. Normally it is nerve energy, but it may be some other form of energy—electricity, for instance. We shall see presently that we must consider nerve force to be a variety of motion, and such also we conceive

* I have not attempted to apply the theory to the various details of the process of contraction. Their precise significance is still uncertain. They will be found described, with his unrivalled lucidity, by Michael Foster ('Physiology,' 5th edit., vol. i, p. 96, *et seq.*).

electricity to be. Every "stimulus" which excites the release of latent chemical energy in muscular contraction can be discerned to be added motion, just as in the case of inorganic substances. The stimulus being conceived as motion and as added to motion, the effect is like that which makes a fire burn or gunpowder explode. As the lighted coal goes on burning because the released motion of heat acts as a stimulus to the adjacent molecules, increasing their motion so as to release them, so the released motion in muscular contraction acts as a stimulus which is propagated along the fibre. It is propagated with great rapidity, comparable indeed to that which occurs in a gas or explosive substance. The conditions that determine the rapidity we cannot discern, but we shall have to note the same thing in the case of nerve energy. However, we should note also this marvel, that the influence thus transmitted along the fibre is, throughout its length, proportioned to the initial change—that is, to the stimulus which excites it. The release of energy does not attain its extreme degree, as it would in all parts of an explosive substance.

The accession of the additional motion of the stimulus is not followed *instantly* by the movement of the atoms that are released. There is a brief interval, towards the close of which there is a release of energy in the form of electricity, perhaps also in the form of heat. Then follows the movement of the atoms.* As that movement develops, the release of

* This is the common teaching, but, according to the latest

the other forms of energy ceases. On the theory I have advanced it would seem that the atoms, being released from the attraction by which they were before held in consequence of the added motion, yield to the attraction of the extraneous atoms of oxygen. These are necessarily chiefly at the exterior of the fibre or fibril. Yielding to the attraction, they move in a uniform direction, and by this movement the previous oscillatory motion is combined and made uniform, and is thus changed into massive motion, and the energy is released as "contraction." But before the movement begins, or as the released motion is being combined, some of it escapes as heat and electricity. Thus the transformation of the minute motion into massive motion—that is, of the latent chemical energy into manifested energy by muscular contraction—is due to the fact that the motion of the released atoms is, by compulsion, uniform, and, by uniformity, that which would otherwise be irregular and inconspicuous, is made conspicuous as the "kinetic" energy of motion. This movement of the atoms in one direction—that is to say, the lateral direction—is, of course, merely another form of stating the fact that the muscular fibre widens. To escape, the atoms must move transversely, and the widening or "contraction" implies this transverse movement. It seems, indeed, to be a movement of

investigations, the latent period is shorter than was believed, and the release of energy in other forms occurs at the beginning of the change of shape. Since it does not continue during the change of shape, the reasoning in the text is not affected.

far more atoms and molecules than escape, but it is conceivable that the escape may involve a general momentary displacement in the same direction. We cannot, as I have said, help connecting the transverse movement with the peculiar visible structure of the muscular fibres which gives rise to their transverse striation. We have, indeed, a similar widening, and so a similar lateral movement, in the case of the unstriated muscular fibres, but atomic escape must be at the sides, and the absence of visible striation does not exclude a structure such as shall determine uniformity of movement. Remember the marvellous framework that has been discovered in the structure of even apparently simple cells, a framework of which no suspicion whatever has until lately been entertained.

To sum up what has been said, we cannot doubt the escape of the atoms. The transverse movement we cannot doubt. The release of energy we cannot doubt. Added motion is the common cause of these changes. The motion of latent chemical energy we conceive as restrained oscillation, fixed minute motion—fixed, inasmuch as it is retained and may be distinguished from like motion that is propagated or conducted. It is released in such a manner that there is a compelled correspondence in direction, and thus it becomes conspicuous motion. In mechanical devices for such a transformation, when they are simple, as in the gas-engine, we can discern the conditions for obtaining such correspondence by lessened resistance in one direction. In the muscle this condition may obtain, combined with the specific attraction of chemical affinity.

It has just been mentioned that the widening of the fibre seems to be far greater than can be ascribed merely to the outward passage of the escaping atoms, and of the complex "radicals" of the molecules or the sub-molecules, which constitute the more complex products of action. Indeed, its mere features suggest that there is a movement of many molecules which afterwards resume their place. It seems conceivable that the attraction between the chief mass of molecules and those released, may involve a movement of the former to the limit permitted by the force that restrains them, and that they resume their former position by the influence of this restraining attraction, by what we call "elasticity." The nature of elasticity is, I doubt not, familiar to you. In every form, metallic or otherwise, we must conceive it as a capacity of movement of atoms or molecules away from each other within the limits of the force of attraction, and of their return if unhindered. This force of attraction between atoms or molecules seems to be the same as that which, when they are aggregated in vastly different degree, we call gravitation. The bending of a spring is precisely analogous to the elevation of a weight, only the attraction in the one case is molecular, in the other massive.

The time occupied by the process of contraction is brief. In a fraction of a second the original form of the muscle is resumed, and with this resumption there returns the capacity for another similar contraction.

Doubtless there remains, after one contraction, abundant capacity for another, but since this recurring sequence may go on for a long time there must be constant renewal of the loss. We must assume that, immediately after the release of atoms or sub-molecules, and of the motion they bear, the place of these in the muscle is taken by other compounds derived from the abundant supply in the lymph. These bear an amount of inter-atomic motion similar to that of the elements removed, and the energy thus renewed similarly available. It is difficult to conceive that such processes of what we call "disassimilation" and "assimilation" take place in so brief a space of time, yet the fact is certain. It is equally difficult to understand on any hypothesis. We cannot help seeing that which we cannot see through. Some of our most "stubborn facts" permit no light to reveal even the outline of that which is within them. Hence the first lesson of science is that we may not say "this cannot be," and I am inclined to think that the second lesson ought to be that we may not say it in words that seem to have a softer sense. The term "inconceivable" seems far less absolute than "impossible," and yet is often only a gentler way of conveying the same opinion.

The rapidity with which the original form is resumed is the more marvellous when we realise that this suffices not only for release, but also for renewal. The relation of the two is one of the most important facts for us to remember. The brevity of this process and the rapidity with which it passes along the fibre when excited at one part, have important relations to nerve-function, to which we next pass.

Yet one incidental consideration tempts me to turn aside for a moment. It is often said that protoplasmic substance has a property of contractility, a peculiar result of Life. This is regarded as the agency of muscular contraction. It is a vague conception,—too vague, indeed, to be precisely stated by modern physiologists, who yet cannot escape from it. Indeed, from that which is embodied in the conception there can be no escape. Yet the literal meaning of the word "contraction," a drawing together in all directions, is scarcely now the sense in which we use it. In muscle there is only change of shape, not of size, and there is no real "drawing together." That which is certain in this case is probable in other instances, in which the process can be discerned only imperfectly. We conceive that, alike in a muscle and in an amœba, the change is the result of some external stimulation. The stimulus must be a form of energy—that is, of motion. May the process not be the same in each case—simply a release of atoms and a release of motion by added motion, definite in character, in relation to the place, character, and degree of the added motion which excites it. If so, is it clear that there is such a property as vital contractility distinct from the necessary effect of external motion on the atomic relations, and change of form entailed by the result? The variety in the degree and in the character of the movement may seem to be incompatible with such an automatic mechanism, but we must remember how perfect is the relation in the degree of muscular contraction to that of the stimulus that excites it.

The Dynamics of Nerve.

The nature of nerve force is unknown, but one fact regarding it is certain—it is capable of propagation along a nerve fibre. That which is capable of such propagation must be either a thing moved or a form of motion. It must be motion of a mass along the fibre, or motion transmitted in the constituent elements of the fibre. This alternative seems to me absolute. We know that nerve energy cannot be motion of a mass, however small; we know that no material atoms can be thus moved along the fibres; and we are compelled, therefore, to assume that it is motion between the elements of the fibre, that it is a form of molecular or atomic motion. This conclusion is one of which the significance is weighty, and narrow. Especially important is it, in combination with the fact, also conspicuous (the assertion of which is almost superfluous), that nerve force is a form of physical energy, and therefore is correlated to other forms. This, indeed, involves the conception that nerve force is motion, if all physical energy is such, and the question becomes: Can we form any conception of the form of motion that constitutes it? In living tissue we may, conceivably, have other forms of motion than those we meet with in inorganic matter. But we are only justified in assuming the unknown when it is certain that the known is inadequate. Here we are certainly not justified in doing so; our knowledge is too vague. We are justified in trying to apply our previous conceptions, but not, at present, justified in assuming that conceptions are needed which are absolutely new.

Nerve force has been thought to be electricity, but one fact recently established, although not recently discovered, seems alone to exclude that conception. It seems certain that every axis-cylinder of a nerve fibre is composed of a great number of fibrils, each of which is a separate conducting path. They can be seen, as they diverge in nerve cells, and without them no mechanism is apparent for the marvellous and minute localisation of the various forms of sensation. If so, however, the conception of the electrical nature of nerve force, as based upon the resemblance of a nerve fibre to an insulated wire, is clearly illusory. There is no such semblance of insulation of the fibrils. We have no knowledge that would permit us to conceive that these continuous nerve fibrils can be separate paths for electricity. The fact that an electrical change, or a release of electricity, occurs during conduction by a nerve fibre, has its significance for the most part destroyed by the similar fact with regard to the muscular fibres. Electricity is liberated when muscles contract, but the energy they manifest is the simplest mechanical form. We may reasonably consider that the electrical change means only that which it signifies in the muscular fibre—initial escape of some of the released atomic motion in that form.

All the facts we know regarding the production of nerve energy, show that it is attended by chemical combination such as that which attends muscular contraction. Alike in what has been ascertained regarding the action of the brain and the action of the retina, we see evidence of this. No facts are known that are incompatible with it. Until such facts are known, we are justified in the conclusion that the source of all nerve energy is the same form of latent energy that is released in muscular action, differing only in its degree and its relations, according to the difference in the elements with which it is associated. If we find it difficult to trace this, we must remember that the compounds in which the energy is latent, those of which nerve tissues consist, are the most elaborate of all with which we are acquainted. Connected with this is extreme instability—that is, delicacy of equilibrium,—and also the capacity for most precise variation. The latter must be due to the influence of life on nutritional arrangement, to which we shall return; but the instability must be due to the nature and arrangement of the elements that compose the tissue. It may be due especially to the presence of phosphorus, an element which, as we have noted, has naturally an atomic motion in excess of its restraint. Its presence may alone make the motion almost equal to the restraint in the living tissue of which it forms part.

Many facts in regard to the mode in which nerve force is excited, have an important relation to the hypothesis that its source is latent chemical energy, conceived as minute motion, liberated and released by added motion.* But before noting one or two salient facts, I must first ask you to realise that all the processes that we are considering must occur with the same precision, irrespective of amount. They must be as precise in the least, as in a considerable degree of change. This is certain, yet the conception needs an effort. We are all familiar with the idea of atoms, but we are not equally familiar with the thought that all the processes in which atoms take part, must go on in the same degree of balanced action, whatever their number, and that the processes of energy connected with these must be equally precise. Every access of motion that we call a "stimulus" is definite in amount, however small it seems according to our estimate of size, and its effect is equally definite. Remember that the force which turns a balance may be most minute compared with that of which the equilibrium is thus destroyed; the balance of an ounce in each scale may be turned by a grain. The amount of nerve energy, needed to liberate muscular energy equal to a foot-pound, may not be enough to move a grain through an inch. That which excites the nerve energy may have a proportional minuteness. Think for a moment of the processes of energy which take place, which must take place whatever their

* See appended note.

actual nature may be, when the lightest touch of a hair upon the skin of the leg acts on the brain, and is perceived. The energy of the touch of the hair is a stimulus to the nerve structures at the spot which subserve the sense of touch. In the elements of the nerve ending, such delicate equilibrium exists between the motion of the atoms and their restraining attraction, that the motion of the hair, added to that already present, releases atoms and releases their superfluous motion. This, definitely related in amount to the energy of the touch, passes, with absolute precision, by a fixed path to the brain. During its swift transit it is maintained unchanged in amount, however small it may be. If you consider the actual dynamical amount of energy concerned in the gentle contact of a hair, and of the processes that are produced by it in the nervous system and are proportioned to it, you will see, I think, that it is no exaggeration to state that we must bring our conceptions of amount of energy, and of its absolute precision irrespective of amount, down to the minuteness of our conception of atoms. Remember, as some aid to this attenuation of idea, the opinion held by the highest authorities of the size of atoms. Conceive, under the microscope, the section of one fibril of the axis-cylinder of a nerve fibre. Could we isolate it we should have in it the smallest point which can be definitely perceived with the strongest available magnification. If we conceive a length of the fibril equal to its diameter, we have in that at least one million atoms, and perhaps twice as many. This will give us as a minimum, one thousand atoms on the surface of every section—*i. e.* in every atomic layer—to subserve conduction. Allowing for the arrangement of the atoms in molecules, we have room for processes such as we conceive may be adequate and complex, and which may be even called considerable, if we regard them from what may be called the lowest standpoint of dynamical perception.

The problem of the nature of nerve force is essentially connected with that of its conduction. In connection with this, two facts seem specially significant. First, the fibres which conduct are continuous with the structures in which the nerve impulses arise, and we can trace no demarcation or essential difference between them. It is not in the cells, but in the "spongy" grey substance into which their ramifying processes pass, that we have to look for the production of the energy. To this fact, most important for us, I will recur in a moment. Secondly, nerve fibres are excitable, as is the grey substance from which they proceed. The stimuli—electricity, &c.—which excite the producing structures, in which the conducted energy arises, can also stimulate the structures which convey it. Every one is familiar with the fact that electricity, applied to a nerve, causes muscular contraction, as does an impulse from the brain, and other stimuli have the same effect. Nerve energy may thus be generated in the fibres as in the grey matter. We conceive that it arises by chemical action, as does the energy manifested by muscles—by the release of the energy latent in the molecules. There is a release of atoms and of the motion connected with them, by means of the added motion of what we call a "stimulus." But the nerve force seems to be less readily produced in the nerve fibres than in the grey matter. These facts point to the conclusion that the function of the generating and conducting structures differs only in degree, that the process of conduction is of the same nature as that of production, and that chemical action underlies both.

Does it seem strange that conduction so rapid as we know that of nerve force to be, should be a result of chemical action? Think of the rapidity with which a train of nitro-glycerine, or even gunpowder, will explode, and the chief part of the difficulty will disappear. Remember, also, that we have, in the passage of contraction along a muscular fibre, from the place at which it is excited, the transmission of a similar process, and almost as rapid. We thus conceive that the transmission of nerve energy is the conduction of released motion by means of propagated chemical action along the molecules of the fibrils. These molecules are in sufficient contiguity, or continuity, to permit the rapid transmission of the process, while, close together as the fibrils are, there is no such relation between the molecules of adjacent fibrils as can permit the passage of the chemical action from one to the other. I speak of "propagated" chemical action, but the word "conducted" is nearer the truth—a word that is indeed instructive in its approximate accuracy. The change is not propelled, it is not led on by another influence, it passes by contagion.

I have said that nerve energy has been thought to be electricity, and also that the opinion is untenable. We believe, however, that electricity is transmitted motion, and that nerve force is the same. The conclusion that they are not identical is thus rendered, at least in aspect, less important. Beyond the fact that nerve energy must be transmitted motion, we cannot yet go, except by cautious, tentative steps. If we knew with certainty the process of transmission, we should know its precise character, for its nature and conduction are, as I have said, so related that we cannot expect to learn much of one apart from the other; our conceptions of both must grow together. In thinking of conduction we are on uncertain ground, because vital structure may involve capacities for the transmission of motion unlike that which we know of elsewhere—unlike, for instance, the transmission of the released motion in an explosive. Holding fast that which we know (know, at least, as highly probable), expecting to meet with the like, we should yet be prepared to meet with that which is quite unfamiliar. In such structure as nerve tissue there may be relations between the complex molecules specially favorable to the passage of released energy, not yet known to us. But we should endeavour to apply the know ledge we possess as far as we can justly apply it, and so to reduce the quite unknown to the smallest limits.

It is, I think, at least conceivable that the conduction of the nerve force takes place by chemical action, and yet may this not be by less chemical action than that needed for its liberation? We may often see analogies in different processes of energy, —analogies that are suggestive and may rightly be used as such. It is perhaps not irrelevant thus to note how the motion of a mass may be facilitated by the motion of wheels or rollers. Note also the remarkable fact of the storage of electricity in batteries. In these "storage batteries" electricity is stored by a chemical process, like that by which it may be generated. Far less is needed to keep it than to produce it, and yet some chemical action is needed. Why this should be does not concern us now, because the fact is relevant only as an illustration. It suggests the question, May there not be a similar analogy between the processes of production and conduction of nerve force? A thorough knowledge of chemical physics might possibly suggest more close analogies, but Life involves conditions too special to make it worth while to pursue far the purely physical analogies. Indeed, it may be thought that the nearest is too distant, and certainly its only value is as an object to glance at alternately with that we study.

Whether the chemical processes in conduction are less than those by which nerve energy arises, or are equal in amount, we must admit them as the agency. But if the conduction is by transmitted chemical action, the marvel is great that the nerve energy should be maintained in absolute precision through the molecules, inconceivable in number, that must conduct it. Yet the precision is as perfect, the molecules are as many, and the mystery remains, whatever conception we may form, or if we contemplate the bare facts in simple wonder.

Not less significant than conduction is excitation—that is, the processes by which nerve energy comes to be as we perceive it. If we think of nerve force as minute motion, and as due to the release of the latent chemical energy that is also motion, it is instructive to note that the stimuli which, from the exterior, act upon the nerve structures, and lead to this production of nerve energy, are almost all distinctly of the nature of motion. "Massive" motion stimulates the nerves of touch. The rapid wave-motion of heat affects the nerves that subserve thermic sensibility; the still more rapid motion of light acts upon the retina, and the far slower motion of sound upon the nerves of the ear. Violent motion in some nerve structures causes pain. In all the structures, nerve energy may be excited by the motion of electricity. The nerves of smell and taste are stimulated by chemical processes which may seem an apparent exception to the law; but here, on consideration, we seem to have only an instance of the released motion of chemical energy acting in a special—indeed, a peculiarly instructive—way. I must leave this, however, to your own thought, and I may safely do so, if I am not too presumptuous in assuming that you have so far followed me along the path, seen dimly as in misty morning air before the dawn. In passing, we should note how remarkable it seems that the wave motion of heat and that of light, which differ only in rapidity and may be changed from one to the other, should affect structures which apparently differ so entirely as those of the skin and those of the retina. Yet the difference can be only in degree, elaborated to an apparent absoluteness in the retina. This is suggested to us by the fact that, in the red rays of the spectrum, we actually feel light by the skin and see heat by the eye. The names are due to the difference in our conscious sensations, but, as a matter of fact, when the red part of the spectrum, falling on the skin, causes a sense of heat, and on the retina a sense of light, the undulations that cause the two effects are the same. In skin and retina alike there is nerve tissue in which the latent energy of minute motion is such that in each the same form of motion, the same stimulus, readily increases it and releases it.

The difference in constitution of the nerve endings may be greater in those of the skin that subserve sensibility to heat and to touch, than is the difference between those in the skin that are sensitive to heat, and those in the retina that respond to red light. The difference must be considerable to make the minute motion the one most readily augmented by that of heat, while in the other it is most readily increased by the relatively coarse motion of a mass, large or small. It is hardly conceivable, I think, that this difference in excitability should not be due to a difference in minute molecular arrangement, or to a difference, perhaps inconceivably small, in the atomic constitution of the molecules.

If this is so, if special susceptibility to massive motion or to the minute motion of heat, implies such difference, and these structures are continuous with the fibrils that conduct, and the two functions differ only in degree,—another question presents itself. Is it not probable that there may be corresponding differences in the conducting fibrils and in the energy conducted? The experiments by which the actual identity in nature of nerves of different function has been supposed to be established, do not seem to me incompatible with the difference I indicate. An energetic impulse may be conducted by any nerve, and yet a slight one may pass only by a special fibre. We have probably, as yet, only a glimpse of the variety in the forms of motion that seem to us the same, especially in their relation to life. In light and heat, indeed, we have noted the constancy with which a slight variation entails a different effect. But we seem to perceive a contrast where there is only a slight difference. We should learn from this to avoid transferring our perceptions to our conceptions. Perhaps equally relevant is the difference between red and blue light in the effect on us, and the susceptibility of different structures revealed. I can only suggest this point for you to think over. Such difference in susceptibility must mean difference in constitution. The pre-existing motion of the latent energy must be in a form specially related to that which it receives as a stimulus and by which it is augmented. If so, as I have hinted, may there not be a difference in the result? May not there be specific differences in nerve energy? We cannot yet say, but the question is not therefore a useless one, because the differences would not end with the conducting agents.

When a "nerve impulse" reaches a centre it acts as a "stimulus" in the same way as the energy by which it was excited. The motion of the nerve impulse disturbs by its addition the preceding equilibrium, and increases the motion in the structures that receive it, so that in them it exceeds the attraction, and there is proportioned release of atoms and of energy; but the energy released is, in general, much greater than the energy of the impulse which excited it. The process may go on in the centre. The atomic motion that is released passes in the same way by other fibrils to other parts of the centre, near or distant, and thence, it may be after many repetitions of the process, it passes to the muscles, or to other structures.

In this process it is most important to note certain facts histologists have lately ascertained; but before doing so there is a question that must have occurred to you while listening to what I have just said—the contrast between the processes of activity in muscle and nerve. The theory advanced brings the contrast into prominence. The attempt to apply it reveals the difference between the two processes, both of which we must conceive as the release of atoms and of energy. I think, indeed, that the result illustrates the service of theory, whether right or wrong, in enabling us, and indeed compelling us, to scrutinise phenomena and their relations more closely. We conceive in nerve, as in muscle, a release of atoms by added motion, but we conceive that this occurs far more readily in nerve because the attraction is in less excess of the motion which it restrains. We must conceive, moreover, that atoms pass away in one case as in the other. Yet there is no change in the shape of the nerve structures coincident with the escape—there is no compelled correspondence in direction of the motion released. On the contrary, the effect passes from molecule to molecule of the nerve, just as it does in the muscular fibre in the process by which the stimulus to one part becomes a stimulus to the whole fibre. We know how swiftly the contraction spreads along the muscle; we know how perfectly proportioned it is throughout to the initial degree, and to that of the stimulus which excites it. It is to this element alone in muscular action that nerve action seems to correspond.* It is a change that passes from molecule to molecule in uniform degree. We may indeed say that throughout its course it is of the nature of a propagated stimulus, although itself due to the stimulation of a slighter and different form of energy. It acts on the centre as a stimulus, and gives rise to a like process. In

* See Michael Foster's 'Physiology,' 5th edit., part 1, p. 155. "In every contraction of a muscular fibre the actual change in form is preceded by invisible changes propagated along the fibre and occupying the latent period, and these changes resemble in this feature the nervous impulse."

noting this we must remember that the conception of a "stimulus" is simply that of a process which causes another process greater in degree. It has nothing to do with the nature of the process. Moreover, in the nervous system the amount of energy in each part of the process must be, in general, far less disproportionate than in the case of the nerve energy that excites muscular contraction. Moreover, the processes are homogeneous, if this term may be transferred to our subject. Throughout the nervous system, from the sensory periphery, on which external energy acts, to the motor periphery, where, through the muscles, the outer world is acted on and other forms of energy are released, all the processes vary only in place and in degree, and not in dynamical character. But the differences in the degree must be great; it may be trifling—an impulse only excites another nearly equal to it—or it may be great, as in many reflex actions. The preceding readiness for action of the centre—in common language, its preceding instability—may cause a slight impulse to have a great effect. When the sole is touched the trifling amount of nerve energy, which the motion of the touch excites, develops enough within the centre to cause the related muscles to generate several foot-pounds of energy. But this involves a question to which I will return.

In comparing or contrasting the process in nerve and muscle we perceive the difference just spoken of, and so clearly stated by Foster,—that in the nerve it corresponds to the stimulation of a muscle rather than to the effect of the stimulation. With this difference we must associate the difference of structure. In the nerve tissues, where the impulses originate, we have no elements comparable to those of muscular tissue. The fact is most important. Its importance is, moreover, increased by the latest knowledge we have obtained by the remarkable results of microscopic investigation.* These have changed much of our thought, changed it in a most important manner, and to the dislocation produced we are not yet accustomed. We used to think that the nerve cells, whence nerve fibres proceed, not only govern their nutrition, but are the sources of the nerve impulses which traverse the fibres arising from them. The researches I refer to have compelled us to alter these conceptions. I say "they have compelled us" because we seem to have no choice but to accept them. They extricate from the tangled skein (or that which seems so) which nature has woven for us in nerve phenomena, threads of fact and evidence, so strong that they draw us to a new point of view, draw us with a cogency so consistent and so concordant with much we before relied on, that against it there can be no resistance. We can no longer think of nerve-cells as the sources of nerve energy, as parts of a divided "nerve battery" whence nerve-fibres conduct the force produced. They are the vital elements in the machine, but they have nothing to do with its

* Raymon y Cajal, 'Proc. Roy. Soc.,' 1894. Schäfer, 'Brain, 1893. v. Lenhossek, 'Der feinere Bau des Nervensystems,' Berlin, 1893.

dynamics. Into the protoplasm of the cell, pass the fibrils which conduct nerve energy; through it they course unbroken; from it they pass, contiguous, as elements of the axis-cylinder of a nerve-fibre. From the cell-body, in each direction, protoplasmic material extends along the fibrils and about them, too trifling in its attenuation to be visible, but potent, however minute in amount, with the absolute power of life. On the preservation of this structural integrity depends the life of the nerve-fibrils. As far as they extend in molecular continuity, their nutritional integrity is maintained by the mysterious influence of the cell. This depends in some way on the presence of its nucleus, around which the protoplasm is collected, but this fact it is alike beside our need and beyond our power even to scrutinise. For us the chief fact is that the vital influence exists, and that it depends on structural continuity, and is irrespective of the nerve impulses and of their direction. We must, therefore, dismiss the idea, which hitherto has seemed helpful to us, that nerve fibres commonly degenerate in the direction in which they conduct. Indeed, our grasp of the conception has never been free from a sense of insecurity, because we have always been confronted with a conspicuous anomaly—the degeneration of the sensory nerves in the opposite direction to that in which they conduct. In them nerve impulses and nutritional influence are opposed. The truth we now perceive to be that we have only been able to observe the relation where the length of fibre is considerable. Where fibres are short (as in the "ramifying processes") it cannot be perceived, and the instances in which the relation is perceptible in long fibres are chiefly those in which the two influences correspond in direction. We cannot doubt that, could we observe the facts in all cases, we should find them uniformly opposed to the idea that there is any correspondence, and that therefore we have no evidence that there is any essential identity between function and nutrition.

I think we shall be best able to perceive the significance of these researches, so ably presented and extended in the recent Croonian Lecture of Professor Ramon y Cajal, if we fix our attention on what we may now regard as the nerve units, the fibrils of the axis-cylinder. I have already had to speak of them. It may be objected that they are indistinguishable in the seemingly homogeneous axis-cylinder, and, indeed, their existence is not easy to reconcile with its general aspect. But we cannot doubt their existence. We must remember the facts I have just referred to, the divergence of the fibrils in the cell, discovered by Max Schultze, their continuity through it, and, moreover, the profound significance of the so-called division of the axis-cylinder. As a division of a homogeneous body we cannot understand this. We can do so if it is a separation of conducting paths, which again diverge at the cell. Moreover—and this I would especially ask you to note—if conduction is, as I suggested, the passage of motion by a chemical process from molecule to molecule, we need only a serial arrangement of molecules in intimate relation. If there is no intimate relation between the adjacent series of molecules, such as we conceive to exist between the molecules of each series, if the molecules of adjacent fibrils have no such connection as those of each fibril present, we need no separation, such as we can call "structural," between them, to constitute distinct conducting paths.

The fact of the nutritional and not functional influence of the cell, involves, of necessity, the recognition of the fact that the spongy grey substance is the source of the nerve impulses. The fact is of the highest importance, alike for our conceptions of normal function and for those of disorded action. It is in this mysterious structure, so intricate as to have baffled all attempts to unravel it, that we must seek for the elements in which nerve energy arises. Although we cannot yet discern the arrangement of its constituents, one fact has been ascertained regarding it, and this is of great significance. The branching processes of the nerve-cells *terminate* within it; they end, and are not continuous with other fibrils. Their endings should, indeed, be thought of as beginnings. The fibrils begin in this structure with merely a slight thickening, a slight increase of the nerve substance, and present no union with other elements. This fact is significant for us, because it agrees with other evidence that there is only a difference in degree between the structures that conduct, and those in which nerve energy arises. Those in which it arises have a slightly greater amount of material, and that is all the difference we can see. The fact also reveals the correspondence in general features between the structures in which nerve impulses begin in the centre and at the periphery. In the skin they arise at enlarged extremities of the sensory fibrils, in the centre they arise at enlarged extremities of the fibrils that form the branching processes.

This perception at once brings before us a new difficulty, as does all fresh knowledge. In the centre, the nerve impulses arise as a result of excitation by other nerve impulses which reach these structures. We have seen that the nerve impulse acts as a stimulus, and that the process is repeated in the central structure. But the path of action is precise, unvarying. Can this be possible without continuity? I am not sure, however, that it is proper to ask *what can be,* if we can ascertain *what is.* As far as we can judge, we must accept the fact of discontinuity of structure and continuity of function. If we do so frankly, looking at it as a fact, we shall find an unexpected reward. There must be definite passage of energy, from a fibril that ends in the centre, to one that begins there. A nerve impulse in the one causes a nerve impulse in the other, and yet the fibrils are not continuous. Contiguous they must be, but they are not continuous. What have we, however, in the nerve endings on the muscular fibres? There, also, we seem to have no molecular continuity between the nerve and muscle tissue. In each case the energy must pass, but cannot pass by the same process as that by which it is conducted along the fibre; this involves, of necessity, molecular continuity. But we can conceive that it passes as simple motion, and, as the nerve impulse must be a form of motion, we can conceive that as simple motion it may end. The stimulation of the nerves at the periphery is, moreover, by simple motion. As it began, so it may end. Thus, the "solution of continuity" becomes, though still a marvel, yet a help in our attempt to perceive something of that which takes place. The same lesson is taught us by the relations of the nerve-ending to unstriated muscular fibres.

It may have occurred to you, Gentlemen, that in what I have said there has been nothing which strictly belongs to the subject as indicated by the title. I have spoken of the dynamical processes which occur under the influence of life, but nothing about the dynamics of Life itself. If you anticipate that I shall come to this, I cannot but disappoint you. I have, indeed, to point out one relation of life to the processes we have been considering; but of the relation of energy to Life itself there is, it seems to me, nothing to be said. Nothing is to be discerned. Not only is the relation of energy to vitality entirely hidden from us now, but I can see no promise that the future has it in store for us. The hand that holds the secret is tightly closed. By "the relation of energy to life" I mean the relation of physical energy to the influence which determines the building up of tissues and the production of the living elements of the complex animal frame. Take as a type of the process, paramount in importance, the process of cell-formation. We may see in the process something of chemical change, and an influence by which latent energy is specially directed to certain ends, but how far physical energy enters into the influence we have no perception. I may best illustrate our ignorance by pointing out what seems to me an important instance. We have no evidence that any one element that is produced in the body, that any form of cell or similar organism, needs more energy for its production than another. We have no evidence that more or less energy is needed for the production of a blood-corpuscle in the spleen or the marrow of bone, or of a mucous corpuscle in the lining membrane of the nose, than for the production of one of the separate living bodies by the union of which the individual is ultimately reproduced. Indeed, we have no real proof that any energy is needed. You will at once perceive the importance of this fact, if it be a fact, for brushing away certain misconceptions as harmful as they are groundless. The term "vital energy," which echoes round us in tones to which we would fain close our ears, is a term which describes a conception that, so far as it is possible to discern, has absolutely no counterpart in fact corresponding to its common meaning. Beyond the physical energy of the processes of the body, we know nothing of anything to be designated by the name; and although, in the mysterious influence that governs nutrition, we may see some semblance of that which we call "energy," we cannot yet see whether it is a mere reflection or a reality, or both. This difficulty, however, brings us face to face with the limit of our efforts.

The Dynamics of Disease.

"Hitherto shalt thou come, but no further." How often, in how many places, does the perception make us pause! We seem almost to hear the words, when our thought is suddenly arrested by problems which we cannot overcome by energy or evade by skill. We have been dealing with that which is within the influence of life, and we have had to perceive, in passing, that there is more in Life than the processes it controls. It is this fact with which we are now confronted. Disease brings us before the problem of Life, not perhaps with more distinctness, but in more conspicuous form, than do the phenomena of normal action. It brings us into the presence of a mystery, inscrutable as the symbol framed of old on the Egyptian plain, by men who felt that which we feel, and who saw perhaps as much as we can see with distinct vision. Does not that grand symbol—the symbol of that which looks but cannot see, with wistful eyes directed above the level of our earth, and yet not much above it—does not that hold in its rugged outlines, and imperishable mass, a story that is true?

We therefore turn, in conclusion, to some aspects of energy in Disease. We take, as I intimated at the beginning, the abnormal process in the nervous system that is presented by epilepsy, an extreme and obtrusive manifestation of energy by the animal body. Our difficulties in applying the conception of latent energy to the normal phenomena of nervous and muscular action, are not likely to be less in the case of abnormal phenomena. Yet, if the conceptions assist us in the one, they should also do so in the other, in spite of the greater difficulty.

We have been accustomed to describe the phenomena of disturbed function of the brain in words which are hardly more than a concise epitome of that which we observe; and we have not been quite free from a delusion that, in doing so, we describe the nature of the processes. We speak, for instance, of "discharge" and "instability" in reference to the deranged action of the nerve centres; but it is evident, on consideration, that the terms are in no sense a statement of the nature of the processes or states. If we attempt to form any conception of the causes of the phenomena we perceive, we shall inevitably be met by essential difficulties. The facts we see must have causes; they must depend upon definite conditions, such as changes in the minute constitution of the nerve elements. Here, also, we must be prepared for the fact that conscious ignorance is a certain effect of knowledge; we cannot fail to feel this strongly in a region hitherto almost untraversed even by the speculative pioneer. If we succeed in discerning anything of the nature of these conditions, or even in forming a reasonable conjecture regarding it, if we can throw any light upon the actual process that takes place, it is certain that one effect will be to show that spaces of darkness intervene between the points we seem to light up, and to suggest that in the dark recesses may be that which would change the relations, if not the aspect, of that which we can discern. Realised ignorance always impresses us more than even definite knowledge; the latter soon becomes familiar, but how much of the unknown and the important the darkness holds, we cannot guess. Yet this effect upon us should not deter from the attempt to see; and if the light is faint, and sight is dim, we must at least gain more than closed eyes would give us.

I have said that we can only define epilepsy as sudden action of the nerve-centres without apparent stimulation—that is, the stimulation, if present, is too slight to be discerned. In the terms of the theory I am advancing, we should say that in the structures concerned, the minute motion is more nearly equal to the restraining force than it is in health, so that an amount of added motion, slighter than is needed under normal conditions, permits the liberation of atoms and of energy. We may even conceive that the motion may gradually, by mere accumulation, become equal to the amount of restraint, and then exceed it, so that the balance is disturbed, and energy is liberated, without any more added motion than the slow nutritional accretion—that is, without a stimulus. Such a condition might result from a very minute general change in the composition of the nerve-tissue concerned, perhaps even from an abnormal relation of the molecules, or their constituent sub-molecules or "radicals" to each other. It is, indeed, the current conception that the undue readiness of action called "instability" is the result of abnormal chemical constitution. If such a condition exists widely, we can understand the manner in which the "discharge" spreads in the brain. Such an extension, even with extreme rapidity, is indeed a normal phenomenon. It is seen whenever organic disease excites, at one spot, an intense "discharge." The released energy excites the release of atoms and of nerve energy in all connected structures, alike in those that are adjacent and in those that are remote. Just as the released energy of motion, in the part of a muscular fibre first excited, is a stimulus to the parts adjacent, so it is in the brain to the parts connected, near or distant. In the nerve-centres the conducting fibres enable the stimulating influence of the released motion to act on distant molecules as if they were near. In that case, there is a transmission of the stimulus, a mediate and not immediate influence, but the result is apparently the same in character and in degree. It is only another instance of the fact which we have already considered, that the length of the fibrils is unimportant for their function.

When action is thus multiplied, the effect of even a minute difference in the general constitution of the nerve-tissue may obviously be very great. It must be especially effective in a material, such as the nerve substance, in which the latent energy—that is, the minute motion—must be always close to the limit of the restraining attraction. It may cause a slight local discharge to spread with the same degree of energy as one that is intense. We are compelled by many facts of diverse character to perceive that every change in chemical composition entails a change in function. It is not easy to avoid the conception that persistent changes in function may often, or even generally, depend on a change in chemical constitution. Facts that illustrate the former statement abound on all sides. The persistent presence of arsenic in the system causes at last visible change in the nerve endings. This is the extreme result of a process which must be, in its beginning, one of infinitely minute chemical constitution. Long before the stage of visible change, there is deranged function in the sensory nerves due to the presence of the arsenic, essentially the consequence of chemical alteration. So with many other poisons. Indeed, it is difficult to understand the effects of strychnine, of curare, belladonna, or other substances of definite chemical composition except by a chemical effect on substances that, although under the influence of life, have yet a definite chemical composition. Such poisons influence the function of certain nerve structures, and do not affect others. The cause we assume to be the chemical differences in the agents, but for the effect there must be chemical differences in the nature of the atoms, or their arrangement, in that living tissue on which the agent acts. The effect of some of them, such as strychnia, seems so conspicuously a disturbance of living function, that we may find it difficult to associate this with chemical composition. Yet poisons are effective, because they bring energy in special form to structures so constituted as to receive it in a special way. That which is true of "poisons" is true of "drugs" which differ only in degree from "toxic agents."

The disordered action of the nerve-centres in epilepsy sometimes presents more obtrusively than any normal action the opposite effect which the same influence may exert when in different degree. Indeed, the same process may have opposite effects, as it is slight or considerable. The process of discharge may be manifested by an arrest of action or by over-action, according to its degree. In the visual centre, for instance, the commencing process may cause sudden darkness, and then, as it increases, bright stars may be seen. The same process may thus stop all influence, on the higher centre, of those impulses which should reach it from the retina—*i. e.* loss of sight; as it increases it may cause a liberation of energy to the higher centre with which conscious sensation is associated. Here we have the two apparently opposite effects as the result of the same process, in the same centre. We may have a like effect in related centres. One feature of "local epilepsy," as it is termed, is that a sensory aura may commence, *e. g.* in the fingers, pass up the arm and down the side to the leg—purely sensory in character. As it proceeds up the arm this becomes almost powerless. The discharge in the sensory structures, which affects consciousness, "inhibits" the related motor centres and arrests their action. A similar, more energetic, discharge may be accompanied by spasm.

I need not remind you of analogous phenomena in the range of normal action. You all know that, while a touch upon the sole may cause a vigorous movement of the leg, a prick may prevent a touch from having any influence.

No attempt has, I think, been made even to guess at the nature of this mysterious process of "inhibition." At first sight it may seem that the theory we are considering increases the difficulty of forming any conception. But we have reason to believe that there must be inter-atomic motion, and that it is the liberation of the atoms that is the chief means of releasing energy in functional action. We have reason also to believe that there must be such a thing as inter-molecular motion, since molecules may escape. Further, we have noted that molecules must be conceived to consist of groups of atoms, sub-molecules (or "radicals"), and the various compounds which result from muscular action compel us to believe that the sub-molecules may be separated and released. This conception of molecules and sub-molecules involves another: their constituent atoms must be united by attraction stronger than that which unites them to other atoms, or else the existence of such groups would be impossible. But this conception involves also that of an influence keeping the groups separate, as well as of an attraction keeping the elements of each group together; the atoms in the sub-molecule, the sub-molecules together in the molecule. This energy we cannot separate from our conception of the motion that we conceive to exist. Inter-molecular motion is involved in the escape of molecules; inter-atomic motion in that of atoms; intra-molecular motion, that between the sub-molecules, is involved in the conception of their existence and of their escape. I am sorry to put it so tersely, but I fear expansion would not increase lucidity, for words have a strong tendency to cause opacity if they are numerous. If there is motion between the molecules, and also between the sub-molecules, an increase in either seat will tend to resist the escape of the atoms, will tend to restrain and prevent the liberation of the energy they hold. Since it is the release of atomic motion that is the chief source of manifested energy, an increase of that between the groups of atoms, the sub-molecules, or between the molecules they constitute, will hinder the release of energy. It will prevent a stimulus having its normal effect. It is conceivable that added motion may pass chiefly between the groups of atoms, if it is great or if it is received under certain conditions. It would then have purely a restraining effect. Does not this afford us a glimpse into a possible conception of the nature of inhibition? If we realise the undoubted fact that motions so different as those which I mentioned in an earlier part of this address may co-exist among the same atoms, and may maintain their separate existence with absolute distinction and constancy in degree, we shall, I think, be less inclined to shrink from the conception which I have just described. The arrangement of the constituents of vital tissues may reasonably be supposed to permit the co-existence of forms of motion in some respects closely allied, and yet in fixed relation alike of co-existence and of interchange. I hesitated to complicate my illustration by the mention of interchange, but I must drive home the marvel by reminding you that all light absorbed which does not cause separation of atoms is simply slowed into heat. This is what occurs when light falls on a dull black surface. A like process may take place in atoms in which there are other forms of motion at the same time. I think a sounding or tuning fork, through which electricity is passing, with a dull black surface on which light falls, should be a hammer to shatter any hesitation in admitting the truth of a dynamical conception merely because of its complexity. Of course, all that its blow can do is to make the mental way a clear one.

To return to our special subject. All that we know shows that the release of energy in nervous and muscular tissues is associated with the release of atoms; increased motion between the molecules must tend to hinder the release of the atoms of which they consist, and we can thus conceive conditions that may constitute the mechanism of what we call inhibition, and also of what we are accustomed to speak of as "resistance." I have referred to the extremely complex structure that has been discovered in what before was thought to be a simple uniform protoplasmic substance. The discoveries regarding many cells suggest that all organic tissues of definite function possess also a structure of complex and definite character, which may determine, in ways of which we have as yet no perception, the direction and character of the minute motion between their atoms, and of the effect of that which reaches them. Moreover, it must be remembered that if this seems complex almost beyond credibility, it is not likely that any conception of the nature of these processes can be offered which does not present the like repellent aspect.

We are accustomed to talk of the action of nerve centres, of their "inhibition," of "lines of resistance," of "increased resistance" and "lessened resistance," of the effects of over-action and the like. I do not know that any attempt has yet been made to pass beneath the surface and to frame any theory of the actual processes on which the observed phenomena depend. But I feel sure that, whatever be the nature of any hypothesis that can be framed, it must be at least as complex as that which I have suggested, at least as unfamiliar, and must seem as strange. All these conditions possess a similar character, and must depend on some similar influence or process. We can trace the processes that underlie such phenomena, or we seem to trace them, in dim outline, as processes of energy in the domain of life. But we cannot carry our perceptions further. We cannot see what determines the conditions in which energy has these effects and undergoes these changes. This is brought obtrusively before us if we pass from the processes to the conditions, if we ask what is it that underlies the derangement that brings before us so conspicuously the features of nerve action.

Disordered action, in what we call disease, brings us to the point where that which we can trace is limited by that of which we can only see the effect. To realise this is of the utmost importance. Disease, as we see it in this instance, is due to the power of Life, of which the nature is beyond our comprehension. The essential feature of the disease as such—that is, as a recurring process of convulsion—is the fact of its recurrence. This involves that renewal of capacity for action which we have already noted in observing the features of muscular activity, but it brings before us also the other fact, that there is not only renewal, but increase. It is this that entails hypertrophy of a much-used muscle or an over-acting heart; it is this by which action entails overgrowth. A like facility makes epilepsy a disease. However minute may be the excess of that which replaces over that which passes away, the excess is certain, both of matter and the energy it bears, and also the increased facility for its release. Not only does the renewal so perfectly correspond to the loss as to make long-continued repetition of the action possible, but it must in some way involve an increased disposition for the like release of motion under the same stimulus, so that the same activity is more readily produced.

This is the secret of all education and training, and of the physical basis of memory. It is the secret also of functional disturbance as a self-perpetuating disease. Epilepsy is a disease, because the tendency to what we call "discharge" is increased each time the tendency has its effect. This renewal of material and of energy, and this increase in both, are the result of the vital power of nutrition. The marvellous ability of the living structure to appropriate to itself, from the organic compounds which come into relation with it, those that exactly correspond to the elements which it has lost, to appropriate them, moreover, in increased amount, is the effect of that vital influence which first builds up the structures, which maintains them, and renews them until a term approaches—when it fails. In youth so strong, in age so feeble, this power of renewal, alike in its strength and in its failure, has disease in its capacity. Perverted energy in early life is thus augmented, defective nutrition in later life is increased in its imperfection. We must not, however, follow further this line of thought. The thread of vital influence might be traced through many an intricacy; but we should thereby be no more able than before to unravel the warp and woof of the strange web into which it enters, or even to discern distinctly the pattern that is woven by it.

And so, gentlemen, in mystery we begin—and end. Was it not Coleridge who said, "In wonder all knowledge begins, in wonder it ends, and admiration fills up the interspace"? Not altogether true, nor everywhere; and yet who is there that does not feel that an earnest effort to perceive that which is unseen leaves him on a higher level, and if he is still at his old standpoint, he has a better view. Whether the effort I have made to-night has this effect or not, I feel that it must leave us more conscious of the mystery that includes so much, and seems essentially impenetrable—the mystery that holds the secret of our being. Search as we may, with eyes however earnest and however aided, that which we call "Life" eludes our search and resists our efforts. We may, indeed, trace the relations to vitality of matter and of the energy it bears—their entrance into the domain of Life, their exit, their effects. We see them dimly shadowed now and then within the luminous mist, but the mist obscures our sight, and the light it radiates hides by its own brightness. We must be content with what knowledge we can gain, secure or insecure, and, while using it as best we may, should realise, in all humility, how much there is we cannot know, and yet we cannot doubt.

APPENDIX.

NOTE—STIMULATION.

In conceiving that a stimulus is added motion, it is important to observe the fact that rapidity of addition has a great influence on the effect, and to consider the significance of this. It indicates that added motion may, as it were, to some extent blend with that which exists before, without disturbance of the relations of the forms of motion. This occurs if a moderate amount is added so gradually as to permit of accommodation. A rapid addition involves disturbance by the motion that cannot, as it were, become concordant, because this concordance can only occur gradually.

The influence of abruptness is especially important because it lessens another apparent difficulty. It may not remove the difficulty, but, next to explanation, the best help is the perception that an explanation is possible.

The difficulty is the fact that, although the stimulus that excites a nerve-impulse is generally added motion, it may also be a diminution of motion. The interruption of a current of electricity will stimulate a motor nerve and cause a contraction in the muscle it supplies; and a diminution of the motion of heat, when a cold object is applied to the skin, causes an impulse not less effective than that which results from a hot object.

The opposition, it should be noted, is a fact, irrespective of theory. However a voltaic current excites a nerve, the excitation occurs not only when it is added but when it is withdrawn, but in each case the result, within certain limits of strength, depends upon the suddenness of addition or withdrawal. A strong current stimulates during its passage. That is, the motion of electricity can co-exist with, and not derange, the motion of latent chemical energy, if moderate in degree. If greater, some of it must pass to the specific motion and augment it. This we see also in a simple inorganic wire; if great, in relation to the number of the atoms, the excess is added to the special motion of heat, and so a thin wire becomes hot. We cannot, indeed, depend on the analogy presented by the inorganic substance to the conditions in the organic molecules which make the sudden change so influential. But we may at least see the room there is for adaptation to the altered motion, and although it is the amount that is influential in this instance, we can conceive that with a smaller amount of added motion, the adaptation needs time. Therefore we can understand that suddenness may involve excess.

But how can diminution mean excess, however suddenly produced? The undoubted effect of rapidity of addition involves that of adaptation, *i.e.* that the pre-existing motion can gradually, in some way, blend with the other, while each still retains its special features. The motion of electricity, which in its passage has no effect, has also no effect in its accession if this is gradual. That is, it becomes so associated with that which is already in the structure, that the latter is undisturbed, so far as we can judge. If this added motion of electricity is gradually withdrawn, we have likewise no disturbance; the preceding state is resumed. If it is suddenly withdrawn, the nerve is excited, nerve-energy is released.

This fact is less difficult to understand if we realise that the inherent motion is modified, though not deranged, by the concurring motion of electricity. We may remember, as an illustration so simple as to be almost, but not quite, useless, the effect of a strong breeze on the motion of falling rain-drops. We know now the two motions blend so as to appear to be in the "resultant." The facts seem to reveal to us, apart from any special theory, that co-existing forms of motion, distinct and precise, even in variations, are not without mutual effect. This is, of course, a familiar fact of physics,—as, for instance, in connection with the polarisation of light. The withdrawal of the added energy, which has thus modified, while not changing in amount or essential character, preceding energy, may have unexpected effects. Sudden withdrawal must cause a derangement which a gradual withdrawal would fail to cause. We can even conceive that it may have such an effect that, in the readjustment, some motion may escape, and thus a stimulation may result such as added motion causes.

The same reasoning applies to the addition and withdrawal of the motion of heat. The condition underlying what we call "thermic" states, must be the same, in essential character, in organic bodies as in substances that are inorganic. All that has been suggested regarding the motion of electricity, so far as access, withdrawal, and adaptation are concerned, seem as definitely probable of heat.

The conspicuous constancy of thermic processes—that is, the presence in all bodies of the undulatory motion of heat—compels indeed the conception that other forms of motion exist with it and change with precision; while its effect on these reveals, even more distinctly than electricity, the fact of mutual adaptation. We know how the motion of heat increases that interatomic and intermolecular motion which the force of attraction restrains. We can understand that heat stimulates nerve-endings—that is, releases atoms and their energy, in proportion to the suddenness with which its motion is added, because adjustment can occur but slowly. We can, I think, conceive that the sudden withdrawal may so disturb the relations of the forms of motion as to liberate motion so as to constitute a stimulus.

We must remember also that the motion of heat may be both intermolecular and interatomic. A consideration of its various effects seems, indeed, to compel the assumption. It is easy to conceive that the first effect of abstraction may be on the intermolecular motion (since the effect of added heat on odorous substances is so distinctly to increase the escape of their molecules). This might cause the abstraction of heat to first lessen the intermolecular motion, which must tend to restrain the atoms, and so to induce a relative excess of the interatomic motion. The effect would be the reverse of that which has been conceived to underlie inhibition. Thus, apart from the conditions possibly involved in the approximation of molecules when heat is withdrawn, it is easy, I think, to see that the apparent difficulty may not be a real one. We must, moreover, remember that there is strong reason to believe that special nerve endings subserve sensibility to cold, distinct from those that are sensitive to heat, and thus a state of minute motion may exist very readily disturbed in such a manner as is assumed.

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